

# Looking Back and Moving Forward



## Proceedings of the Wild Trout XI Symposium

Holiday Inn, West Yellowstone, Montana  
September 22-25th, 2014



Wild Trout XI

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# Proceedings of the Wild Trout XI Symposium

West Yellowstone, MT

September 22-25, 2014

Symposium Chair, Dan Schill

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Thank you to the wonderful photographers who let us use their photos in this publication:  
Matt Mitro, Mark Smith, Lorie Stroup, and Leslie Reinhart.  
And to Eric Stark for helping us capture “the moment” as an image.

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# Wild Trout XI Symposium Program





## 2014 Program Schedule

### Monday, September 22

- 4:00 Wild Trout XI Steering Committee Meeting
- 5:00 Registration Opens/Speaker Presentation Check-in/Poster Setup
- 6:30 Wild Trout Ice Breaker Social

### Tuesday, September 23

- 6:30 Breakfast
- 7:00 Registration Desk Open /Speaker Presentation Check-in /Poster Setup
- 8:00 Plenary Session
- 12:20 Lunch
- 1:00 Afternoon Session
- 4:30 Adjourn
- 5:00 Poster Session I
- 6:30 Dinner

### Wednesday, September 24

- 6:30 Breakfast
- 8:00 Morning Session
- 11:50 Awards Lunch
- 1:00 Afternoon Session
- 4:30 Adjourn
- 5:00 Poster Session II
- 6:30 Banquet

### Thursday, September 25

- 6:30 Breakfast
- 8:00 Morning Session
- 12:20 Adjourn
- 1:00 Post-Symposium Debrief and WTXII Planning



## Sponsors

The Wild Trout Symposium gratefully appreciates the support provided by these agencies and individuals. These contributions help preserve, protect and perpetuate wild trout around the world for the generations to come. For more information concerning sponsorship opportunities, visit us at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com).

### Premier Sponsors



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Today TU is a national organization with more than 150,000 volunteers organized into about 400 chapters from Maine to Montana to Alaska. This dedicated grassroots army is matched by a respected staff of lawyers, policy experts and scientists, who work out of more than 30 offices nationwide. These conservation professionals ensure that TU is at the forefront of fisheries restoration work at the local, state and national levels.

Nearly 50 years after its founding, no other conservation organization is as well placed as TU to make a difference for the nation's coldwater fisheries. To learn more about TU's ambitious conservation agenda, please visit the conservation section of our website TU Conservation.



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The mission of the IDFG is that all wildlife, including wild animals, wild birds, and fish, within the state of Idaho, is hereby declared to be the property of the state of Idaho. It shall be preserved, protected, perpetuated, and managed. It shall only be captured or taken at such times or places, under such conditions, or by such means, or in such manner, as will preserve, protect, and perpetuate such wildlife, and provide for the citizens of this state and, as by law permitted to others, continued supplies of such wildlife for hunting, fishing and trapping

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Founded in 2003, the Madison River Foundation is an advocate for the Madison amid the challenges of rapid residential and population growth, commercial development, increasing recreational use and the traditional Western competition over scarce water resources. We strive to work collaboratively with all those who live, work, and recreate on this storied river and its related watershed.

Based in Ennis, Montana, the Madison River Foundation is a tax-exempt, non-profit membership organization incorporated under Section 501(c)(3) of the Internal Revenue Code. We are supported by the voluntary contributions of members, friends and donors.

The Foundation has a dual mission: advocacy and conservation. In its advocacy role the Foundation seeks to be “a voice for the river” in the public arena, advocating worthy public and regulatory policies based on sound science. In its conservation role, the Foundation funds and provides through its membership “boots in the water” volunteer labor for a variety of conservation-oriented projects.



#### USDA Forest Service

The U.S. Department of Agriculture Forest Service is a Federal agency that manages public lands in national forests and grasslands. The Forest Service is also the largest forestry research organization in the world, and provides technical and financial assistance to state

and private forestry agencies. The Forest Service motto, "Caring for the Land and Serving People," captures the spirit of our mission, which we accomplish through five main activities: 1) Protection and management of natural resources on National Forest System lands; 2) Research on all aspects of forestry, rangeland management, and forest resource utilization; 3) Community assistance and cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands to improve conditions in rural areas; 4) Achieving and supporting an effective workforce that reflects the full range of diversity of the American people; and 5) International assistance in formulating policy and coordinating U.S. support for the protection and sound management of the world's forest resources.



### U.S. Geological Survey

The USGS is a science organization that provides impartial information on the health of our ecosystems and environment, the natural hazards that threaten us, the natural resources we rely on, the impacts of climate and land-use change, and the core science systems that help us provide timely, relevant, and usable information. Scientists in the USGS Ecosystem Mission Area conduct research and monitoring on freshwater, terrestrial, and marine ecosystems and the fish and wildlife within them. Healthy ecosystems provide our society with essential ecosystem services, such as crop pollination, water and air purification, harvestable populations of fish and wildlife, soil replenishment, pest control, and nutrient cycling.



### Western Native Trout Initiative

The Western Native Trout Initiative (WNTI), established in 2006, is a public-private Fish Habitat Partnership that works collaboratively across 12 western states to conserve, protect,

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restore and recover 21 native trout and char species. Covering over 1.75 million square miles of public and privately managed lands, WNTI and its partners combine science-based assessments with expert and local knowledge to establish joint priorities for native trout conservation at a landscape scale.

Proposed and led by local communities and resource agencies, these projects are funded and supported through WNTI's grant programs and in-kind contributions by our partners. WNTI seeks to support and sustain the ongoing efforts of our on-the-ground partners by raising awareness for the importance of healthy native trout watersheds and facilitating greater public support for native trout conservation within local communities. Through our Campaign for Western Native Trout, WNTI helps encourage private investment and involvement in native trout projects and regional native trout conservation initiatives



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#### Fisheries Conservation Foundation

The Fisheries Conservation Foundation (FCF) is a 501(c)3 nonprofit organization that promotes the work and knowledge of aquatic scientists, resource managers, and environmental professionals. FCF strives to ensure that objective, peer-reviewed scientific information about fisheries and aquatic resources reaches policy-makers and the public, so the decisions made about the use of our freshwater and marine ecosystems are logical, informed, and based on the principles of sustainability. We work to connect the scientific expertise with other conservation partners and like-minded organizations to inject current scientific knowledge of aquatic resource issues into the public and political knowledge base.



### International Federation of Fly Fishers

The International Federation of Fly Fishers is a 49-year-old international non-profit organization dedicated to the betterment of the sport of fly fishing. The organization's motto is Conserving, Restoring and Educating through Fly Fishing. The idea to create a national federation of fly fishing clubs by people who also were willing to take action, seems to have sprung up on both coasts in the early 1960's. In June 1965, the first Conclave of the Federation of Fly Fishers took place in Eugene Oregon and was hosted by the McKenzie Flyfishers. It was immediately a national organization with the inclusion not only of West Coast fly fishing clubs, but also the Theodore Gordon Flyfishers from New York. Twelve clubs had joined the Federation by the end of 1965, and by the second Conclave held at Jackson Hole Wyoming in September 1966, the number of clubs had risen to 29.

Today, the organization has thousands of members, almost 300 clubs and councils in 37 countries around the world. The mission is to advance the art, science and sport of fly fishing as a way of fishing most consistent with the preservation and use of game fish resources; promote conservation of recreational resources and facilitate and improve the knowledge of fly fishing.

### Flycasters, Inc. of San Jose



Flycasters, Inc. of San Jose is proud to be a sponsor of Wild Trout Symposium XI in honor of the late Marty Seldon.

Flycasters was honored to have Marty Seldon as a member who was very active in fisheries conservation for our club, the Federation of Fly Fishers (FFF) and on the organizing committee of every WT Symposium until 2010. Marty said that, "I'm a firm believer of catch-and-release and very concerned about the preservation of the genetics of

our wild fish for future generations." Marty received the first Aldo Starker Leopold Award at the WT Symposium in 1984. The Flycasters is very proud of Marty and for his lifetime of service to preserving wild trout. The Flycasters of San Jose is a large fly fishing club promoting and teaching all aspects of fly fishing with a history of supporting fisheries conservation and the preservation



### Supporting Sponsors

#### Henry's Fork Foundation

For nearly 30 years, the Henry's Fork Foundation has been the only organization whose sole purpose is to conserve, protect, and restore the unique fisheries, wildlife, and aesthetic qualities of the Henry's Fork of the Snake River and its watershed. The Foundation is an advocate for wild trout, and its credibility has earned it a seat at the table in managing water resources to benefit the fishery and those who depend on it, local businesses that rely on the health of the river, and anglers from all over the world who love the river and help fuel the local economy.



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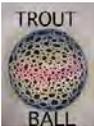


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## In-Kind Sponsors

### Trout Ball by Greg Keeler



Greg Keeler generously crafted the song "Born to be Wild" for the WT-IX Symposium in 2007, in West Yellowstone, Montana. Professor Keeler teaches English by day at Montana State University-Bozeman and entertains the rest of us with wonderful, irreverent, original songs concerning all things fishing. Take a moment to visit his website for captivating art and prose. Thank you, Dr. Keeler, for sharing your gifts with the Wild Trout Symposium.



### Performance Fly Rods

Dave Lewis, a lover of nature and visual arts, as well as stellar custom rod maker, spent many an hour capturing the beauty of fish and fishing across the country. The wild trout community lost Dave to cancer in 2008, after a long full life of appreciating the spirituality of wild trout country. His photos grace the WT Symposium web pages and we thank him for the opportunity to experience these extraordinary images and through them, him.



### Beyond Words

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An avid fly fisher, Carol has attended and produced the symposium proceedings for Wild Trout, Inc. since 1997.

### American Fisheries Society



The American Fisheries Society has generously helped to publicize the Symposium by posting

announcements in [Fisheries](#) magazine and by sending out notices to its members. An overview of Wild Trout Symposia was published in [Fisheries](#) several months before this year's meeting.

## Aldo Starker Leopold Wild Trout Award Sponsor

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The Wild Trout Symposium gratefully acknowledges ATS and their support of the Aldo Starker Leopold Medal. Dick Reichle and his wife, Laura, stepped forward to make the casting of these bronze medals possible. Thank you.

## Wild Trout XI Awards Luncheon Presentation

### Steve Moore, Master of Ceremonies

Welcome to the Wild Trout-XI Awards Luncheon. This is the 40th anniversary of these symposia. Without doubt during my career, this is and has been one of the best meetings I have ever attended. The reason I say this is for four reasons. First, is because of the people involved in the planning of the event. Second, as we saw during the plenary session many of the past participants were legends in the wild/native trout world. Third, each meeting I have attended has always been a mix of the “Old Mossbacks” like Bob Greswell and myself, state and federal wild trout biologist from across the U.S. and Canada and a few international biologist, those attending for the first time and aspiring students whose career goals are to work with and protect wild and native trout. Fourth, this is a “bottom up” symposium. We all work together for a common cause, the protection and preservation of native and wild trout and the places they live. These reason and the great mix of people attending, sharing information, and forging working relationships is what makes this meeting so special in my opinion.

I attended my first Wild trout Symposium in 1989. At that point in my career, I knew that this meeting had the potential to be really good because many of the foremost wild trout biologists in the nation would be here and secondly I would have a few days to spend fishing in Yellowstone. I recall being somewhat intimidated by all of this and I was overwhelmed by how friendly everyone was. I recall the Awards Lunch and meeting Marty Seldon, what a treat. Marty served as the awards Chairman through 2007 and at this point due to failing health he turned the rains over to Jim Daley, New York State Cold Water Fisheries Unit Leader. However because of travel restrictions, Jim could not attend in 2010 so Marty stepped up and served as the Master

of Ceremonies in 2010. Marty passed away December 2011 and for those of us who knew him, he will be missed. So for the first time in the 25 years I have been involved with this prestigious event, the Awards Chairman torch has been passed. I hope and pray that I can do the job half as well as Marty did.

Historically the Awards Committee consisted of the Awards Chairman and the former recipients of the Aldo Starker Leopold Wild Trout Award.

Unfortunately many of these recipients have passed away. The Organizing Committee for Wild Trout XI decided that in the future the Awards Committee would consist of the Awards Chairman and three to four volunteers from the Organizing committee. Each member rated all applications and provided their rankings to the Awards Committee Chairman. **Committee members this year are Steve Moore, Liz Mamer, and Carol LoSapio.**

Awards to be presented today are: The Ron Remmick Undergraduate Scholarship Award, The Marty Seldon Graduate Scholarship Award to two students, the Trout Unlimited-Federation of Fly Fishers Stewardship Award for outstanding wild trout related projects, and the Aldo Starker Leopold Wild Trout Medal in the professional category.

Robert "Bob" Gresswell, is a well published long-time symposium organizing committee member and author, who started out in New Mexico and Utah before receiving a PhD in Fisheries Science from Oregon State University. He is presently a research



Steve Moore, Awards Chair



**Bob Gresswell**

biologist at the USGS Northern Rocky Mountain Science Center in Bozeman. Bob developed the Ron Remmick Scholarship Award and is with us today to confer it.

## Ron Remmick Undergraduate Scholarship Award

Ron Remmick worked for the Wyoming Game and Fish Department for over 25 years. As the Green River Regional Supervisor, he and his staff worked tirelessly to secure the future of the Colorado River cutthroat and Bonneville cutthroat. He provided the foundation for native fish management, conservation, and restoration. He worked diligently with federal agencies to implement the Interagency Colorado River Cutthroat Trout Management plans for the Upper Green River drainage, and to develop the Conservation Agreement and Strategy for Colorado River Cutthroat Trout in Colorado, Utah and Wyoming.

Ron initiated surveys and studies to establish the conservation and management needs for this Bonneville cutthroat trout in the Bear River drainage, and contributed his significant skill and efforts to obtain multi-agency implementation of the Interagency Bonneville Cutthroat Trout Management plan. Ron was a member of Trout Unlimited, President of the AFS Colorado-Wyoming Chapter from 1998 to 1999, and was active on several AFS Committees. Ron Remmick's continual and contagious enthusiasm, innovative and proactive approach to native fish restoration and conservation, his outgoing personality, and willingness to assist all combine to make this award a fitting memorial to his life's work.

The awards committee made a valiant effort to get the word out about the student awards to universities across the nation. Unfortunately no qualified applications were received for this year's event. However, we would like to recognize Henry Hansen who was selected to receive this award last year. He did arrive at the meeting only to learn that it had been cancelled due to the government shutdown.

## Marty Seldon Graduate Student Scholarship Awards

This award was established in recognition of Marty Seldon's over 30 years of contributions to the Symposium Organizing Committee. The Award is presented at each Symposium to two outstanding students, each award consists of a \$500 stipend to assist with travel or other costs incurred in their attendance at these conferences.

Even though there was a government shut down in 2013 that delayed the symposium for a year, two outstanding graduate students in the field of fisheries management and biology, were awarded the Marty Seldon Travel Scholarship at the reception held in West Yellowstone.



**Marty Seldon**



**Jessica R. Reilly**

Jessica is working on her Master of Science degree at the University of Alberta. Her research is focused on using genetic techniques to characterize patterns of genetic differentiation in Artic Grayling populations in Alberta.



**David C. Kazyak**

David is working on his PhD through the University of Maryland. His research focuses on brook trout population dynamics in western Maryland.

Casey Weathers is a PhD candidate at Penn State. His dissertation research is examining the existence of metapopulations of native brook trout populations in GRSM by assessing adaptive gene complexes and comparing DNA assays. For his Master's degree he examined morphometric differences between native brook trout populations in different drainages in GRSM and evaluated the effect of slope and elevation on population characteristics.

Casey is active student member of the American Fisheries Society. He received the best graduate student oral presentation award at the 8<sup>th</sup> Annual Regional Science Consortium, Erie, PA. His career goals are to eventually obtain a teaching/research position within a university. In this role he hopes to motivate and excite young people about current and future opportunities working with wild trout conservation.



**Casey Weathers and Steve Moore**



**Chris Free and Steve Moore**

Chris Free is currently pursuing his PhD at Rutgers University. His research is evaluating the motivations for increased fishing in Mongolia and evaluating the impact of illegal fishing on two endangered salmonid species, the Hovsgol grayling and the taimen. His work will hopefully provide guidance for the management and conservation of these species in Mongolia. Chris began graduate school in the management of large scale fisheries and in fact most of his work history is in this area. However, he became interested in smaller scale inland fisheries in developing countries and the importance of balancing economic and conservation objectives in these countries.

Eventually he would like to become a government fishery scientist so he can have input into policies that will help protect fishery resources or a career in academia where he plans to provide information that regulators can use to make informed management decisions. He has an impressive resume and already has authored or co-authored 5 peer reviewed publications and 4 technical reports.



## Trout Unlimited-Federation of Fly Fishers Stewardship Award

This award is cosponsored by TU and the FFF in recognition of the importance of nonprofit organizations and the thousands of volunteers that are ready, willing, and able to pick up a shovel and roll rocks in our combined efforts to implement specific projects that preserve and restore wild trout. The Award was developed by the Organizing committee for Wild Trout IX and includes a \$1,000 honorarium to the recipient.

This year's recipient is Jeff Hastings, Project Manager for the Driftless Area Restoration Project. Jeff Hastings was hired as the manager in 2006. Since that time he has worked tirelessly to engage partners, acquire funds and educate landowners and agencies on the benefits of watershed restoration. Annually he organizes the Driftless Symposia that is attended by hundreds of professionals and volunteers anxious to learn about new research results, riparian restoration techniques, and related watershed conservation issues. Jeff also holds an annual Project Planning Workshop that teaches attendees how to plan a project, seek funding, organizes work days and reaches out to the media and public to demonstrate their success.

To date their stream bank restoration efforts have increased the density of native brook trout from 270/mile to over 2,100/mile. Additionally wildlife populations that depend on healthy aquatic ecosystems have benefited.



**Jeff Hastings, Project Manager**

## The Aldo Starker Leopold Wild Trout Award

At the suggestion of Former Assistant Secretary of the Interior, Nathaniel P. Reed, and others, the Organizing Committee established the symposium's most prestigious honor, The Aldo Starker Leopold Wild Trout Medal.



**Aldo Starker Leopold**

Aldo Starker Leopold, was a world-renowned scientist, dedicated teacher, distinguished author, outstanding naturalist, and a beloved angling and hunting companion to many. He was an influential speaker and participant at both Wild Trout I and II. His death, on August 23, 1983, a year before Wild Trout III - was at his home near the University of California Berkeley campus where he taught and was the retired head of the Zoology Department. Many of us still miss him and his counsel. The Symposium Committee established the Aldo Starker Leopold Wild Trout medal in 1984 in Starker's memory.

A. Starker Leopold was born in Burlington, Iowa the eldest son of Aldo Leopold. Following in his father's footsteps, he became one of the world's most influential and honoured authorities on wildlife ecology and management. He attended the University of Wisconsin, Yale Forestry School, received his Ph.D. from the University of California at Berkeley in 1944, and retired there as Emeritus Professor of Biology in 1978.

Starker was heavily involved in public policy at the highest levels. He chaired a Special Advisory Board on Wildlife Management of the Department of the Interior, was a member of the Advisory Committee on Predator Control and an international consultant on wildlife conservation policy. He was a Director

and President of the California Academy of Sciences, a Director and Vice President of the Sierra Club, and was involved in a broad range of other public service activities.

Starker's main goal was a world suited to wildlife and therefore fit for people. His personality was characterized by eminent academic and scientific achievements, love of the outdoors, and a positive personal warmth, and sensitivity. A. Starker Leopold was a friend to fish and wildlife, and to all of us. The great late wild trout advocate Ernie Schwieber designed the medal and the Awards Committee had it coined.

### **Aldo Starker Leopold Professional Award**



**Jerry Mallet**

The winner of the Aldo Starker Leopold Professional Award for \$500 goes to Jerry Mallet. This award was presented to Jerry at the Wild Trout reception in 2013.

Jerry is a fisheries professional, who in the eyes of his peers, has made long-time and significant contributions to the enhancement, protection, and preservation of wild trout.

### **Aldo Starker Leopold Wild Trout Medal: Professional**

The WT-XI Professional Aldo Starker Leopold Wild Trout Medal Recipient is Mark Hudy, Senior Science Advisor-Fisheries, USGS. I have known Mark for over 25 years. If my memory serves correctly we first met at a Southern Division AFS Trout Committee meeting. Throughout the years our paths have crossed many times. One of the things I have always admired about Mark is his passion for



**Mark Hudy and Steve Moore**

wild trout and for providing scientific data that will inform management decisions. Mark is no stranger to this meeting and has presented the results of his work at several of the Wild Trout Symposiums.

Mark's work history is rather diverse. He began his career as a trout biologist for the Arkansas Department of Game and Fish. He then moved to South Carolina as the Forest Fish biologist for the Sumter National Forest. After a short stay he moved to Virginia where he was the fisheries Biologist for the George Washington and Thomas Jefferson National Forest. In this position he initiated the forest monitoring program based on water quality and macroinvertebrates. He also spearheaded acid deposition mitigation using helicopter delivery of lime on several acidified streams that since recovery have served as long-term monitoring sites for brook trout population response.

Apparently this position did not have enough challenges for Mark so he moved to US Forest Services Washington office. Where he served as the Eastern and National Aquatic Ecologist, and as the National Fisheries Program Leader, where he helped lead the Agency's adoption of aquatic organism passage (AOP) assessments, provided training in AOP design, promoted use of large wood in aquatic habitat enhancement, and worked tirelessly to benefit trout and a host of non-game species on National Forest System lands. Then somehow in his

role a National Aquatic Ecologist he got assigned to work with Department of Biology at James Madison University, Harrisonburg, VA where he taught courses in Biological Research in Freshwater Fish and Aquatic Ecology, and advised and mentored 8 graduate students and over 16 undergraduate students. He and his students have tackled a number of important research questions applying innovative approaches in the realms of brook trout ecology, acid rain remediation, restoration of spring creeks, riparian tree survival, coldwater habitat vulnerability to climate change, instream habitat, and aquatic organism passage, as well as behavior of white sucker, sculpin and brook trout.

During this time he also worked with the Eastern Brook Trout Joint Venture and used GIS tools to translate a range wide status and threats and

assessment into a range wide map that displayed the current state of brook trout into a visual tool that is easily understood by resource professionals and the public. This work served as the foundation for the Eastern Brook Trout Joint Venture Conservation Strategy.

A couple of years ago Mark moved to his current position as Senior Science Advisor-Fisheries, USGS. I'm not real sure what he has been up to in that position but I'm fairly confident that it will benefit wild trout in some way.

The one thing I've never understood about Mark is how a guy that can't hold a job can accomplish so much.

Please join me in congratulating on a job well done.



**Mark Hudy, Aldo Starker Leopold Award Winner**

**Prior Recipients of the Wild Trout Medal include.**

Year	WT	Professional	Non-Professional
1984	WT-III	Robert J. Behnke	Martin M. Seldon
1989	WT-IV	Frank Richardson	Otto H. Teller
1994	WT-V	Ronald D. Jones	Gardner L. Grant
1997	WT-VI	Roger A. Barnhart	Ernest G. Schwiebert
2000	WT-VII	Robert L. Hunt	Bud Lilly
2004	WT-VIII	Ray J. White	R.P. Van Gytenbeek
2007	WT-IX	Nathaniel P. Reed	Nick Lyons
2010	WT-X	Stephen E. Moore	Tom R. Pero



Photo courtesy of Eric Stark.

# Plenary Session



**Robert Carline, Kevin Meyer and Robert Gresswell**



**Kevin Meyer, Robert Carline, Robert Gresswell and Dan Schill**

## EVOLUTION OF THE WILD TROUT SYMPOSIUM: A MOSSBACK'S PERSPECTIVE

**Robert E. Gresswell**

U. S. Geological Survey, Northern Rocky Mountain Science Center, 2327 University Way, Suite 2, Bozeman, MT 59715

The evolution of the Wild Trout Symposium series is a story of social change. There have been changes in how anglers perceived fish, how the public perceived biodiversity, and how fish were managed by agencies across the country. The changes were gradual and subtle. Nothing earth-shattering, but viewed through the lens of 40 years, they were significant. Although these changes may not have been driven by the Wild Trout Symposiums, they were reflected in the meetings and ultimately, affected by the meetings.

The creation story of the Wild Trout Symposium begins in Denver with a lunch gathering that included Frank Richardson (then Associate Regional Director of the U.S. Fish and Wildlife Service for the Rocky Mountain Region), John Peters (then Chief Environmental Officer of the U.S. Bureau of Reclamation), and Pete Van Gyteenbeek (then Executive Director of Trout Unlimited). These men were all active in Trout Unlimited, and all loved to fly fish. By the end of lunch, they had developed the outline of the first symposium to review and discuss trout and salmon resources. They contacted Nathaniel (Nat) Reed (then Assistant Secretary of the Interior for Fish, Wildlife and Parks), and he arranged for the Department of Interior to cosponsor the meeting with Trout Unlimited. The first Wild Trout Symposium was held in Yellowstone National Park, September 25-26, 1974.

This first symposium featured scientists, managers, conservationists, and anglers from across North America and around the world. Many of the speakers were at the cutting edge of fish and wildlife management during that period. The symposium proceedings were edited by Willis King, a true innovator in fisheries management, who worked for the U.S. Fish and Wildlife Service. As the head of the service's Division of Fisheries Services, he instituted fisheries assistance programs with Native American Tribes, national parks, wildlife refuges, and the Department of Defense, and developed the Cooperative Fishery Unit program between universities, state agencies, and the Fish and Wildlife Service.

Presentations at the Wild Trout Symposium focused on fish biology, aquatic habitat, and relationships with anglers, and how these factors, and interactions among these factors, influenced management of wild trout. Unifying concepts of the first symposium were associated with the need to curb fish stocking, habitat degradation, and overharvest by anglers. Of course, special angling regulations were at the core of many of the presentations at the initial symposium. The mantra that a wild trout was too valuable to only be caught once was repeated often.

After the first Wild Trout Symposium, the series continued, initially on a 5-year recurring interval. The importance of strong political backing for the concepts associated with wild trout management was apparent from the beginning. In addition to Nat Reed, two other Assistant Secretaries of Interior, Bob Herbst (Carter administration) and Ray Arnett (G. H. W. Bush administration), participated in second and third symposiums, respectively. Reed returned to give a keynote address at the Wild Trout IV, and Bruce Babbitt, Secretary of the Interior in the Clinton administration, was the keynote speaker at Wild Trout V.

At the local level, Yellowstone National Park has been intimately involved with the Wild Trout Symposium series since its inception. Jack Anderson, Superintendent of Yellowstone National Park during the first Wild Trout Symposium ushered in sweeping changes to angling regulations in the park including size limits, season closures, and harvest restrictions (including catch-and-release-only rules) on all of the major fisheries. The emphasis of the fisheries program shifted from providing fish for anglers to managing fish as an important component to the entire park ecosystem, and native trout became the focal species. In 1974, Yellowstone National Park supported some of the most progressive wild trout regulations in the country.

The role of Yellowstone National Park in the Wild Trout Symposiums can hardly be exaggerated. Virtually all superintendents, or their representatives, have attended the meetings. In addition to Jack

Anderson, this list includes superintendents John Townsley, Bob Barbee, and Mike Finley, Deputy Superintendent Frank Walker, and Chief of the Center for Resources, John Varley. It is noteworthy, that in a previous job with the U.S. Fish and Wildlife Service (1973-1980), Varley played an influential role shifting the emphasis of the fishery program in the park from consumption to ecosystem management. At Wild Trout VI, the keynote address was delivered by Karen Wade, the Regional Director of the Rocky Mountain Region of the National Park Service.

From the beginning, the Wild Trout Symposium series has been a forum for interactions with leading conservationists. Perhaps no individual deserves recognition more than Nat Reed does. The Endangered Species Act, ban on use of DDT, Marine Mammal Protection Act, Endangered Species Convention, Clean Waters Act, National Environmental Policy Act, and Alaska Lands Act were all enacted while, or immediately following, his tenure as Assistant Secretary. Although there were many factors interacting during the period that made this plethora of environmental legislation possible, Reed provided the leadership necessary for success. He has remained active as a board member of numerous conservation groups such as The Nature Conservancy, the Natural Resources Defense Council, American Rivers, and the Everglades Foundation, and he is a staunch advocate for wild trout.

It is also critical to acknowledge the role of A. Starker Leopold with the Wild Trout Symposium series. Starker had a strong reputation as a scientist and conservationist long before the first Wild Trout Symposium report. For example, he chaired a panel of scientists appointed by the Secretary of the Interior, Stewart Udall, to examine wildlife management in national parks; the resulting report is still being used to guide wildlife management today. Starker acted as science advisor to Assistant Secretary Reed, and he was also an ardent fly fisher. During the first Wild Trout Symposium, he presented a paper on the deterioration of public lands under a policy of multiple use in which he expressed concern about the effects of grazing on stream habitat. Indeed, concern about aquatic habitats continues as a theme of Wild Trout Symposiums today.

Of course, the participation of individuals making extraordinary contributions to wild trout management has continued through the years. Researchers,

managers, and philosophers, such as Luna Leopold, Bob Hunt, Bob Behnke, Ray White, and Paul Schullery, have provided numerous innovative ideas. In addition, these meetings have been a forum for angler conservationists, including Lee Wulff, Gardiner Grant, Bud Lily, Otto Teller, Nick Lyons, and Ernie Schwiebert. Contributions of these individuals to the perpetuation aquatic systems and the wild trout they support have been extensive.

Beyond the opportunity to be exposed to new and thought-provoking ideas, the Wild Trout Symposium series has provided the environment for dynamic collegial interaction. It has been a place where discussions are focused for days on the issue of wild trout and the factors that affect their persistence, and a place where old friends and new acquaintances can talk about problems, concerns, and innovations. It is truly a source of energy for those involved with wild trout.

Beginning with Wild Trout III, awards in honor of Starker Leopold have been presented to individuals making outstanding contributions to wild trout conservation and management. Recipients are chosen in two categories, professional and non-professional, and each is provided a medal originally designed by Ernie Schwiebert. The first individuals to receive the award were Bob Behnke (professional) and Marty Seldon (nonprofessional), two people that continued to influence wild trout management throughout their lives.

Themes of biology, aquatic habitat, and angler relationships have continued to provide the framework for the Wild Trout Symposium through the years. At the same time, specifics are constantly changing. For example, the effects of natural disturbances, such as fire, on fish populations and aquatic habitats have been explored in detail. Issues associated with invasive species, including the exotic disease organism that causes whirling disease, are a growing concern in many parts of the country. More recently, discussion concerning the effects of climate change on wild trout populations and possible adaptation strategies is common.

Over the past four decades, however, emphasis of Wild Trout Symposiums has shifted from wild trout to native salmonids. In fact, the theme for Wild Trout VI was “Putting the Native back in Wild Trout.” Interactions among conceptual, social, and technological aspects of native trout management have

gained increased emphasis. Indeed, at the beginning of the 21<sup>st</sup> century, efforts to reestablish or protect populations of native trout often include removal of existing populations of wild trout introduced from stocks originating from other parts of North America, or in some cases Europe.

Wild Trout VI was notable in other ways. The interval between symposiums was reduced from 5 years to 3 years because the issues associated with wild trout management had become more pressing since the inception of the series. Under the direction of symposium organizer Pat Dwyer, the program was opened to contributed papers for the first time. This was a significant change because it not only provided the opportunity for individuals conducting interesting new, but often unrecognized, work to inform others, but it substantially broadened the base of participants in the symposium series. Furthermore, the top-down structure of the organizing committee that had been so important for establishing and initially perpetuating the symposium, was replaced by a more bottom-up, volunteer-driven group of individuals.

It also marked the first time that a Wild Trout Symposium was held outside of Yellowstone National Park; meeting dates were in mid-August instead of late September. Facilities at Montana State University included a substantially improved sound system, but it was not Yellowstone National Park. The message from participants (and most of those who chose not to participate) was “move the Symposium back to Yellowstone.”

Topics at Wild Trout VI were diverse, as usual. One unique occurrence was the participation of the first “talking trout” in the session on public outreach. Although there was some concern that outreach was not real science, it proved to be a harbinger of science communication in the 21<sup>st</sup> century. Perhaps more intriguing were negative comments about the number and complexity of talks focused on genetics. This seems almost unbelievable now considering the important and ever increasing role of genetics in the management of native trout, but it is a very real example of the evolution in trout management over the past 40 years.

The Wild Trout Symposium series moved back to Yellowstone National Park for Wild Trout VII and has remained there (or West Yellowstone) since 2000. During this period, the Wild Trout Symposium became incorporated, a move that provided a means to more

efficiently manage funds associated with the meetings and a broader array of fund raising options. This change includes an official logo; volunteers are now “riding for the brand.”

Topics at the meeting have continued to evolve in the last 14 years. The emphasis on native trout has increased and the geographic scale of interest has broadened. Interest in management of Brook Trout across the historic range of this iconic species of the eastern portion of the continent now rivals that of western native trout. In the West, Artic Grayling and Bull Trout are species that are at the center of numerous landscape-scale management programs. In recent years, interagency, interstate working groups for the management of native trout have become common, even in the absence of listing under the Endangered Species Act.

The effects of scale, both spatial and temporal, on understanding and managing aquatic habitats are topics that have become common in recent Wild Trout Symposiums. This change reflects a major conceptual shift how habitat is perceived. Habitat management has moved beyond site-base habitat restoration to a broader watershed-scale perspective that incorporates the capacity of a stream’s physical template and corresponding biological potential. Regional assessments have become more common, and therefore, decisions concerning where and when habitat restoration is warranted have become strategic and less reactive. The entire process has become less mechanistic and more probabilistic.

In addition to the more general approaches to wild trout biology and management, changes in the mechanics of the meeting also continue. For example, poster presentations have become a major component of the meeting. From meager beginnings, this portion of the program continues to grow. Participation was so great at Wild Trout XI that the poster session had to be divided over two evenings. Virtually all attending the session were actively participating in discussions with presenters.

New awards have been incorporated into the Wild Trout Symposium series in recent years. The Trout Unlimited/Federation of Fly Fishers Wild Trout Stewardship award was presented for the first time at Wild Trout X. This award is presented to groups “for significant contributions to the conservation, protection, restoration, or enhancement of a coldwater fishery.” In 2010, the award was presented to the Little River Chapter of Trout Unlimited.

The Ron Remmick Undergraduate Student Award and the Marty Seldon Student Travel Scholarship were also initiated at Wild Trout X. These two awards recognize outstanding students with an interest in wild trout management. More generally, these student awards reflect the importance of encouraging new meeting participants and wild trout advocates. The Ron Remmick Undergraduate Student Award was presented to Charles Cathcart at Wild Trout X, and Bradly Allen Trumbo and Daniel A. James received the Marty Seldon Graduate Student Award.

At the beginning of this discussion, I suggested that the evolution of the Wild Trout Symposium series was a reflection of social change over the past 40 years. This evolution is probably most apparent in the gradual shift away from a top-down process directed by a few key individuals to an increasingly broad bottom-up organization. It could be argued that the series would not have emerged and certainly would not have persisted without the strong leadership from a few individuals during the early years. On

the other hand, without the evolution to a bottom-up organization driven by a large number of volunteers, the series could well have withered on the vine decades ago. A brief perusal of photographs of the organizing committee for the last three symposiums provides evidence of this change. A gradual, but significant shift in the gender balance of the committee provides a strong reflection of similar changes that have occurred in resource management science and practice during that time period. These are all positive signs that suggest to me that even considering the enormity of challenges to the persistence of native salmonids throughout the northern hemisphere, there has been, and continues to be, a growing number of highly motivated and skilled scientists and managers that are ready to take up the challenge. Furthermore, and maybe most importantly, there appears to be growing support for wild native trout among the public at large; without their continued support, it will be impossible to succeed.

## WILD TROUT SYMPOSIA: THE INTERSECTION OF POLITICS, POLICIES, AND SCIENCE

**Robert F. Carline**

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### SPECIAL REGULATIONS

My task was to review the proceedings of past Wild Trout symposia and provide a synopsis of important issues and themes that have been addressed. Rather than compiling a list of the many and varied subjects that have been covered over the past 40 years, I have chosen a handful and will trace their evolution through time, with the intent of exploring how these meetings have contributed to the science, management, and conservation of wild trout.

Hence, this paper is essentially an essay; it represents my reflections and impressions of past Wild Trout symposia.

While reviewing the proceedings of past symposia, I came across several pieces of legislation that altered the course of wild trout management. I envision this process as the intersection of politics (legislation) and policy (management). A third important element of these meetings is the underlying science that guides management. Thus, the intersection of these three elements forms the essential basis of past and future symposia.

Wild Trout I was significant, because it was the first time that fisheries professionals and angling groups cooperatively organized a meeting of this type. The U.S. Department of the Interior, led by the Fish and Wildlife Service, and Trout Unlimited were the sponsors. Presentations at that meeting covered the status of wild trout and salmon stocks in the USA and Canada, and there were several overview or synthesis papers that dealt with a wide range of topics. No issues were given special attention by the symposium organizers, but there was considerable discussion about the effects of stocking catchable-size trout on wild trout and a bit of hatchery bashing. The effects of stocking on wild trout will be reviewed in a paper by Schill (this volume); hence, I will not address this topic. However, I believe it is important to note here that the widespread belief in the negative effects of stocking catchable-size hatchery trout first gained momentum at Wild Trout I and was extended in several papers in subsequent Wild Trout symposia.

At Wild Trout II several themes were emphasized. One of them was special regulations, and in particular, Catch and Release, which might entail no harvest or a bag limit of 1 or 2 trout/d. Gresswell (1980) noted that some of the impetus for adopting Catch-and-Release regulations stemmed in part from a desire to move away from the concept of Maximum Sustained Yield (MSY). In the 1940s and 1950s, MSY was promoted as a desirable management objective for all types of fisheries. By the 1960s it became evident to managers of wild trout that MSY was not an appropriate objective, but rather, objectives for wild trout fisheries might best be couched in terms like maximizing the quality of the fishing experience. Hence, Catch and Release became a favored tool of many trout biologists and angling groups, because it could provide high catch rates, above average size of angled trout, and protect against overexploitation.

At Wild Trout II there were a few references to restrictive regulations in the first half of the 20<sup>th</sup> century. In 1907 a flies-only regulation was implemented on the Ausable River in Michigan, and a flies-only, two-trout/d regulation was adopted in 1938 on Spring Creek in Pennsylvania. But, it was not until the 1960s that restrictive regulations begin to be more widely used. For example, no-kill and artificials-only regulations were implemented on the Beaverkill in New York, and in Yellowstone National Park in 1969, Catch-and-Release regulations were adopted for Grebe Lake, an Arctic Grayling *Thymallus arcticus* fishery. By the 1970s, Catch-and-Release regulations became common. There are numerous notable examples in Wild Trout proceedings: several states including Colorado and Montana adopted these regulations for the first time, and British Columbia applied Catch-and-Release regulations to 33 steelhead streams for at least part of the year.

Apparently, the enthusiasm for Catch-and-Release regulations spread to some politicians. The first good example of the intersection of politics and policy comes from California. In 1979 their state legislature

passed a law requiring the California Department of Fish and Game to designate no less than 25 miles of streams and one lake as Catch-and-Release waters annually for 6 years. Imagine the politicking that went on to bring about this law. No other speakers mentioned pressure from legislators to implement Catch-and-Release regulations; hence, I assume that management agencies were the primary instigators of this movement.

Yellowstone National Park played a key role in promoting Catch-and-Release regulations. They implemented regulations on four river reaches and two lakes in 1973 and immediately began evaluations of these new restrictions. The staff at Yellowstone National Park and several other state agencies were in the forefront of instituting restrictive regulations to benefit or restore native species. Many of these changes were not popular with an angling public accustomed to harvesting trout.

At Wild Trout III in 1984, biologists from Yellowstone National Park reported on 10 years of evaluations of Catch-and-Release regulations. And, early reports of evaluations came from several other states including California, Colorado, Montana, and New York. Results of these evaluations were mostly positive, with increases in trout density and catch rates. Where it was assessed, angler satisfaction was high. For the most part, fishery responses to Catch-and-Release regulations were meeting expectations.

There were a variety of other types of special or restrictive regulations that were reported at Wild Trout symposia. These included assessments of bag limits, length limits, hook types, and use of bait in no-kill waters. I vividly recall a report by Kulp and Moore (2004) that summarized results from a large variety of regulations on streams in the Great Smoky Mountains National Park. It represents an excellent summary of how Rainbow Trout *Oncorhynchus mykiss* populations with high mortality in infertile streams failed to respond to restrictive regulations. Droughts and floods had more influence on population density than did regulations.

While reviewing results from a wide range of studies on regulations presented at past symposia, it quickly became apparent that one needs to take into account a complex array of biological and social factors when attempting to formulate regulations for wild trout. We have seen some excellent studies on specific regulations, but we have not seen an overview paper that attempts to incorporate the wide range of variables that need to be considered. I have tried to capture at least some of these factors in Figure 1. No doubt, more items can be added to the diagram. Here lies a paper, or rather a monograph that is crying out to be written. It should be a comprehensive assessment of how regulations can be formulated and how they can be expected to work given all of these biological and social considerations.

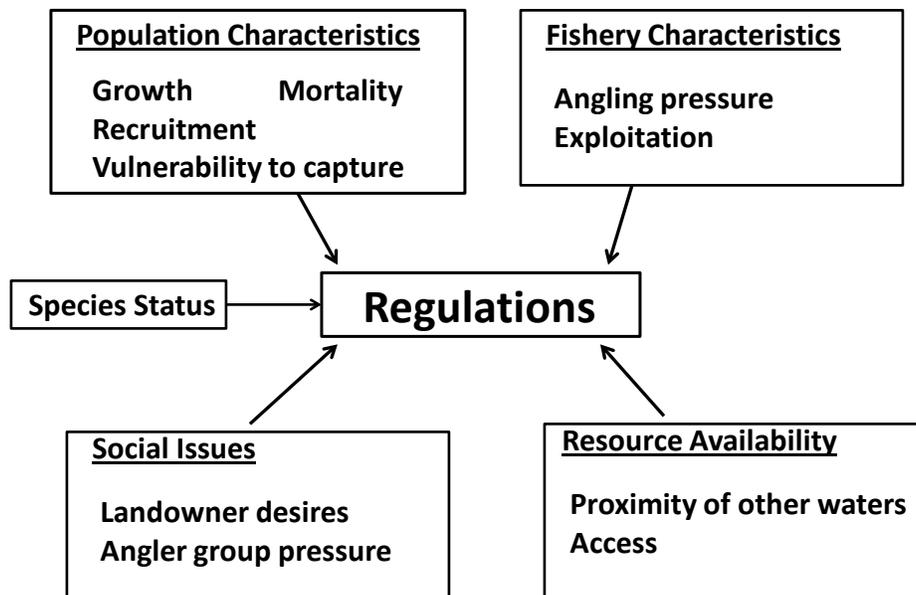


Figure 1. Biological, fishery, and social considerations that need to be taken into account when formulating regulations for wild trout.

So, how effective have Wild Trout symposia been in promoting and understanding effects of special regulations for the benefit of wild trout management? I think we have done pretty well and I gave us a grade of B+; we are just lacking that one good synthesis paper.

## ADOPTING AN ECOSYSTEM APPROACH AT THE WATERSHED SCALE

At Wild Trout I, A. Starker Leopold (1975) pleaded with the audience to take an ecosystem approach to quantify effects of disturbances on western forests. He suggested that fishery biologists were a bit myopic in how they viewed trout fisheries. To understand why fisheries might be declining, one needs to take a broad view, that includes water quality, riparian habitat, and landscape disturbances. He was critical of the concept of multiple use, and he was particularly concerned with effects of grazing on wildlife and fishery resources. At Wild Trout II, Leopold (1980) again argued for the need to work with entire ecosystems, the conceptual framework, and he pointed to watersheds as a logical working framework. In my view, the best examples of watershed-scale studies and restoration projects are those in which organizers have reached out to include the full range of interested parties: all levels of government, NGOs, businesses, landowners, etc.

The Alsea Watershed Study, presented at Wild Trout I, is an excellent example of research dealing with the effects of logging at the watershed scale (Lantz 1975). Similarly, Platts and Martin (1980) describe effects of grazing and logging at the watershed scale in Wild Trout II. We find some good examples of watershed scale efforts from Wild Trout III in 1984 to Wild Trout VI in 1997. But then in 2000 at Wild Trout VII, some excellent management examples emerge. The Oregon Plan is noteworthy because it represents a blueprint for recovery efforts instigated by the Endangered Species Act. At the same meeting we saw several really good recovery plans that were making significant progress. This is another example of where politics, in particular, the Endangered Species Act, intersected with policy and changed the course of management.

At Wild Trout VIII more watershed scale restoration projects were reported. Trout Unlimited's Watershed Program provides a great model for restoration projects that rely on collaboration. And

more recently, the initiation of the National Fish Habitat Action Plan and the partnerships that it has spawned, will further promote restoration efforts at the watershed scale.

How well have Wild Trout symposia embraced the ecosystem approach for the study, management, and restoration of wild trout resources? I gave us a grade of A-; in the last 10-15 years we have made significant progress in ecosystem level management, and there is every indication that management of wild trout resources will continue in that vein.

## INVESTIGATIONS AND CONSERVATION OF FISH GENETICS

During the first four symposia a few speakers, and in particular R. Behnke, alluded to genetic issues, but the topic was never a major emphasis. The organizers of Wild Trout V in 1994 devoted a session to genetic studies, and several additional contributed papers had a strong emphasis on genetic considerations. It took 20 years, but this subject finally was brought to the forefront. During the next five symposia, papers dealing with genetic issues became a regular part of the program.

Another parallel trend with the increasing importance of genetic issues, was the shift in emphasis from just wild trout to native trout. In the early Wild Trout symposia, there was hardly a mention of native species – if fish were wild, that was a desirable condition. Through time the emphasis changed, and folks from the Park Service were among the first to stress the importance of management and conservation programs that favor native species over introduced species. Beginning at Wild Trout V, we begin to see descriptions of recovery plans for listed species in which protection and propagation of existing genetic diversity is a key element. Here is another example of the intersection of politics in the form of the Endangered Species Act, policy, and science.

In the first five Wild Trout symposia, we heard several papers dealing with conservation and management of Atlantic Salmon *Salmo salar*. The importance of conserving native gene pools is well illustrated in the attempted restoration of Atlantic Salmon runs in the Connecticut and Merrimack rivers. The Connecticut River is more than 400 miles long; it is the longest river in New England. The Merrimack River is a much smaller watershed just to

the north of the Connecticut River. These are among the southernmost New England rivers that historically had salmon runs. Those runs were lost many years ago, and none of that genetic diversity has survived. The U.S. Fish and Wildlife Service had been involved with restoration efforts on the Connecticut River for 45 years. In 2012 the Service announced that it would no longer provide hatchery support for the program on the Connecticut River (U.S. Fish and Wildlife Service 2013a), and last year they suspended their support of the Merrimack River restoration (U.S. Fish and Wildlife Service 2013b). The program failed, but not because of a lack of effort or money.

These restoration efforts faced a whole score of serious obstacles. Some obstacles that are often mentioned by biologists involved with this program include the following: acidified headwaters, obstructed upstream and downstream passage at dams, predation on smolts by invasive predators in the rivers, intensive predation in the estuaries, and high seas predation and exploitation. From my perspective, the loss of the entire original genetic diversity that existed in these systems made these restoration efforts impossible to succeed. We need to remind ourselves of the message so often delivered by geneticists – there is much genetic diversity in isolated populations of salmonids. This diversity is too precious to lose. We cannot replace it.

How well have Wild Trout symposia promoted the investigation and conservation of fish genetics in the management of wild trout. I gave us a B+. We were slow getting into it, but have come a long ways in the past 20 years and paper on fish genetics have become a regular part of our meetings.

## LARGE-SCALE ENVIRONMENTAL PERTURBATIONS

The manner in which acidic precipitation and climate change were treated at Wild Trout symposia provides an interesting contrast that merits some attention. The first symposium report of acidic precipitation was at Wild Trout II when Schofield (1975) noted that the pH of rainfall in New York was 4.0-4.2, more than 10 times the acidity of rain falling through unpolluted air. The pH had declined in many poorly buffered lakes, and more than one-half of the high elevation lakes in the Adirondack Mountains were fishless. He also noted huge losses of fish in

many Scandinavian lakes. Clearly, acidic precipitation was not just a regional issue.

At the next Wild Trout symposium, Watt (1984) reported that Nova Scotia had lost Atlantic Salmon runs in 13 rivers owing to acidic precipitation with serious populations declines in eight others. Reports from other New England states and Pennsylvania indicated that many miles of streams were either chronically or episodically acidified. This was a major environmental crisis.

Reports of such scientific findings slowly began to show up in the popular media. I believe that one of the parallels between acidic precipitation and climate change was a relatively long lag time between reports in the scientific literature and appearance in the media. I recall in the late 1980s doing a search of newspaper articles on acid precipitation. I found numerous articles in Western European newspapers but hardly any in the USA. My impression is that the same phenomenon occurred with climate change – the media in the USA was far behind the European media in reporting on these major environmental problems. I do not know if the media in Canada was also slow to bring this issue to the forefront.

Media coverage finally got the attention of the public, which called for government action. The U.S. Congress amended the Clean Air Act in 1990. The law reduced allowable emissions of sulfur and nitrogen compounds responsible for acidic precipitation. Industry claimed the standards were too strict and environmental scientists said they were not strict enough. These amendments did not solve the problem, but greatly slowed the acidification process. Here was yet another example of the intersection of politics, policy, and science.

The first presentation on climate change at a Wild Trout symposium came in 1989. Fox and Moir (1989) reported on the evidence for climate change and some possible consequences. The next paper we heard was 8 years later at Wild Trout VI; Flebbe (1997) discussed habitat fragmentation for Brook Trout *Salvelinus fontinalis* owing to climate change. There were no papers dealing with climate change at Wild Trout VII or Wild Trout VIII. At Wild Trout IX we heard two papers that predicted of effects of climate change on salmonids and offered some potential adaptation strategies. Despite the paucity of papers on the subject, some members of the wild trout community were concerned. Gresswell (2007) articulates this concern:

“Climate change may ultimately be the greatest threat to the persistence of native western trout, because it will exacerbate current negative effects of invasive aquatic species and habitat degradation.”

The program committee for Wild Trout X decided to more thoroughly address the topic, with an invited plenary speaker and a large session. It was an excellent session that finally addressed this important topic. When compiling this history, I was surprised at how little attention we paid to this issue up until a few years ago. The American Fisheries Society had a major symposium on climate change at its annual meeting in 1990, and the papers were published the following year. Yet, it was 20 years later before Wild Trout took a close look at climate change.

Turning now to the political side of this issue, as I noted earlier, despite a large amount of scientific inquiry and publications about climate change, the media in the USA was slow to thoroughly report on climate change and its consequences. Now, articles on climate change are fairly common. Despite improved media coverage, the public is not particularly excited about climate change. Here are some examples.

In June 2013 the Pew Research Center reported results of a public opinion poll. Respondents were asked what should be the top priorities for the President and Congress. Among the 21 issues listed in the survey, global warming ranked last. In April of this year the Gallup poll asked respondents how concerned they were about global warming. Based on a series of questions they grouped respondents into three categories: Concerned Believers 39%, Mixed Believers 36%, and Skeptics 25%. This particular survey was first run in 2001. The proportion of Concerned Believers has remained about the same, the Mixed Believers have declined, and the Skeptics have increased from 12% to 25%.

Given this tepid level of public concern, it is no surprise that Congress is deeply divided on this issue. When a presidential candidate in 2012 declares that climate change is a hoax, it tells me that the scientific community (and the popular media) has a lot of work to do in public outreach and communication.

How well have Wild Trout symposia investigated and reported on large-scale environmental perturbations? I gave us a B-. I expect that we will see more papers on climate change, but how well will we communicate the science remains to be seen.

## COMMUNICATION AND EDUCATION

While making this presentation at the symposium, I asked if any members of the audience were aquatic education specialists, representatives of the media, or free-lance outdoor writers. I predicted that there would be three individuals in these categories, but instead there was just one, which I suspect was typical of most past meetings. At every symposium we have had one or more speakers emphasize the need to better inform anglers and the general public about the value of wild trout conservation. We have even had a few sessions devoted to outreach and communication. From my perspective, we have done a poor job of transmitting our message to the media. I cannot recall coverage of our meetings in any of the angling media outlets. And, I have asked folks who have attended more symposia than me, and their recollection is that we hardly ever or never get coverage.

How well have Wild Trout symposia communicated with the media? Based on media coverage, I would say not well. I gave us a grade of C-. Nearly all of our symposia have identified important issues that our constituencies need to understand. We need to find ways to get those messages to the media.

## QUALITY OF THE SCIENCE

Finally, I want to comment on the quality of the science presented at Wild Trout symposia. In the early symposia, most of the presentations were review or synthesis papers. And, they were quite good. Through time, especially by Wild Trout V, we see a shift towards more contributed papers and posters. In recent years, reports on research findings and case history studies have become the main types of presentations. But perhaps more importantly, over the decades many of these papers represent really solid pieces of work. And oftentimes, the papers were of the type we would categorize as “you heard it here first”. While our proceeding papers are not anonymously peer-reviewed, they certainly meet a high standard of excellence and many are in fact subsequently published.

How does the quality of science at Wild Trout symposia rank? I gave us an A-. I have had the opportunity to read nearly all of the papers that you will hear over the next few days. After listening to these presentations, I think you will agree with me, that all of us at Wild Trout XI have been exposed to some very insightful and informative work.

## REFERENCES

- Flebbe, P. A. 1997. Global climate change and fragmentation of native brook trout distribution in the southern Appalachian Mountains. Pages 117-121, in Gresswell, R. E., P. Dwyer, and R. H. Hamre, editors. Putting the native back in wild trout; Proceedings of the Wild Trout VI Symposium; 1997 August 17-20, Bozeman, Montana. 216 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Fox, D. G., and W. Moir. 1989. Greenhouse fish. Pages 34-40, in Richardson, F., and R. H. Hamre, editors. Proceedings of the Wild Trout IV Symposium; 1989 September 18-19; Bozeman, Montana. 233 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Gresswell, R. E. 1980. Yellowstone Lake – a lesson in fishery management. Pages 143-147, in King, W. editor. Proceedings of Wild Trout II Symposium, 1979 September 24-25; Bozeman, Montana. 164 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Gresswell, R. E. 2007. Conservation and restoration of native trout in the face of climate change, invasive species, and development. Pages 247- 249, in Carline, R. F., and C. LoSapio, editors. Sustaining wild trout in a changing world; Proceedings of Wild Trout IX Symposium; 2007 October 9-12; Bozeman, Montana. 308 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Kulp, M. A., and S. E. Moore. 2004. A case history in fishing regulations in Great Smoky Mountains National Park: 1934-2004. Pages 205-213, in Moore, S.E., R. F. Carline, and J. Dillon, editors. Working together to ensure the future of wild trout; Proceedings of Wild Trout VIII Symposium—30<sup>th</sup> anniversary; 2004 September 20-22; Bozeman, Montana. 392 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Lantz, R. L. 1975. Land-use management – a case history of the effects of logging on aquatic resources. Pages 36-40 in King, W., editor, Proceedings of the Wild Trout Management Symposium; 1974 September 25-26; Bozeman, Montana. 103 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Leopold, A. S. 1975. Ecosystem deterioration under multiple use. Pages 96-98 in King, W., editor, Proceedings of the Wild Trout Management Symposium; 1974 September 25-26; Bozeman, Montana. 103 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Leopold, A. S. 1980. Summary – Wild Trout Symposium II. Pages 2-4 in King, W. editor. Proceedings of Wild Trout II, 1979 September 24-25; Bozeman, Montana. 164 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Platts, W. S., and S. B. Martin. 1980. Livestock grazing and logging effects on trout. Pages 34-46 in King, W. editor. Proceedings of Wild Trout II, 1979 September 24-25; Bozeman, Montana. 164 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- Schofield, C. L. 1980. Impacts of acid precipitation on trout waters. Pages 62-66 in King, W. editor. Proceedings of Wild Trout II, 1979 September 24-25; Bozeman, Montana. 164 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))
- U.S. Fish and Wildlife Service. 2013a. Atlantic Salmon management. Available: [www.fws.gov/r5csrc/atlantic\\_salmon\\_program.htm](http://www.fws.gov/r5csrc/atlantic_salmon_program.htm).
- U.S. Fish and Wildlife Service. 2013b. Fish and Wildlife Service ends investments in Merrimack River Atlantic Salmon program; shifts focus to shad, other fish species. Available: [www.fws.gov/northeast/fisheries/news.html](http://www.fws.gov/northeast/fisheries/news.html)
- Watt, W. D. 1984. Acid rain and Atlantic salmon. Pages 157-161 in Richardson, F., and R. H. Hamre, editors. Proceedings of Wild Trout III Symposium, 1984 September 24-25; Bozeman, Montana. 192 pages. (Copy available at [www.wildtroutsymposium.com](http://www.wildtroutsymposium.com))

## The Future of Wild Trout Management

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As the wrap-up of the plenary session, I was asked to talk about what wild trout management will look like several decades from now. With such a broad topic, it was difficult to narrow down what material to cover. From the beginning, I felt some caveats were needed to establish sideboards. The first is that it appears highly likely that the earth will be at least 1-2°C warmer by the middle of the 21<sup>st</sup> century. So rather than get into specifics here regarding climate change, let us just proceed on the notion that this warming will likely occur, and that wild trout in the future will likely be affected by climate change in meaningful ways (Jonsson and Jonsson 2009; Wenger et al. 2011). My second caveat is that it was hard enough for me to think about what is happening now and what is likely to happen in the future regarding wild trout management in North America, let alone Europe, New Zealand, South America, and other areas of the globe where anglers pursue wild trout. So although this symposium has overseas attendees, herein I focus on North America, though much of the material I cover will hopefully apply to other areas of the globe as well.

Having laid this groundwork, how do you predict what the future of wild trout management will be like? One of my favorite quotes is by Harry Truman, who once said that “The only thing new in the world is the history you don’t know.” Considering only the historical summaries that Bob Gresswell and Bob Carline gave us in their plenary talks, anyone might have some ideas of the general trajectory that we will be following for wild trout management over the next many years. In fact, one could ponder the history of “wild trout management in the future” talks that have been given at past Wild Trout Symposiums. The first was sort of a compilation of concluding statements at Wild Trout I in 1974, given by Willis King, Nathaniel Reed, and Bill Luch. Their general conclusions were that wild trout habitat was being destroyed, that hatchery stocking was ruining wild trout stocks, and that these two things needed to be turned around soon or there would not be any wild trout left to manage.

The next “future of wild trout” talk was given by Lee Wulff at WTII in 1979. His opening line was, “It

is one of the great joys of my life that I have lived long enough to see us turn the corner in trout management and know that we are swinging back upward toward great trout fishing in the future.” What a turnaround in just five years. The major problem he railed against was the need for more restrictive angling regulations, including catch-and-release, which actually was a big issue because this was back in the day when most anglers kept everything that they caught.

There was a gap in “futuring” talks for a while, but at WTV, in 1994, there was an entire session devoted to the subject. By this time, depending on who was speaking, the focus had turned to native trout, protecting quality trout habitat, providing a diversity of angling opportunities, and helping to solve overcrowding and social conflicts on wild trout waters. Remember that the movie “A River Runs Through It” had just come out in 1992.

Fast forward 13 years to WTIIX in 2007 where a few more “future of wild trout” talks were given. One was given by Peter van Gytenbeek, who concluded that in the next twenty years, wild trout management probably would not change much at all.

So there is our history lesson. And like Mr. van Gytenbeek, I do not anticipate that wild trout management in the near future will look that much different than it does right now. I think we can all see some trends that will likely continue for the foreseeable future. One is that we will probably see more catch-and-release regulations on wild trout fisheries. We have already seen catch-and-release waters grow in popularity, and it is hard to imagine that not continuing. As people have recognized for decades, anglers who live farthest from trout fishing waters, in urban environments, are usually the ones who want more restrictive harvest or catch-and-release regulations. In contrast, anglers who live near trout streams in rural areas are usually the ones that still want to harvest wild trout. Since the world is becoming more and more urbanized, and will increasingly do so in the future, there will likely be a continued push for more catch-and-release waters. Organized groups such as Trout Unlimited continually push to expand catch-and-release regulations, and their

voices grow ever louder compared to Joe six-pack who might want to dunk a worm and take a few fish home. So, some level of expansion of catch-and-release waters for wild trout anglers is probably inevitable.

However, we have to continually ask ourselves, now and in the future, whether catch-and-release regulations are really necessary or helpful on any given water to provide quality wild trout fishing, because catch-and-release regulations can be sort of a cop-out by fish managers. In these days, when most anglers voluntarily release their catch, regardless of the angling regulations, will adding more catch-and-release regulations really help to grow substantially more fish, or bigger fish, or both? Is the small amount of harvest that now goes on in wild trout fisheries really having big impacts on the populations? I would assert that in most instances the answer is no.

Anglers, and even biologists, are often under the impression that if wild trout populations were left alone, mortality in the population would be extremely low, and you would have larger trout and more of them in every run, riffle and pool in the stream. In reality, in most instances, about half of each age class is lost each year to natural causes. What results is that, even in unexploited trout populations with good fish growth and in a relatively remote setting, you generally get very few trout larger than 16 inches – no matter how productive the water is. So in many instances, you can have some fish harvested by anglers, or lost to natural mortality, but either way, a lot of wild trout this year are not going to be around next year.

Of course, each species of trout has a different capacity to withstand angler harvest. Brook Trout *Salvelinus fontinalis*, for example, which mature early in life, have a short lifespan, and are highly fecund for their size, can in some areas withstand exceptionally high levels of harvest without having hardly any measurable impact on the population. About 10 years ago I evaluated a Brook Trout eradication effort, and found that total annual mortality in the population was already 92% before the removal began, so all the eradication effort did was substitute eradication mortality for what used to be natural mortality, and total mortality did not change at all. Sometimes harvest actually improves Brook Trout fisheries by reducing their overabundance and improving growth and size of the catch by anglers. In contrast, Cutthroat Trout *Oncorhynchus clarkii*, because they are easy to catch, tend to be quite susceptible to overharvest by anglers,

and there are lots of examples of overexploitation in Cutthroat Trout populations (e.g., Mallet 2013).

A debate that may gain momentum in the relatively near future is whether innovations in bait hooks may reduce the historical incompatibility between bait fishing for trout and catch-and-release angling. Circle hook use in marine fisheries usually reduces deep hooking and, consequently, hooking mortality. These hooks appear to also work well in stream settings for wild trout (Sullivan et al. 2013; High and Meyer 2014), and there will actually be a talk here on this topic Friday morning. Whether it ever becomes common to allow bait fishing in catch-and-release trout waters as long as you use circle hooks remains to be seen. That seems unlikely because in reality, there is little demand these days to harvest trout or to use bait to fish for wild trout in streams. In reservoirs or community ponds, harvest and bait fishing by trout anglers is still very popular, but usually these types of waters do not support wild trout to begin with, so those people wanting to harvest trout are already focusing their time and energy on waters that are usually supported by hatchery trout, and they have pretty much lost interest in fishing for wild trout in streams, because so often they cannot keep fish anyway.

A debate that is gaining momentum in Europe is whether catch-and-release angling should be allowed at all. Animal rights activists argue that it is inhumane to catch and release a fish because angling causes pain and stress in fish. Their argument is that you should either not be allowed to angle at all, or you should at least be required to keep what you catch and stop fishing when you reach your limit. In other words, “catch-and-release is bad”. I am sure if we asked the fish whether they would rather be caught and kept or caught and released, they would prefer the latter, but regardless of the fish’s sentiment, the fish welfare argument has not resonated with people in North America like it apparently has in Europe, and we should all cross our fingers that it does not resonate more strongly any time soon.

If there is less desire to harvest wild trout, then presumably there will be even less need to stock hatchery trout in streams, since the main reason for stocking hatchery trout is to allow harvest opportunities. But in reality, this change has already taken place in many areas. In fact, in many states there is now only a small fraction of stream reaches

stocked with hatchery fish as there once was 30-40 years ago. Anyone who is still concerned with genetic introgression between wild native trout and hatchery trout can stock sterile fish and eliminate that concern, and many states and provinces do that, including the agency I work for (Kozfkay et al. 2006). I think that hatchery trout get an unsubstantiated bad rap among wild trout enthusiasts; in my opinion we should look at them as a useful tool for wild trout management, because they can divert harvest-oriented anglers away from wild trout waters and onto waters that do not support wild trout but can support harvest opportunities on hatchery-stocked fish.

Will barbless regulations be expanded in the future? Are they needed now? This is an issue that many anglers and biologists are very passionate about. For wild trout, the overwhelming evidence in the literature suggests that you can release fish quicker with barbless hooks, and they may cause less severe injuries, but they appear to have no impact on fish survival. What they do appear to impact, according to a recently published study, is angler landing success, especially for novice anglers (Bloom 2013). It is usually the experienced anglers who are the ones pushing for barbless hook regulations, probably because using barbless hooks does not reduce their landing success very much. The people who see the big drop-off in landing success with barbless hooks are the inexperienced anglers, the ones we always say we are so concerned about in trying to recruit them to the sport of angling, to be another voice (or voter) that supports wild trout conservation. So it seems to me that we are shooting ourselves in the foot by requiring novice anglers who want to fish in catch-and-release waters to use terminal tackle that does not improve survival of released fish but does reduce the number of fish they are likely to have the satisfaction of landing.

There has been a surge of interest in the last decade or two in preserving and protecting native trout, and that will probably continue for the foreseeable future. In the not-so-distant past, wild trout meant just that. In fact, at Wild Trout I, there was not a single talk about native trout. Rather, nearly every talk was just about wild trout, or about wild vs. hatchery trout. These days, more anglers are interested in catching not just wild trout, but wild native trout. Yet despite this relative surge of interest in native trout, the vast majority of anglers these days still do not really care what wild trout they are catching, as long as they

are wild. Native does not matter to them. In fact, your average angler does not even know which species are native and which are not. For example, in western North America many anglers use the name “German brown trout” to describe the fish they are catching without it dawning on them that that is where Brown Trout *Salmo trutta* are native, not North America. So we as fish managers must be cautious in not outpacing the public’s interest in native trout. I circle around to public interest again at the end of the paper.

Even though there will probably be less angler harvest of wild trout in the future, there will be even more pressure on wild trout resources due simply to an expanding human population. It is estimated that the human population in North America and the rest of the globe will stabilize by about the year 2050, so the heavy impact that human population growth has on natural resources may soon stabilize in many areas. However, wild trout in North America are currently doing best where human population size is under-seeded, such as Alaska and the Rocky Mountains (from northern Canada to Colorado). This is not a coincidence. Pressures on natural resources tend to be lower in these areas because there are fewer people, so areas like this tend to serve as reservoirs of biodiversity. Unfortunately for wild trout, the human population in these under-seeded, lighter populated areas will not stabilize by 2050, but instead will likely continue to grow through the end of the century as people flock to these areas to get their own slice of elbow-room (Lackey 2001). With climate warming already expected to further restrict wild trout populations in the future, the continued increase in the human population size in these reservoirs of biodiversity may exacerbate climate-related declines in wild trout populations.

Robert Lackey is a Professor of Fisheries at Oregon State University who (with colleagues) predicts that four core drivers will constrain salmon recovery in the Pacific Northwest through the 21<sup>st</sup> century (Lackey et al. 2006), and I would argue that these same drivers will also constrain wild trout management across the continent. They are (1) the economy, (2) the increasing scarcity of and competition for natural resources, (3) the increasing human population in the region, and (4) individual and collective lifestyle choices and priorities. This last driver - lifestyle choices and priorities - I will cover later, but the other three are pretty self-explanatory.

If the economy tanks, people are going to be less concerned about conserving wild trout and more concerned about putting their children through college or being able to afford health care coverage. These other two drivers kind of go together, because the more out-of-control human population growth is, the more pressure there tends to be on the remaining natural resources in the area, especially water.

Stream habitat in the 19<sup>th</sup> and early 20<sup>th</sup> century was annihilated in many areas of North America primarily because of poor mining, logging, and grazing practices, and this was one of the two major themes of Wild Trout I: to stop the destruction of stream habitat. It has taken a long time for streams to recover, in some areas they are still recovering, and in still others they may never recover. But reasonably strict environmental laws have now been in place for many decades in America and Canada, and adequate habitat for wild trout is now relatively common across the continent. I am not suggesting that everything has been restored, and I think we all recognize that we need wood to build houses, coal and gas to produce electricity, and phosphorus to fertilize crops and gardens, so there will continue to be more resource extraction in the future, and thus more stream habitat degradation. But I think it is reasonable to state that in many areas of North America, stream habitat is better now than it used to be. Thus, do not get your hopes up that we will see substantial improvements in stream habitat across North America in the future.

Another change we can obviously expect to see is in the world of technology, but I think we are getting so used to that type of change that it really is not a change at all. Computer technology that once filled a room now fits in the palm of your hand, and soon will fit on the head of a pin. Technological advances in PIT-tags, radio tags, eDNA, SNPs, and genetic engineering (to name just a few) will continue to skyrocket into the future. What this means is that the amount of fisheries data we are able to collect will someday stagger the mind. The key will be not letting the quantity of data overwhelm the quality of the data, or the reason you are collecting the data in the first place.

All of these changes are things we can all see coming. But there are probably some changes that we cannot see coming. I was in grad school in the mid-1990s when, seemingly overnight, the whirling disease scare burst onto the scene. Many people thought that the future of wild trout was threatened,

that whirling disease was going to obliterate wild trout populations across North America, especially in the west. That never happened. Currently, many people think that climate change is going to obliterate wild trout populations across North America, and around the globe. Is that really going to happen? That depends on how much warming actually occurs, what we do about the warming and about carbon emissions, and how resilient wild trout are to stream warming and reduced stream flow. What other issue might crop up in the next 20 years that will dominate wild trout management, and how much of an impact will it actually have? That is very hard to predict. But regardless of how many challenges we face in managing wild trout in the future, I bet that well after I retire, anglers will still be able to go to countless areas throughout North America and have a good day of trout fishing. Maybe that is just the optimist in me being misguided.

How wild trout management in the future *will not* change, and this is also pretty predictable, is that it will still largely come down to what people want. Abe Lincoln once said “In this age, in this country, public sentiment is everything. With it, nothing can fail; against it, nothing can succeed. Whoever molds public sentiment goes deeper than he who enacts statutes, or pronounces judicial decisions.” He was talking about slavery back then, but it is still a poignant statement, and it applies perfectly to the future of wild trout management. The preservation of native trout in particular, and to all wild trout in general, really comes down to public sentiment.

This is where we come back to the fourth of Dr. Lackey’s core drivers: lifestyle choices and priorities. Will wild trout be a priority for society in the future, and will our lifestyle choices allow space for sustainable wild trout fisheries? Can these values compete with our modern need for instantaneous stimulation? As people in general, around the globe, become less aware of the natural environment, and less associated with it, this will be an increasingly difficult challenge.

In fact, maintaining the public’s interest in nature in general, or wild trout in particular, may be our greatest challenge as fisheries professionals. Sure, kids these days have a reasonably strong resource ethic – perhaps stronger than ever - because they are taught in school curriculums and at home about recycling, buying locally produced foods, minimizing the use of

hormones or herbicides in agriculture, and reducing greenhouse gases. But as we live in a society that is more detached from the natural environment, as fewer parents of children hunt, fish, or spend time in other outdoor recreational activities, and as camping experiences more often involve motor homes with generators at a developed campground and less often involve tents, headlamps or lanterns, and sleeping bags in the backwoods, biologists may find themselves more marginalized than ever before.

This is probably the crux of the matter. Although federal environmental laws are already set up to protect species, public land, and clean water, it is only because people value these things. If those values are diminished, you can bet that protection and preservation of those resources will be diminished as well.

In one of his stand-up comedy routines, George Carlin once said, “The planet has been through a lot worse than us. Earthquakes, volcanoes, plate tectonics, continental drift, solar flares, sun spots, magnetic storms, the magnetic reversal of the poles, comets and asteroids and meteors, worldwide floods, tidal waves, worldwide fires, erosion, cosmic rays, recurring ice ages ... And we think some plastic bags and aluminum cans are going to make a difference... The planet will shake us off like a bad case of fleas.” I think he was right. Long term, and I mean really long term, the earth will be fine. Someday there may not be a trace of our ever having been here. All of this conservation of natural resources, of wild trout, is for ourselves, because we value these things. And if that is true, then how much preservation occurs in the future will come down to the values that our children and grandchildren hold in the future. In other words, it will come down to public sentiment, just as Abe Lincoln said.

But by public sentiment, I do not just mean “values” in the loose sense of the word. As Dr. Lackey has pointed out (Lackey 2001), if you asked people, they would probably say they do value wild salmon (or trout). But are they willing to make the personal or societal changes needed to preserve wild salmon, or wild trout? Dr. Lackey argued that to date, “society has collectively shown scant willingness to adopt the policy choices necessary to reverse the long-term downward trend in wild salmon”. Fortunately, wild trout usually do not have to swim through countless dams and survive commercial, recreational, and tribal harvest like salmon do, so the path for the long-term

preservation of wild trout, I would argue, is a lot easier than for salmon.

So, our best chance, as always, is to reach out to the children, to help instill within them a sincere interest in preserving nature, not in order to save the earth, or to save native species, but because they have a passion for these things. Because they love hiking in the mountains and along rivers, and they love to hunt for, fish for, or watch wild animals in their natural environments. We must help to foster within them an avid interest in these things. That is really all we have to do. Because if they are avid in these interests, something that is beyond “valuing” them, then they will protect these natural resources, and wild trout and all other wild things will continue to have a strong place in the fabric of our society. As Aldo Leopold once said, “there are some who can live without wild things and some who cannot.” We want our children and grandchildren to NOT be able to live without wild things, including wild trout. If they cannot live without wild things, then everything else will work itself out in the wash.

Can we achieve this? Can we help to instill a love of wild things in our children, in such an urban-oriented planet? As I said earlier, I am an optimist. Winston Churchill once defined an optimist as someone who sees the opportunity in every difficulty, and a pessimist as someone who sees the difficulty in every opportunity. Certainly it will be difficult to keep people avidly interested in wild things. But as a profession, we have a great opportunity, and an obligation, to do all we can to promote a love of all things wild, including wild trout.

## LITERATURE CITED

- Bloom, R. K. 2013. Capture efficiency of barbed versus barbless artificial flies for trout. *North American Journal of Fisheries Management* 33:493-498.
- High, B., and K. A. Meyer. 2014. Hooking mortality and landing success using baited circle hooks compared to conventional hook types for stream-dwelling trout. *Northwest Science* 88:11-22.
- Jonsson, B., and N. Jonsson. 2009. A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. *Journal of Fish Biology* 75:2381-2447.
- Kozfkay, J. R., J. C. Dillon, and D. J. Schill. 2006. Routine use of sterile fish in salmonid sport fisheries: are we there yet? *Fisheries* 31(8):392-401.

Lackey, R. T. 2001. Defending reality. *Fisheries* 26(6): 26-27.

Lackey, R. T., D. H. Lach, and S. L. Duncan. 2006. Wild salmon in western North America: forecasting the most likely status in 2100. Pages 57-70 in R. T. Lackey, D. H. Lach, and S. L. Duncan, editors. *Salmon 2100: The Future of Wild Pacific Salmon*. American Fisheries Society, Bethesda, Maryland.

Mallet, J. 2013. Saving Idaho's Westslope Cutthroat Trout fisheries. Idaho Department of Fish and Game, report number 13-14. Boise, Idaho.

Sullivan, C. L., K. A. Meyer, and D. J. Schill. 2013. Deep hooking and angling success when passively and actively fishing for stream-dwelling trout with baited J and circle hooks. *North American Journal of Fisheries Management* 33:1-6.

Wenger, S.J., D. J. Isaak, C. H. Luce, H. M. Neville, K. D. Fausch, J. B. Dunham, D. C. Dauwalter, M. K. Young, M. M. Elsner, B. E. Rieman, A. F. Hamlet, and J. E. Williams. 2011. Flow regime, temperature and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences* 108(34): 14175-14180.



# Session 1

## Role of Ecological Resilience in Wild Trout Management



Photo courtesy of Mark Smith.



Photos courtesy of Mark Smith.



## LIFE-HISTORY DIVERSITY INCREASES RESILIENCE OF RAINBOW TROUT POPULATIONS IN THE COLUMBIA BASIN\*

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**Abstract**—Rainbow Trout *Oncorhynchus mykiss* express a wide variety of life-history tactics including resident, fluvial, adfluvial, and anadromous types. Existence of multiple life-history types in the same watershed is common within salmonid species. This type of life-history plasticity is thought to be reflective of habitat-dependent trade-offs between resident survival and increased reproductive output resulting from migration to more productive rearing areas. Though “partial migration” is commonly observed within *O. mykiss* populations, the extent to which different life-history forms are reproductively-mixed remains somewhat equivocal. We demonstrated that resident Rainbow Trout produce significant numbers of anadromous (steelhead) offspring. Otolith microchemistry (<sup>87</sup>Sr/<sup>86</sup>Sr) techniques were used to determine the maternal life-history (resident or anadromous) of 498 emigrating steelhead kelts in the Yakima Basin, Washington. Five geochemically distinct freshwater rearing regions were identified within the basin. All five regions were predicted to produce steelhead with resident maternal life-histories. Basin-wide, 20% and 7% of steelhead collected in 2010 and 2011, respectively, had resident maternal origins. Our data support the conclusion that resident and anadromous Rainbow Trout, where they coexist, are members of a reproductively-mixed population. Similar observations have been made in other watersheds throughout the Columbia River basin, including the Hood River, Grande Ronde River, Imnaha River, and Touchet River. Examples of sympatric, reproductively-isolated or genetically divergent *O. mykiss* polymorphisms are rare and can usually be explained by anthropogenic influences or natural migration barriers. Our findings in the Yakima Basin, concurrent with evidence from elsewhere in the Columbia River basin, suggest that resilience of Rainbow Trout populations is dependent on existence of a diverse array of migratory and nonmigratory life-history types.

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### INTRODUCTION

Partial migration, when one portion of an animal population migrates while the other portion remains sedentary (Lundberg 1988), has been well documented in salmonids (Jonsson and Jonsson 1993). Examples of this type of migratory behavior include fluvial and adfluvial life-histories where trout migrate from main-stem riverine habitats and lakes to spawn in tributaries. A related term, ‘partial anadromy,’ refers to a similar behavioral strategy whereby fish of the same population adopt divergent anadromous and resident freshwater life-history strategies (Hendry et al. 2004). Most salmonid species are capable of partial anadromy (Table 1). This type of life-history diversity is believed to buffer against extinction (Hilborn et al. 2003; Greene et al. 2010).

The term ‘steelhead,’ which has been conventionally used to identify anadromous Rainbow Trout *Oncorhynchus mykiss*, represents one of several potential life-history forms within *O. mykiss* populations (Pavlov et al. 2001). Stream residency is also common for this species, with resident individuals remaining in freshwater throughout their life-cycle, often moving between suitable habitats (Gowan et al. 1994), but never venturing to the ocean. In watersheds with ocean access, researchers have found that in addition to interbreeding (McMillan et al. 2007), resident Rainbow Trout and steelhead can produce progeny of the alternate life-history form (Pascual et al. 2001; Thrower and Joyce 2004; Korman et al. 2010).

Available genetic and observational data collected on Rainbow Trout populations throughout the Pacific

\*This paper represents a slightly modified and abbreviated version of the information published in Courter et al. (2013). Copyright permission was granted for republication in these Proceedings by the NRC Research Press. Courter, I.I., D.B. Child, J.A. Hobbs, T.M. Garrison, J.G. Glessner, and S. Duery. 2013. Resident rainbow trout produce anadromous offspring in a large interior watershed. Can. J. Fish. Aquat. Sci. 70: 701-710.

**Table 1. Salmonid species known to exhibit both freshwater-resident and anadromous life-history forms within the same watershed. From Courter et al. (2013).**

Atlantic Salmon	<i>Salmo salar</i>	Fleming (1998)
Brown Trout	<i>Salmo trutta</i>	Jonsson (1985)
Sockeye Salmon	<i>Oncorhynchus nerka</i>	Wood (1995)
Masu Salmon	<i>Oncorhynchus masou</i>	Arai and Tsukamoto (1998)
Cutthroat Trout	<i>Oncorhynchus clarkii</i>	Zimmerman et al. (1997)
Rainbow Trout	<i>Oncorhynchus mykiss</i>	Pavlov et al. (2008)
Dolly Varden Char	<i>Salvelinus malma</i>	Koizumi et al. (2006)
Bull Trout	<i>Salvelinus confluentus</i>	Brenkman and Corbett (2005)
Brook Char	<i>Salvelinus fontinalis</i>	Curry et al. (2010)
Arctic Char	<i>Salvelinus alpinus</i>	Nordeng (1983)

Rim (Pascual et al. 2001; Thrower and Joyce 2004; McPhee et al. 2007) suggest that, in habitats with ocean access, resident Rainbow Trout produce some anadromous offspring that survive and return as adult steelhead. To test this hypothesis, we quantified the proportion of steelhead produced by native female resident Rainbow Trout in the Yakima Basin, Washington using otolith primordial Sr isotope ratios. We also examined whether the proportion of steelhead derived from resident female spawners differed spatially by comparing Sr isotope ratios from freshwater growth portions of the otolith with ratios from water samples collected throughout the basin. Evidence of cross life-history form production within partially anadromous Yakima Basin *O. mykiss* populations would indicate an important source of resilience for the currently depressed anadromous component of the population, and may explain the continued existence of steelhead throughout the watershed in spite of numerous generations with low spawner abundance in some regions.

## METHODS

The Yakima River basin is a 16,000-km<sup>2</sup> interior Columbia Basin watershed that drains the eastern slopes of the Cascade Mountain Range and discharges into the Columbia River (rkm 539; Figure 1). The basin hosts a variety of habitat types ranging from high elevation mountain streams, to large, seasonally stable rivers and arid, low elevation ephemeral streams. The variety of riverine habitat types and lack of present-day *O. mykiss* hatchery influence makes the Yakima Basin an ideal place to study steelhead production by native resident Rainbow Trout.

Though hatchery stocking no longer occurs, in an effort to bolster steelhead returns, the Yakama Nation Fisheries Program developed a practice of reconditioning emigrating kelts in hopes of increasing the proportion of fish that survive their first spawning event to return and reproduce a second time (Branstetter et al. 2010). Downstream adult steelhead migrants are collected during late spring and summer in the lower Yakima River at the Yakama Nation's Chandler Juvenile Evaluation Facility (Figure 1), near Prosser Dam where they are held and fed at Prosser Salmon Hatchery until release during the late fall.

The kelt reconditioning program provided a convenient sampling source. Three hundred native adult steelhead carcasses were collected at Prosser Hatchery during the Summer and Fall of 2010. An additional 209 carcasses were collected in the Spring, Summer, and Fall of 2011. Sagittal otoliths were extracted from each fish, cleaned, and dried. Otoliths were then mounted in the sagittal plane on glass microscope slides, sanded to the primordial core, and polished prior to laser ablation. A detailed description of otolith preparation procedures is available in Courter et al. (2013).

A water chemistry profile was generated for the Yakima Basin by collecting water samples from 34 candidate stream reaches, including the Yakima River main stem and 17 major tributaries, to characterize water <sup>87</sup>Sr/<sup>86</sup>Sr values in seven regions within the Yakima River basin (Figure 1). Sample locations were chosen to cover the full range of habitats used by steelhead during their life-cycle. Water samples were collected at base flow conditions during the fall of 2010 and 2011. Otolith and river water <sup>87</sup>Sr/<sup>86</sup>Sr

**Water Sampling Regions**

-  Upper Yakima
-  Upper Naches
-  Lower Naches
-  Mid Yakima
-  Toppenish
-  Satus
-  Lower Yakima

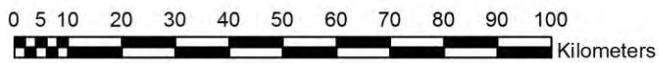
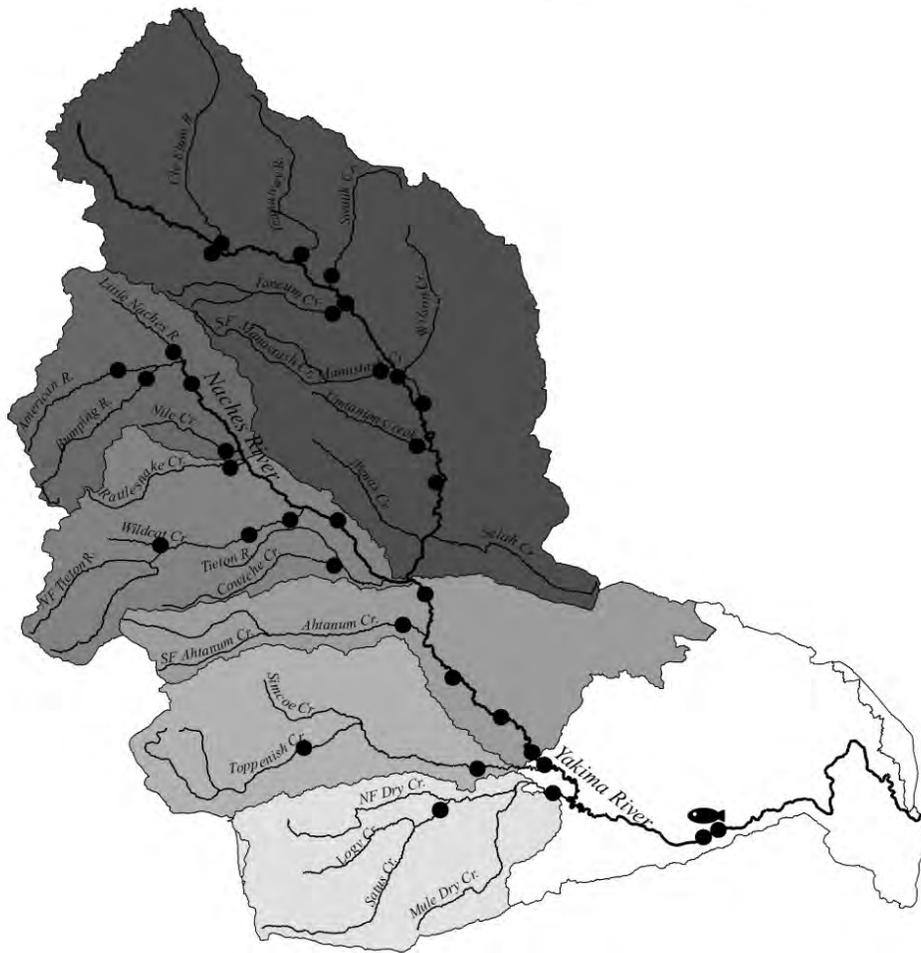


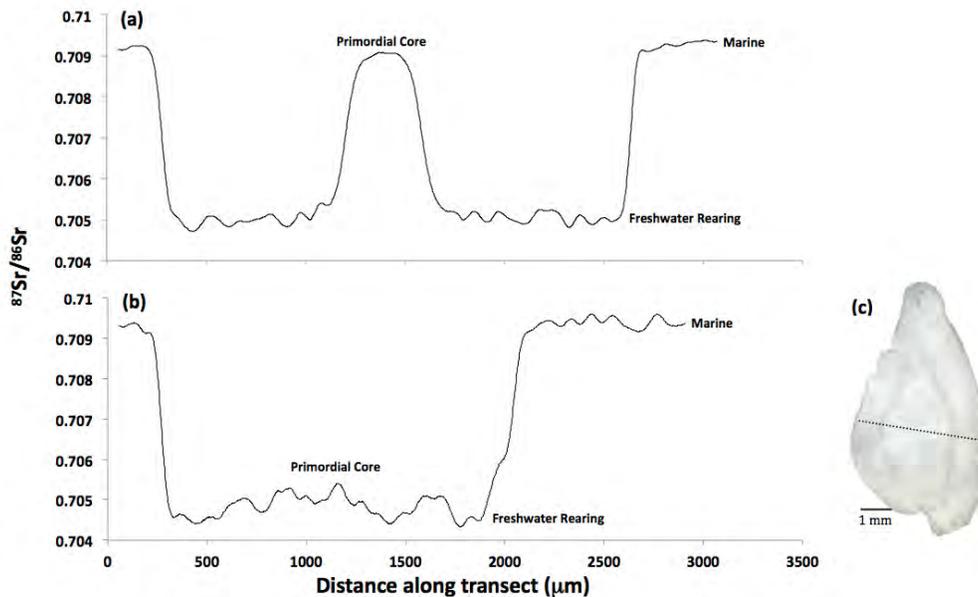
Figure 1. Map of the Yakima Basin showing the location of the seven water sampling regions, water sample sites (black dots), and steelhead kelt collection facilities near Prosser Dam (fish icon). From Courter et al. (2013).

values were measured at the University of California Davis Interdisciplinary Center for Plasma Mass Spectrometry. For otolith analysis, a multi-collector inductively coupled plasma mass spectrometer was interfaced with a laser for Sr isotope measurement by laser ablation. A laser beam of 55- $\mu\text{m}$  diameter traversed across the otolith from the core to the edge at 10- $\mu\text{m}$  per second. The freshwater rearing  $^{87}\text{Sr}/^{86}\text{Sr}$  values were taken from an approximately 100- $\mu\text{m}$  region post primorida on the  $^{87}\text{Sr}/^{86}\text{Sr}$  profile. When we observed primordial core values that were indicative of a freshwater resident maternal life-history, three additional spot analyses (with a 55- $\mu\text{m}$  diameter beam) were conducted on the core region to ensure accuracy. Purified solutions derived from each water sample were also analyzed with the mass spectrometer to determine the  $^{87}\text{Sr}/^{86}\text{Sr}$  value.

Measurements of  $^{87}\text{Sr}/^{86}\text{Sr}$  values within primordial core and freshwater rearing strata from each otolith were compared with known marine  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.70918; Hodell et al. 1990) and those observed in water samples collected throughout the Yakima Basin. Measurements made in the primordial core were used to determine maternal life-history, and measurements made in the freshwater rearing portion of the otolith were used to identify the natal origin of each fish (Figure 2).

Instead of using a predetermined cutoff value to determine the maternal life-history of each fish, we estimated this value using univariate K-means clustering. This procedure separated otolith primordial core signatures into two groups, whereby primordial core signatures less than the estimated cutoff value were assigned a resident maternal life-history and primordial core signatures greater than the estimated cutoff value were assigned an anadromous maternal life-history. To quantify the amount of uncertainty in the percentage of fish assigned to each group, a nonparametric bootstrap procedure was used, resampling the primordial core signature database 1,000 times. When summarizing results, the median and 95% bootstrap confidence interval (CI), comprising the 2.5 and 97.5 percentiles of observations, are reported.

Summary statistics were used to examine the degree to which a single predefined geographic region provided distinct separation of water  $^{87}\text{Sr}/^{86}\text{Sr}$  values compared to other regions. If two adjacent geographic regions had indistinguishable  $^{87}\text{Sr}/^{86}\text{Sr}$  values, they were pooled. In doing so, the certainty associated with assignments of fish to their natal freshwater region increased, but at the cost of reduced spatial resolution.



**Figure 2.** Examples of  $^{87}\text{Sr}/^{86}\text{Sr}$  values derived from steelhead sagittal otoliths collected in the lower Yakima River with (a) anadromous and (b) resident maternal life-histories using laser ablation coupled with plasma mass spectrometry. The elevated primordial core  $^{87}\text{Sr}/^{86}\text{Sr}$  value was used to distinguish anadromous from resident maternal life-histories. (c) Photograph of polished steelhead sagittal otolith with dotted line indicating the approximate location of laser ablation transects. From Courter et al. (2013).

## RESULTS

Of the 300 steelhead collected in 2010 and the 209 collected in 2011 from the lower Yakima River, 295 and 203, respectively, produced otoliths from which primordial core  $^{87}\text{Sr}/^{86}\text{Sr}$  values could be measured. Bimodal distributions of primordial core  $^{87}\text{Sr}/^{86}\text{Sr}$  values were evident in both 2010 and 2011, emphasizing the presence of a mix of steelhead with resident and anadromous maternal life-histories. In both 2010 and 2011, K-means cluster analysis estimated a cutoff  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.707. Otoliths with primordial core  $^{87}\text{Sr}/^{86}\text{Sr}$  values greater than 0.707 were classified as anadromous maternal life-history and otoliths with primordial signatures less than 0.707 were classified as resident maternal life-history.

The percentage of steelhead predicted to have resident and anadromous maternal life-histories varied between sampling years. K-means cluster analysis indicated that 20.34% (95% CI: 15.59% – 25.08%) of fish from the 2010 sample were assigned to the resident maternal life-history group, whereas 79.66% (95% CI: 74.92% – 84.41%) were assigned to the anadromous maternal life-history group. For fish collected in 2011, 6.90% (95% CI: 3.94% – 10.84%) were assigned to the resident maternal life-history group, whereas 93.10%

(95% CI: 89.16% – 96.06%) were assigned to the anadromous maternal life-history group.

Water sample  $^{87}\text{Sr}/^{86}\text{Sr}$  values revealed five geochemically distinct regions. Freshwater rearing  $^{87}\text{Sr}/^{86}\text{Sr}$  values collected from native Yakima Basin steelhead otoliths in 2010 and 2011 aligned most frequently with water samples from the Naches River, Middle and Upper Yakima River, Toppenish Creek, and Satus Creek subbasins. The range in  $^{87}\text{Sr}/^{86}\text{Sr}$  values from water samples collected in the Lower Yakima River, though large, overlapped infrequently with otolith  $^{87}\text{Sr}/^{86}\text{Sr}$  values. A high frequency of otolith  $^{87}\text{Sr}/^{86}\text{Sr}$  values corresponded with water samples from the Satus Creek and Naches River sub-basin (lower and upper), which may have reduced our ability to differentiate between fish from those regions.

Of the 300 adult steelhead collected in 2010 and 209 collected in 2011, freshwater rearing  $^{87}\text{Sr}/^{86}\text{Sr}$  values were measured in 275 and 188 otoliths, respectively. The distribution of regional assignments remained relatively consistent for both years, with the majority of steelhead predicted to be natal to the Lower Naches region and Upper-Middle Yakima region, which included Toppenish Creek (Figure 2). A large proportion of our steelhead were also predicted to be natal to the Upper Naches region.

**Table 2. Proportion of adult steelhead kelts collected in the Yakima River basin during 2010 and 2011 assigned to each of five geochemically distinct regions, and the proportion within each region derived from resident and anadromous females. Median and 95% bootstrap confidence interval, comprising the 2.5 and 97.5 percentiles of observations, reported in parentheses. From Courter et al. (2013).**

<b>2010, n=275</b>	<b>Total</b>	<b>Resident</b>	<b>Anadromous</b>
Upper Naches	0.19 (0.15-0.24)	0.26 (0.14-0.38)	0.74 (0.62-0.86)
Lower Naches	0.38 (0.32-0.44)	0.21 (0.13-0.29)	0.79 (0.71-0.87)
Toppenish / Mid-Upper Yakima	0.32 (0.27-0.38)	0.19 (0.11-0.28)	0.81 (0.72-0.89)
Lower Yakima	0.03 (0.01-0.05)	0.38 (0.00-0.78)	0.62 (0.22-1.00)
Satus	0.08 (0.05-0.12)	0.17 (0.04-0.35)	0.83 (0.65-0.96)
<b>2011, n=188</b>			
Upper Naches	0.19 (0.13-0.24)	0.03 (0.00-0.10)	0.97 (0.90-1.00)
Lower Naches	0.34 (0.27-0.40)	0.02 (0.00-0.05)	0.98 (0.95-1.00)
Toppenish / Mid-Upper Yakima	0.38 (0.30-0.44)	0.13 (0.05-0.23)	0.87 (0.77-0.95)
Lower Yakima	0.03 (0.01-0.05)	0.17 (0.00-0.67)	0.83 (0.33-1.00)
Satus	0.07 (0.04-0.12)	0.07 (0.00-0.23)	0.93 (0.77-1.00)

## DECISION

Results demonstrated the occurrence of cross-life-history form production within *O. mykiss* populations in the Yakima Basin, indicating that persistence of the steelhead and resident Rainbow Trout life-history types may benefit from regular exchange between types. Reproductive exchange between different life-history forms is likely an important component of partially anadromous fish population biology that has a significant effect on population viability. Codependence of multiple life-history types makes salmonid populations more resilient (Bisson et al. 2009) and may explain their ability to persist despite detrimental impacts from numerous, compounding sources of mortality. In the same way that a small amount of immigration from source populations can dramatically reduce extinction risk of stream-resident trout (Hilderbrand 2003), a small amount of cross-life-history form production may significantly reduce the probability of partially anadromous fish population extinction. Moreover, evidence from breeding studies with Rainbow Trout suggests that the capacity to express diverse life-history types may itself be resilient (Thrower and Joyce 2004). Evolutionary stability of life-history diversity would provide an additional source of resilience, ensuring that selective pressures, such as fluctuating environmental conditions, would not eliminate life-history strategies that could be important to future persistence of the population.

Mortalities from the Yakama Nation's kelt reconditioning program provided ideal samples for our study because they were naturally produced adult steelhead. Previous studies either relied on relatively small sample sizes of adult fish (Zimmerman and Reeves 2000), or focused on juvenile fish collections (Zimmerman et al. 2009; Korman et al. 2010; Mills et al. 2012), which can be confounded by presence of diverse migratory freshwater life-histories (Mellina et al. 2005; Tattam 2006; Wilzbach et al. 2012). Partially anadromous salmonids produce offspring predominantly of the same life-history form, and rates of cross-life-history form production can vary throughout a watershed. Therefore, a robust sample of adult fish across a large area is necessary to accurately determine whether cross-life-history form production is occurring among female spawners.

While maternal life-history of Yakima Basin steelhead could be predicted with reasonable confidence, predictions of their natal origins within geochemically distinct habitat areas were less certain. Geochemical differentiation between water samples collected throughout the basin was small, which made our analysis sensitive to perturbations in  $^{87}\text{Sr}/^{86}\text{Sr}$  values within the freshwater rearing portion of the otolith used to predict each fish's natal origin. This resulted in higher uncertainty about regional assignments. Obtaining additional trace elements from water samples and otoliths would be useful for making more accurate assignments of steelhead to their natal habitat areas. For example, Muhlfeld et al. (2012) relied on both Sr/Ca and  $^{87}\text{Sr}/^{86}\text{Sr}$  to predict movements of Cutthroat Trout between natal and non-natal streams.

Steelhead with resident maternal life-histories were predicted to occur in all five geochemically distinct regions evaluated in this study, with the highest numbers of resident-derived steelhead produced in the Upper and Lower Naches River sub-basins and the region encompassing the Toppenish, Middle Yakima, and Upper Yakima sub-basins. This provides some evidence that cross-life-history form production may be spatially structured such that areas with abundant resident trout produce larger numbers of steelhead with resident maternal life-histories. There was also evidence for annual variation in cross-life-history form production, most notably in the Naches sub-basin where rates were quite high in 2010 (21-26%) and low in 2011 (2-3%). Conversely, cross-life-history form production rates in the Upper-Middle Yakima and Toppenish Creek region remained relatively stable during both years (13-19%).

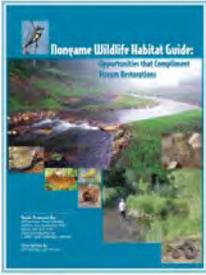
## ACKNOWLEDGEMENTS

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## REFERENCES

- Arai, T., and Tsukamoto, K. 1998. Application of otolith Sr: Ca ratios to estimate the migratory history of masu salmon, *Oncorhynchus masou*. *Ichthyological Research*. 45:309–313.
- Berntson, E.A., Carmichael, R.W., Flesher, M.W., Ward, E.J., and Moran, P. 2011. Diminished reproductive success of steelhead from a hatchery supplementation program (Little Sheep Creek, Imnaha Basin, Oregon). *Transactions of the American Fisheries Society*. 140:685–698.
- Bisson, P. A., Dunham, J. B., and Reeves, G. H. 2009. Freshwater ecosystems and resilience of Pacific salmon: habitat management based on natural variability. *Ecology and Society*. 14:45.
- Branstetter, R., Stephenson, J., Pierce, A., and Hatch, D.R. 2010. Steelhead kelt reconditioning and reproductive success. 2009 Draft annual report. Prepared for Bonneville Power Administration, Division of Fish and Wildlife. Project Number: 2007-401-00.
- Courter, I.I., D.B. Child, J.A. Hobbs, T.M. Garrison, J.G. Glessner, and S. Duery. 2013. Resident rainbow trout produce anadromous offspring in a large interior watershed. *Canadian Journal of Fisheries and Aquatic Sciences*. 70: 701-710.
- Curry, R.A., Bernatchez, L., Whoriskey Jr., F., and Audet, C. 2010. The origins and persistence of anadromy in brook charr. *Reviews in Fish Biology and Fisheries*. 20:557–570.
- Fleming, I.A. 1998. Pattern and variability in the breeding system of Atlantic salmon (*Salmo salar*), with comparisons to other salmonids. *Canadian Journal of Fisheries and Aquatic Sciences*. 55 (Suppl.): 59–76.
- Greene, C. M., Hall, J. E., Guilbault, R. K. R., and Quinn, T. P. 2010. Improved viability of populations with diverse life history portfolios. *Biology Letters*. 6:382–386.
- Gowan, C., Young, M. K., Fausch, K. D., and Riley, S. C. 1994. Restricted movement in resident stream salmonids: a paradigm lost? *Canadian Journal of Fisheries and Aquatic Sciences*. 51:2626–2637.
- Hendry, A.P., Bohlin, T., Jonsson, B., and Berg, O.K. 2004. To sea or not to sea? Anadromy versus non-anadromy in salmonids. *In evolution illuminated: Salmon and their relatives*. Edited by A.P. Hendry and S.C. Stearns. pp. 92-125.
- Hilborn, R., Quinn, T.P., Schindler, D.E., and Rogers, D.E. 2003. Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Science*. 100: 6564–6568.
- Hilderbrand, R.H. 2003. The roles of carrying capacity, immigration, and population synchrony on persistence of stream-resident cutthroat trout. *Biological Conservation*. 110:257–266.
- Hodell, D.A., Mead, G.A., and Mueller, P.A. 1990. Variation in the strontium isotopic composition of seawater (8 Ma to present): Implications for chemical weathering rates and dissolved fluxes to the oceans. *Chemical Geology. (Isotope Geosciences Sections)* 80:291–307.
- Jonsson, B. 1985. Life history patterns of freshwater resident and sea-run migrant brown trout in Norway. *Transactions of the American Fisheries Society*. 114:182–194.
- Jonsson, B., and Jonsson, N. 1993. Partial migration: niche shift versus sexual maturation in fishes. *Reviews in Fish Biology and Fisheries*. 3:348–365.
- Koizumi, I., Yamamoto S., and Maekawa K. 2006. Female-biased migration of stream-dwelling Dolly Varden in the Shiisorapuchi River, Hokkaido, Japan. *Journal of Fish Biology*. 68:1513–1529.
- Korman, J., Schick, J., and Clarke A. 2010. Cheakamus river steelhead juvenile and adult monitoring: Fall 2008-Spring 2009. Final Report prepared for B.C. Hydro. Available online at: <http://www.bchydro.com>
- Lundberg, P. 1988. The evolution of partial migration in birds. *Trends in Ecology and Evolution*. 3:172–175.
- McMillan, J.R., Katz, S.L., and Pess, G.R. 2007. Observational evidence of spatial and temporal structure in a sympatric anadromous (winter steelhead) and resident rainbow trout mating system on the Olympic Peninsula, Washington. *Transactions of the American Fisheries Society*. 136:736–48.
- McPhee, M.V., Utter, F., Stanford, J.A., Kuzishchin, K.V., Savvaitova, K.A., Pavlov, D.S., and Allendorf, F.W. 2007. Population structure and partial anadromy in *Oncorhynchus mykiss* from Kamchatka: relevance for conservation strategies around the Pacific Rim. *Ecology of Freshwater Fish*. 16:539–547.
- Mellina, E., Hinch, S.G., MacKenzie, K.D., and Pearson, G. 2005. Seasonal movement patterns of stream-dwelling rainbow trout in North-Central British Columbia, Canada. *Transactions of the American Fisheries Society*. 134:1021–1037.
- Miller, J.A., Butler, V.L., Simenstad, C.A., Backus, D.H., and Kent, A.J. 2011. Life history variation in upper Columbia River Chinook salmon (*Oncorhynchus tshawytscha*): a comparison using modern and ~500-year-old archaeological otoliths. *Canadian Journal of Fisheries and Aquatic Science*. 68:603–617.
- Muhlfeld, C.C., Thorrold, S.R., McMahon, T.E., and Marotz, B. 2012. Estimating westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) movements in a river network using strontium isoscapes. *Canadian Journal of Fisheries and Aquatic Science*. 69:906–915.
- Nordeng, H. 1983. Solution to the “charr” problem based on Arctic charr (*Salvelinus alpinus*) in Norway. *Canadian Journal of Fisheries and Aquatic Sciences*. 40:1372–1387.

- Olsen, J.B., Wuttig, K., Fleming, D., Kretschmer, E.J., and Wenburg, J.K. 2006. Evidence of partial anadromy and resident-form dispersal bias on a fine scale in populations of *Oncorhynchus mykiss*. *Conservation Genetics*. 7:613–619.
- Pascual, M., Bentzen, P., Rossi, C.R., Mackey, G., Kinnison, M.T., and Walker, R. 2001. First documented case of anadromy in a population of introduced rainbow trout in Patagonia, Argentina. *Transactions of the American Fisheries Society*. 130:53-67.
- Pavlov, D.S., Savvaitova, K.A., and Kuzishchin, K.V. 2001. Theoretical aspects of the problem of the distribution pattern and formation of life-history strategy of mikizha (*Parasalmo mykiss* (Walbaum), Salmonidae, Salmoniformes) on the Kamchatka Peninsula. *Doklady Biological Sciences*. 379:344–346. Translated from 2001 *Doklady Akademii Nauk* 379:139–141.
- Tattam, I. A. 2006. Seasonal life history of *Oncorhynchus mykiss* in the south fork John Day River Basin, Oregon. M.S. Thesis. Oregon State University. Oregon. P. 145.
- Thrower, F.P., and Joyce, J.E. 2004. Effects of 70 years of freshwater residency on survival, growth, early maturation, and smolting in a stock of anadromous rainbow trout from southeast Alaska. *American Fisheries Society Symposium Series*. 44:485–496.
- Wilzbach, M.A., Ashenfelter, M. J., and Ricker, S. J. 2012. Movement of resident rainbow trout transplanted below a barrier to anadromy. *Transactions of the American Fisheries Society*. 141: 294–304.
- Wood, C.C. 1995. Life history variation and population structure in sockeye salmon. *In* *Evolution and the aquatic ecosystem: defining unique units in population conservation*. Edited by J.L. Nielsen. American Fisheries Society Symposium Series. 17:195–216.
- Zimmerman C.E., and Reeves, G.H. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry. *Canadian Journal of Fisheries and Aquatic Science*. 57:2152–2162.
- Zimmerman, C.E., Currens, K.P., and Reeves, G.H. 1997. Genetic population structure of coastal cutthroat trout in the Muck Creek basin, Washington. *In* *Sea-run cutthroat trout: biology, management and future conservation*. Edited by J.D. Hall, P.A. Bisson, and R.E. Gresswell. Oregon Chapter, American Fisheries Society, Corvallis, Oregon. pp. 170–172.
- Zimmerman, C.E., Edwards, G.W., and Perry, K. 2009. Maternal origin and migratory history of steelhead and rainbow trout captured in rivers of the Central Valley, California. *Transactions of the American Fisheries Society*. 138:280–291.



## HABITAT FOR THE WILD AND RARE: A USERS GUIDE

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**Abstract**—Each year federal, state, and county conservation agencies spend millions of dollars to stabilize streambanks and create habitat for trout. However, past stream restoration projects in the upper Midwest have often failed to incorporate habitat for nongame species such as snakes, frogs, turtles, and birds, primarily because of a lack of knowledge about those species' habitat needs. Every state has prepared a Wildlife Action Plan as a prerequisite to receive federal funding to implement habitat projects for nongame species. Developing habitat for nongame species at the same time that construction equipment is being used for trout stream projects is efficient and cost-effective. Not combining habitat for these species is a missed opportunity. In the Driftless Area of the upper Midwest, conservationists are planning projects that improve water quality and riparian habitat while implementing these projects in a way that benefits multiple nongame species.

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### INTRODUCTION

The Driftless Area, located in the heart of the Upper Mississippi River Basin, is a geographically distinct 24,000 -mi<sup>2</sup> area primarily in southwestern Wisconsin and includes areas of southeastern Minnesota, northeastern Iowa and extreme northwestern Illinois. This area is interlaced with more than 1,200 streams (more than 4,000 river miles) that spring from the underlying limestone bedrock. This area includes very steep topography with elevations ranging from 603 to 1,719 ft. The peculiar terrain is due to its having escaped glaciation during the last glacial period (approximately 10,000 years ago).

The streams and riparian habitats of the Driftless Area suffer from a history of human disturbances. Land-use practices have led to extensive erosion and subsequent sedimentation of the watersheds in this region. The steep topography of the region has exacerbated these human influences. Across the region, hundreds of miles of spring creeks have been inundated with soils and fine sediment, resulting in degraded water quality, increased stream temperatures, damage to aquatic habitat, and altered watershed hydrology. For over 50 years conservationists and conservation organizations have been working to improve Driftless Area streams by stabilizing streambanks and incorporating habitat for trout. Each

year federal, state and county conservation agencies spend millions of dollars to stabilize streambanks and create habitat for trout. However, past stream restoration projects in the upper Midwest have often failed to incorporate habitat for nongame species such as amphibians, birds, invertebrates, mammals and reptiles, primarily because of a lack of knowledge about those species' habitat needs. Developing habitat for other nongame species at the same time that construction equipment is being used for stream restoration projects is efficient and cost-effective. Not combining habitat for these species is a missed opportunity.

Having a better understanding of what kinds of nongame wildlife live in your project area and a basic understanding of their life history will help you create a better project. A good place to start gathering information on which nongame species would benefit from additional or improved habitats is by reviewing your state's Wildlife Action Plan. All of the states in the Midwest have developed Wildlife Action Plans identifying natural communities and their associated *Species of Greatest Conservation Need* (SGCN) (low or declining populations that are in need of conservation action). From this you can generate a target species list for your region. It will be helpful to then obtain a more precise list of species

that are likely to exist in your more immediate area by contacting local species experts in your area, such as biology departments at local colleges and universities and Department of Natural Resources staff. These professionals may also be able to put you in touch with local non-agency species experts.

NOTE. Your target species list should also include common wetland, riparian or aquatic nongame species as well as species that use upland habitats as well as the aforementioned habitats.

### STUDY SITE

Located in the heart of the Upper Mississippi River basin, the geographically distinct 24,000-mi<sup>2</sup> Driftless Area of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois is interlaced with more than 1,200 streams (more than 4,000 river miles) that spring from the underlying limestone bedrock (Figure 1).

### METHODS

Since 2005 Trout Unlimited has been working with county, state and federal conservation field offices in the Driftless and Bob Hay, former Wisconsin DNR herpetologist, to better understand herptiles and their needs. To date over 50 stream restoration projects have used a variety of instream habitat features to improve the habitat for turtles, frogs, and snakes.

In 2009, with funding from the National Fish and Wildlife Foundation, Trout Unlimited developed a Nongame Habitat Guide that provided information about the habitat needs of a variety of upland, riparian, wetland and aquatic nongame species and described a number of specific habitat features that can benefit them. By integrating some of these features into projects, where appropriate, you may be able to make a positive contribution toward increasing the carrying capacity of instream, wetland, riparian and upland habitats for nongame birds, herptiles, invertebrates, mammals and possibly nongame fish.

#### *Driftless Area Restoration Effort*

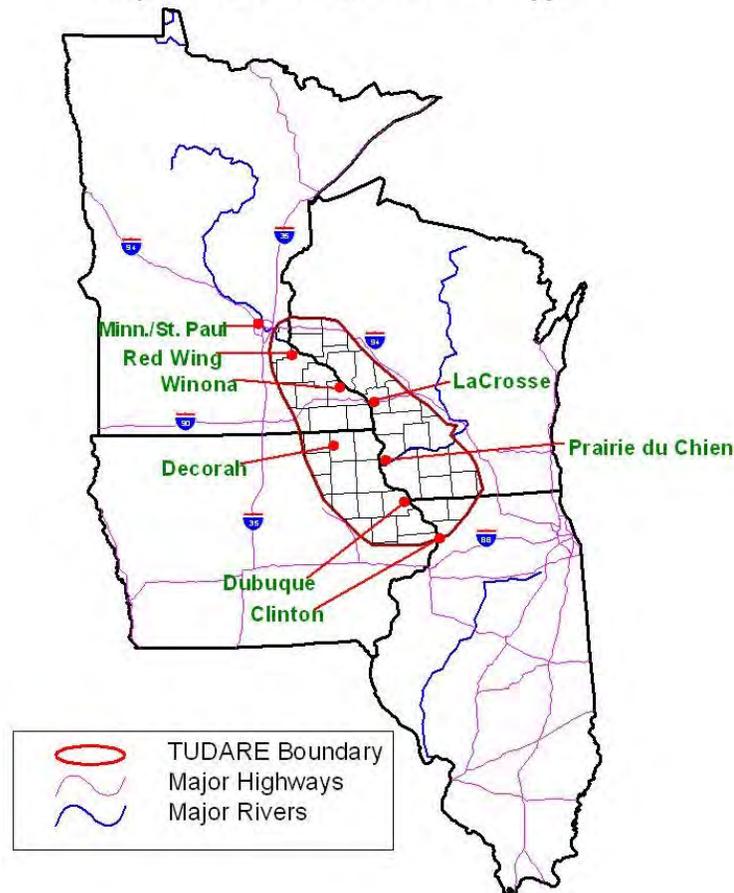


Figure 1. Driftless Area – covering four states.

Since the 2009 edition of the Nongame Habitat Guide, we have started the development of a second edition which includes modifications to help project planners better determine whether any particular habitat feature is likely to accomplish its intended purpose within the immediate habitats and within the surrounding landscapes (Figure 2). The previous guide simply provided a suite of habitat features that could benefit nongame species. A habitat, species and landscape matrix is also provided to help planners and agency reviewers determine which habitat features are most likely to benefit species on a target list. For example, adding wetland “scrapes” (small potholes) within an intact riparian corridor is likely to benefit populations of common amphibian species in an area and may also improve populations of SGCN species like the northern cricket frog and the pickerel frog. On the other hand, adding wetlands scrapes within an active pasture may have more limited benefits for amphibians. Wetland scrapes in a pasture may be even less likely to succeed if the surrounding landscape is comprised primarily of row crops. This improvement to the guide will help project proponents develop plans that only incorporate habitat features that are likely to succeed and should allow staff to make better informed decisions within the project reviews and approval process.

### Reptiles (Class Reptilia)

Reptiles, for purposes of this guide, include snakes and turtles. They are cold-blooded animals with scales covering most or all of their skin as

opposed to having smooth moist skin like amphibians. Terrestrial and most aquatic reptiles lack the ability to internally regulate their body temperatures but instead rely on external influences to establish their body temperatures. As such, they rely on ambient air and ground temperatures and sun and shade to thermally regulate their body temperatures. Varied habitat structure that offers a range of canopy conditions and that favors open canopy conditions is important for reptiles. Reptiles also require overwintering microhabitats underground or underwater to avoid freezing during the winter.

Reptiles, especially turtles, are slow to mature and are often long-lived species. As a result, extremely low annual adult mortality is essential to population maintenance. Therefore, project installations, both in and adjacent to streams, must avoid their overwintering period, typically from mid-September through mid-April.

Natural hibernacula in streams are often created by tree falls along the streambank that lead to either deep bank undercutting or that create slack water immediately downstream of the tree up against the bank. These areas eventually fill in with fine sediments that turtles will opportunistically bury in during winter. Unfortunately, some of the worst streambank erosion occurs adjacent to these unstable trees and roots, and an unanchored tree may be good for a year or more but eventually moves downstream during flood events. A more permanent artificial overwintering structure has been developed to create a similar sediment trap (Figure 3). These structures are strategically placed

Feature	Riparian Conditions (minimum 66-foot easement post project)	Immediate Adjacent Landuse (edge of easement to 300 yards past stream on both sides- post project)	Landscape Context (outer edge of 300 yards habitat to .5 miles from stream on both sides)
<b>Snake Hibernaculum</b>	Row cropped- No value- do not consider this feature ●	> 70% row crop or active pasture ●	100% row crop and active pasture ●
	Active pasture or forested habitat ●	<70% row crop or active pasture >30% undisturbed open canopy ○	>70% Ag & <30% fallow ○
	>70% of one side of stream is undisturbed open canopy ○	< 50% row crop or active pasture > 50% undisturbed open canopy ○	<50% Ag >50% fallow ○
	Revegetated and undisturbed open canopy habitat on both sides of stream ●	Established old field or planted natural community (not to be pastured) ●	<30% Ag >70 % fallow/planted natural community ●
You must score at least <u>moderate to good</u> under the Riparian Conditions and at least <u>low to moderate</u> in the Immediate Adjacent Landuse to potentially benefit streamside community snakes. Having red in all three habitat categories will improve your potential to benefit a broader snake community.			

Figure 2. Snake Hibernaculum – Habitat Feature Landscape Matrix.



**Figure 3. Turtle hibernaculum being installed.**

under the bank immediately downstream of flow deflectors placed on the upper inside end of bends. These structures are specifically designed for snapping turtles but may occasionally be used by other turtles. The turtle hibernacula, made of a hard wood, will be virtually rot resistant once it is placed fully submerged. The current design uses 2-in thick rough oak, 8 ft long, which is what we typically use for building other habitat structures.

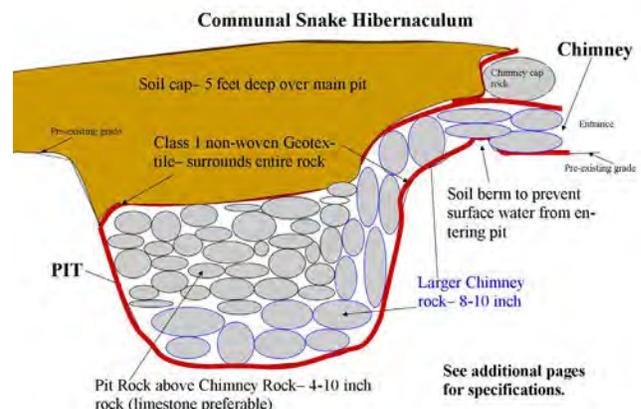
Aquatic and semiaquatic turtles require basking surfaces to increase their body temperatures. This helps them digest food, acquire Vitamin D and maintain shell health. Gravid females bask in spring to elevate their temperatures in order to allow for timely egg develop. Many turtles will commonly emerge from overwintering habitats as soon as the ice melts. Basking in the sun not only helps regulate their body temperature, but the warmth of the sun allows the shell to dry, inhibiting bacterial and fungal growth (Christoffel et al. 2002). Creating permanent basking logs, or escape logs (Figure 4), is a simple task with an excavator. Logs are anchored into the bank and placed just off the surface of the water where they would not obstruct water flow and turtles could escape predators by sliding off into a deep pool.

Snakes are primarily terrestrial animals. They have relatively high thermal preferences and prefer open canopy habitats. The most commonly encountered snake along streams in the Driftless Area includes the common gartersnake and the common watersnake. Many of these snakes are communal denning, meaning that they congregate to overwinter. In areas where natural den sites are limited or absent, artificial



**Figure 4. Placed basking log.**

structures can be created to meet their overwintering needs. Snakes are known to migrate up to 2 mi from their summer range to their hibernation site, but the migration is often shorter. Species may have different overwintering microhabitat preferences even when they use the same hibernaculum; hence, designing a one-size-fits-all hibernaculum is easier said than done. Two key elements are critical for snakes to overwinter successfully; conditions must prevent snakes from freezing and sufficient moisture is required to prevent damaging water loss during the long period they remain underground. A number of studies have shown the lack of adequate hibernacula to be a limiting factor for some snake populations (Christoffel et al. 2002). The hibernaculum design and specifications were developed by gaining experience with the design of several old and abandoned dug wells that support several of the communal denning snakes (Figure 5).



**Figure 5. Communal snake hibernaculum.**



Figure 6. Restored wetlands adjacent to stream.



Figure 7. Creating shallow backwater areas.

### Amphibians (Class Amphibia)

Amphibians, such as frogs and salamanders are cold-blooded animals, most of which metamorphose from a larval form to an adult form. A majority of them require access to both aquatic and terrestrial habitats. Most amphibians lay their eggs in standing water but have varied habitat preferences on land, ranging from open canopy grasslands to dense forests. Suitable breeding habitat is critical to their long-term survival.

Frogs and salamanders have thin, semipermeable skin that needs to remain moist. Therefore, upland habitats must provide microhabitats that allow them to avoid damaging water loss. Downed woody debris or healthy duff layers often supply this microhabitat. Adult salamanders often live underground or under large woody debris on land outside of the breeding period.

Vernal pools and ponds were not historically abundant in the Driftless Area due to steep topography and narrow valleys. The impacts of overgrazing and early agricultural practices have significantly altered most stream drainages in this area, often resulting in broader floodplains. These floodplains provide managers with the opportunity to create and restore wetlands adjacent to these streams (Figure 6).

A few frogs native to the Driftless Area have the ability to withstand freezing. The Wood Frog *Rana sylvatica*, Western and Boreal Chorus Frog *Pseudacris triseriata*, Northern Spring Peeper *Pseudacris crucifer*, and the Copes Gray Treefrog *Hyla chrysoscelis*, can freeze solid during the winter. Frogs are able to do this by generating an “antifreeze”, consisting of high levels of sugars and sugar alcohols in their tissues that keep their cells from freezing (Premo 2005). Projects targeting amphibians were aimed at creating shallow backwater areas (Figure 7), and constructing point bars that allowed for the deposition of sediment and created shallow flats.

These shallow gradient mud or sand flats below the eddies, which typically support low and sparse vegetation, are ideal for a number of frogs, but are particularly ideal for Wisconsin’s only endangered amphibian the Blanchard’s Cricket Frog *Acris crepitans blanchardi*. Creating side channels that connect to the stream but are slightly warmer in temperature will also provide additional refuge for frogs and forage fish.

### Birds (Class Aves)

Birds are warm-blooded species that maintain stable internal body temperatures regardless of external influence. Because winters in the Midwest impact food availability for many birds, they migrate south to take advantage of warmer climates where access to food resources is not limited by cold temperatures, ice, or frozen soils. This includes many of the riverine and wetland associated birds. Most water-associated nongame bird species fall into the category of being insectivores, are piscivores or are more general predators, eating a wide variety of prey including insects, fish, amphibians, reptiles and small mammals along with wetland and aquatic vegetation and seeds. A wide variety of birds can be found along stream corridors, but are not dependent on these habitats alone.

Shallow wetlands, low gradient shoreline of ponds, and mud flats and backwater areas along

streams provide excellent foraging areas for wading birds. Perches over the water are important for a variety of insectivorous birds such as eastern kingbirds and for piscivores like the kingfisher. Dead trees provide perching areas for hawks and other birds and can provide structure for nesting and foraging. Vertical banks can be important nesting habitats for bank swallows and kingfishers. Varied habitat structure (trees, brush and grasslands) in riparian habitats can provide a variety of nesting opportunities.

Belted kingfishers *Megaceryle alcyon* and bank swallows *Riparia riparia* are often found nesting in vertical eroding banks, often where we are planning a project. One way to avoid destroying nests during construction is to place netting over the nesting holes prior to the nesting season.

Vertical eroding banks are one of the most vulnerable nesting areas in the riparian corridor. Nests built in the spring are susceptible to flooding and bank collapsing with every storm event.

We are experimenting with the soil we remove from the eroding banks during construction to construct vertical nesting banks (Figure 8). The mound is constructed in close proximity to the stream restoration project, but out of the flood plain and the vertical face facing the stream. The face of the structure should be tall enough to prevent terrestrial predation from below or above and the lens (nesting



Figure 8. Vertical bird nesting banks.

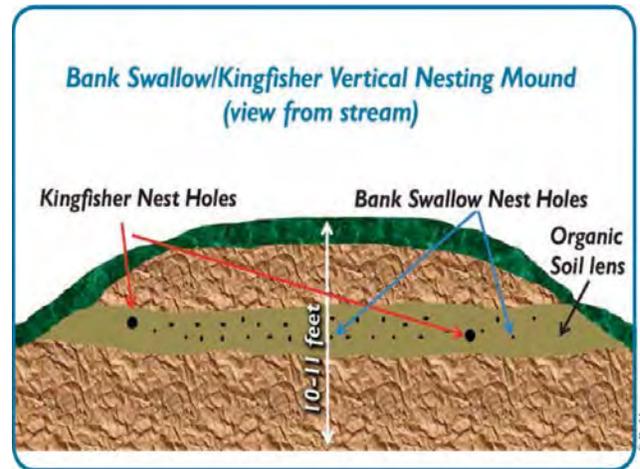


Figure 9. Schematic of vertical nesting bank.

area) constructed with a lighter organic soil. The mound is stabilized by compacting each layer of soil as it is constructed and finish by seeding with a short-canopy of cool and warm season grasses (Figure 9).

## DISCUSSION

We have developed all of our habitat designs into the Standard Designs of Natural Resources Conservation Service and have approached all four states in the Driftless Area to adopt these standards so that they are eligible for Farm Bill dollars (Figure 10).

We have also compiled a suite of monitoring protocols to assess nongame wildlife on larger projects that incorporate several to many of the habitat features listed in our guide. The purpose of monitoring is to determine if the added nongame habitat features accomplish their intended purpose of improving nongame diversity and relative abundances. In order for monitoring to have value, pre- and post-monitoring is necessary.

While monitoring will not provide definitive results for all species, it will help managers and funding agencies make decisions about which habitat features are most beneficial. Over time, monitoring results should help identify which practices to continue promoting and which to exclude.

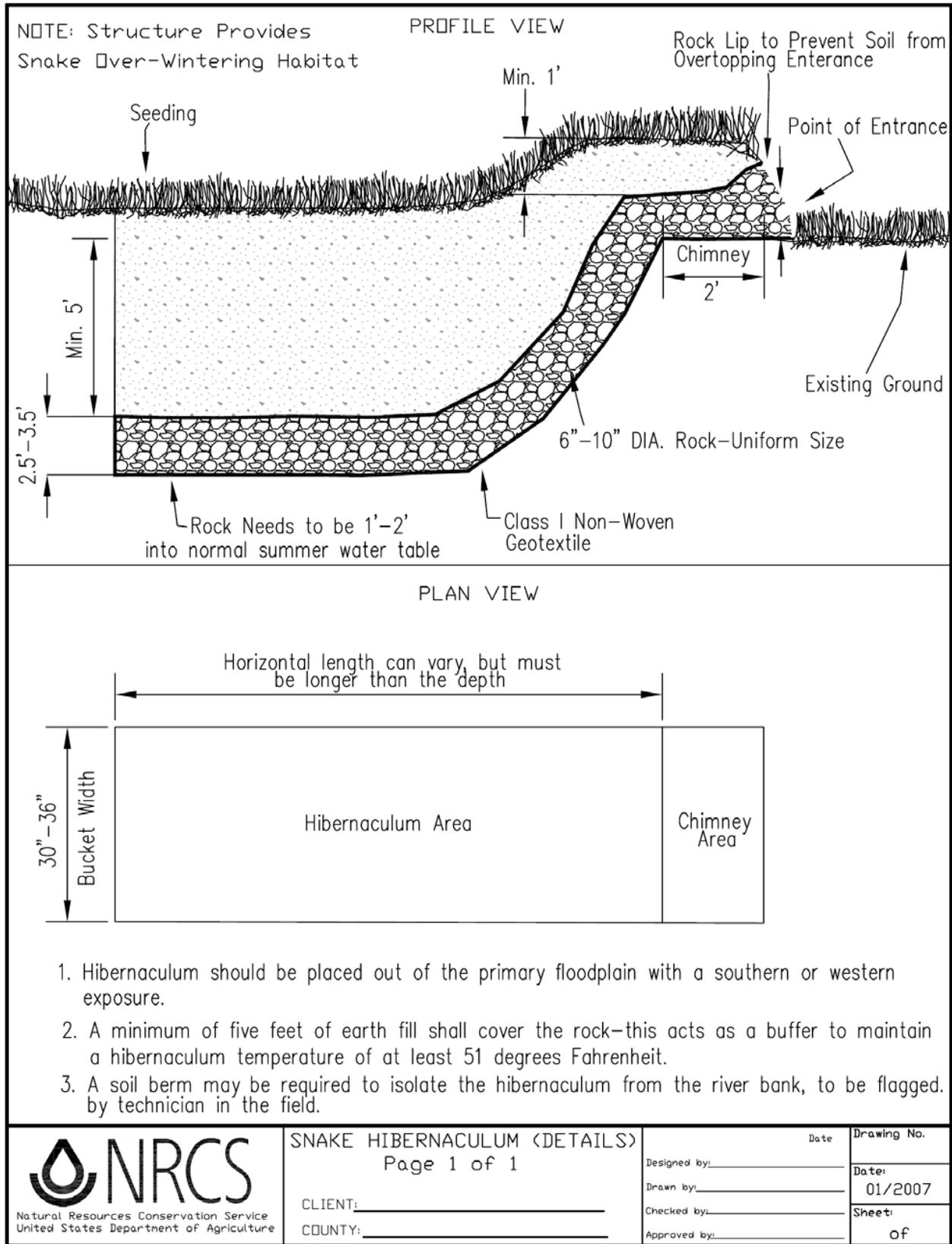


Figure 10. Standard drawing for "Snake Hibernaculum."

## REFERENCES

- Christoffel, R., R. Hay, and M. Monroe. 2002. Turtles & Lizards of Wisconsin. Wisconsin Department of Natural Resources. Report GP6/02, Madison.
- Christoffel, R., R. Hay, and L. Ramirez. 2000. Snakes of Wisconsin. Wisconsin Department of Natural Resources. Report GP3/00, Madison.
- Christoffel, R., R. Hay, and M. Wolfgram 2001. Amphibians of Wisconsin. Wisconsin Department of Natural Resources. Report GP5/01, Madison.
- Premo, D. 2005. A Long Winter's Nap – Amphibians and Reptiles Sleep it off. *Lake Tides*. 30(1) 1-3.
- Thrall, T. 2007. TU DARE - Interim Report - Coldwater Stream Restoration Data Collection and GIS Catalogue, 2007. Thrall Conservation Consulting, LLC, Madison, Wisconsin.

## CALIFORNIA GOLDEN TROUT AND CLIMATE CHANGE: IS THEIR STREAM HABITAT VULNERABLE TO CLIMATE WARMING?

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**Abstract**—To determine the current range of water temperatures in streams inhabited by California Golden Trout *Oncorhynchus mykiss aguabonita*, we deployed and monitored water temperature recording probes from 2008-2013 in three meadows in the Golden Trout Wilderness in the southern Sierra Nevada, California. Ninety probes were placed in three meadow streams: Mulkey Creek in Mulkey Meadow (2,838 m), South Fork Kern River in Ramshaw Meadows (2,640 m) and Golden Trout Creek in Big Whitney Meadow (2,963 m). Year-round water temperatures were successfully downloaded from seventy-nine probes along with measurements of stream shade. Water temperatures ranged from -0.1 to 26°C in Mulkey and Ramshaw meadows while in Big Whitney Meadow maximum temperature did not exceed 21°C. Temperatures were highest in late July through mid-September. Salmonids generally prefer cool water and become stressed when temperatures exceed 22°C, and water temperatures are predicted to increase with future climate warming. Thus, these results indicate that current stream temperatures in the Golden Trout Wilderness are high and may lack the resiliency to future warming.

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### INTRODUCTION

The California Golden Trout *Oncorhynchus mykiss aguabonita* is native to the South Fork Kern River and Golden Trout Creek (Behnke 1992), and most of its native range lies within the Golden Trout Wilderness (GTW) in the southern Sierra Nevada (Figure 1). California Golden Trout (CGT) populations in the GTW are long lived and slow growing (Knapp and Dudley 1990; Knapp and Matthews 1996). Cattle grazing has also increased spawning habitat by widening channels and as a result, CGT exist at high densities of small fish (Knapp et al. 1998). The CGT has been the subject of management interest because of its status as California's state fish, limited natural distribution, and several perceived threats to its viability, including introduction of nonnative Brown Trout *Salmo trutta* and habitat degradation caused by livestock grazing. The CGT was the focus of a major restoration effort in the 1970s-1980s (Pister 2008) to remove exotic trout throughout its native range. Several studies have described Golden Trout habitat preferences (Matthews 1996a, 1996b) and concluded that adult trout prefer habitats (vegetated and undercut banks) that are typically reduced by cattle grazing

(Kaufman and Krueger 1984). One emerging threat that has not been evaluated is the impact of climate warming that could further stress CGT streams already near their temperature maximums due to cattle grazing.

Cattle grazing typically results in reduced streamside vegetation and shallow, widened streams which in turn increases stream warming (Armour et al. 1991; Platts 1991; Belsky et al. 1997). Climate warming models predict streams and lakes in the Sierra Nevada will experience significant warming in the next 100 years and the currently degraded streams may not have the resilience to withstand increased warming. Several recent papers have noted the similar impacts of cattle grazing and climate warming to stream habitats and recommend major changes in grazing management in Wilderness areas to increase resiliency of stream habitats (Beschta et al 2013; Hughes 2014). This project was designed to determine the range of water temperatures and stream shading currently experienced by the California Golden Trout in GTW streams. This report will highlight some preliminary water temperature and stream shade data from the ongoing study and discuss whether their habitat will be vulnerable to climate warming.

## METHODS

This study was conducted in three large (5–7 km long) montane meadows of the Golden Trout Wilderness in the Inyo National Forest of the southern Sierra Nevada, California. Mulkey Meadow (36°24'19"N, 118°11'42.14"W, 2,838 m), Big Whitney Meadow (36°26'23"N 118°16'11.66"W, 2,963 m) and Ramshaw Meadow (36°20'53"N, 118°14'52.62"W, 2,640m) (Figure 1). These meadows are part of the largest meadow complex in the Sierra Nevada and occur in depositional basins along the South Fork Kern River. All meadows were historically grazed by cattle and sheep since the 1800s but only Mulkey Meadow is currently grazed by cattle. The meadows are generally covered with snow from November to May, and the summer growing season lasts from approximately late May to August, depending on the timing of snow melt. The meadows occur in a semiarid region where annual

precipitation is 50–70 cm and most precipitation is in the form of snow.

To determine the water temperature vulnerability of the CGT within its stream habitat in the GTW, I deployed 90 temperature probes (Onset HOBO Water Temp Pro v2 and tidbits) throughout the stream to include a typical range of stream areas: areas degraded by cattle grazing (collapsed banks, little vegetation, shallow depth) and those in recovering areas with more streamside vegetation and greater depth. Temperatures were recorded every 20 min and were downloaded at least once per year from 2008 to 2013. Solar radiation input (opposite of shade) was measured using the Solmetric Suneye 210; measurements (0–100%) were made at each temperature probe. Measurements of 100% indicate full solar input with no shade; conversely 0% indicates no solar input and full 100% shade.

## California Department of Fish and Game Golden Trout Recovery Work on Kern Plateau

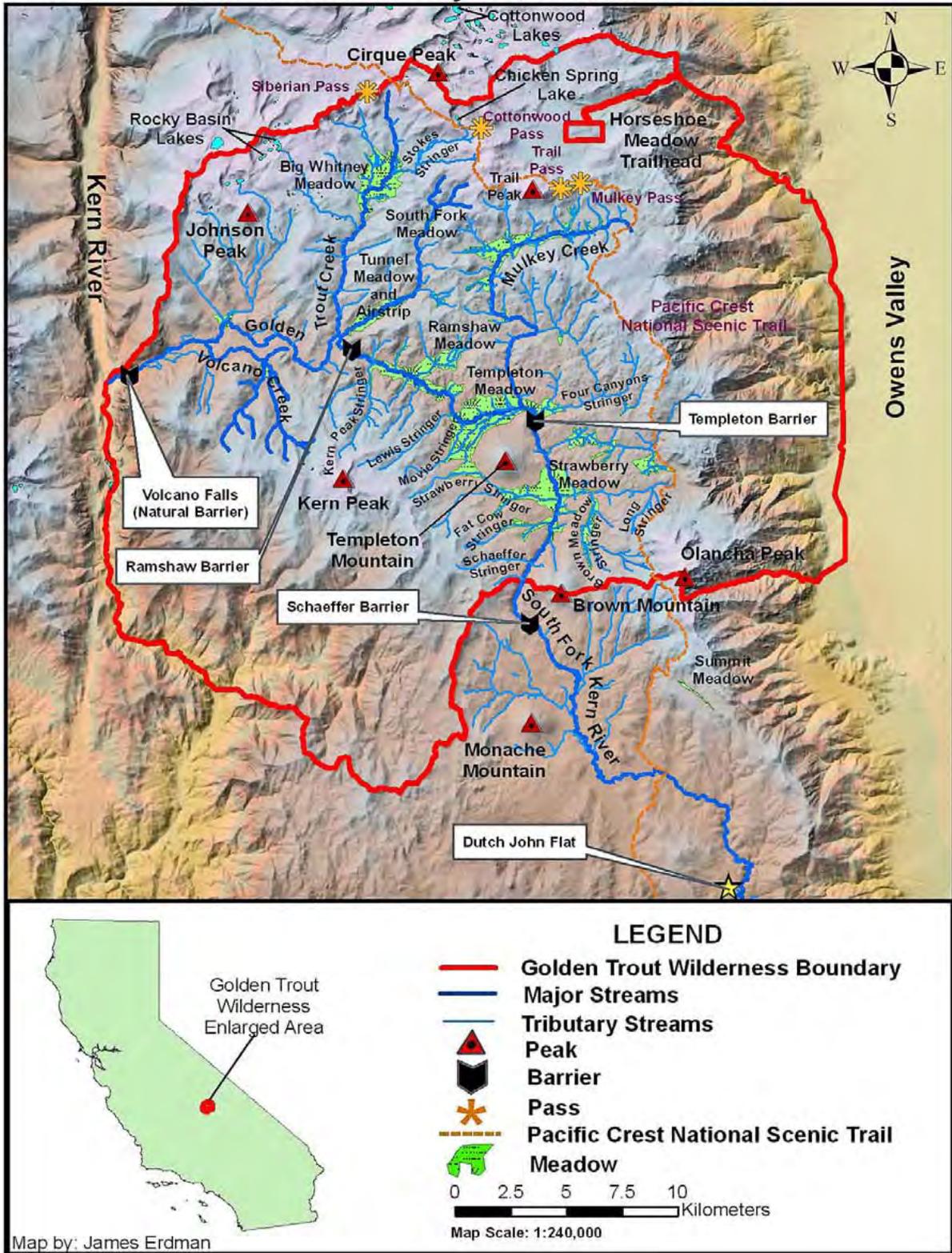


Figure 1. Map of Kern plateau from Pister 2008.

## RESULTS

Temperature probes were successfully downloaded from 79 probes; 30 from Mulkey Meadow, 29 from Ramshaw Meadow, and 20 from Big Whitney Meadow. Of the originally deployed 90 probes, nine were never recovered and two were found out of the stream and damaged by animals (likely marmots or coyotes). Year-round temperatures ranged from -0.1 to 26°C in Mulkey and Ramshaw meadows while

in Big Whitney Meadow maximum temperature did not exceed 21°C (Figure 2). Median year-round temperatures were highest in Mulkey Meadow and lowest in Big Whitney Meadow. Yearly (2008-2013) water temperatures ranged from maximums of 23-26°C to minimums of 0 to 4°C (Figure 2). Water temperatures were highest during summer weeks 25-34 (late June-mid September; Figure 3a-c).

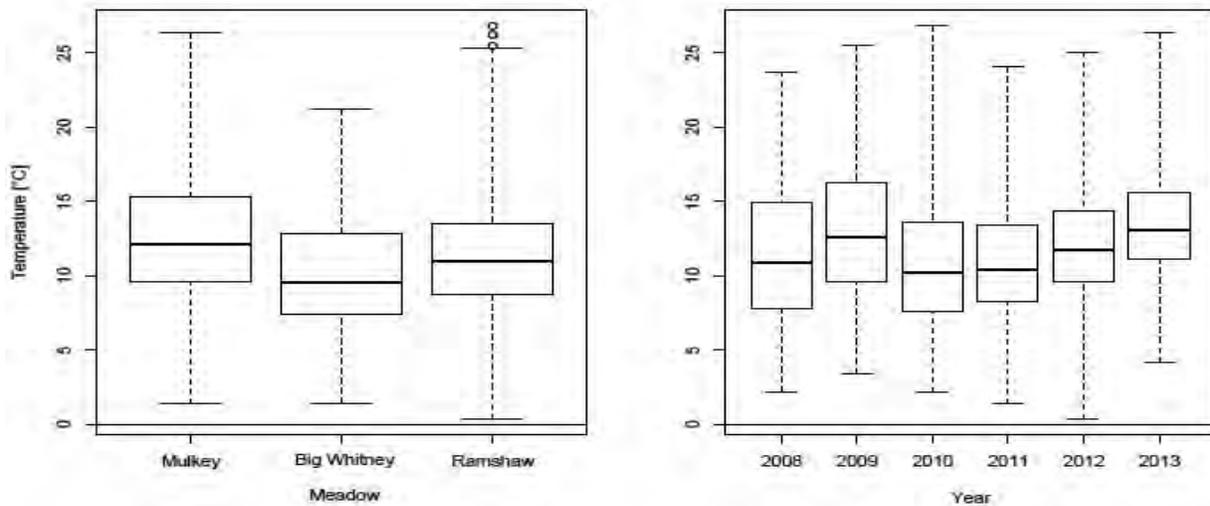


Figure 2. Boxplots of water temperatures (°C) for Mulkey, Big Whitney, and Ramshaw meadows 2008-2013 combined, and the median temperatures for individual years 2008-2013.

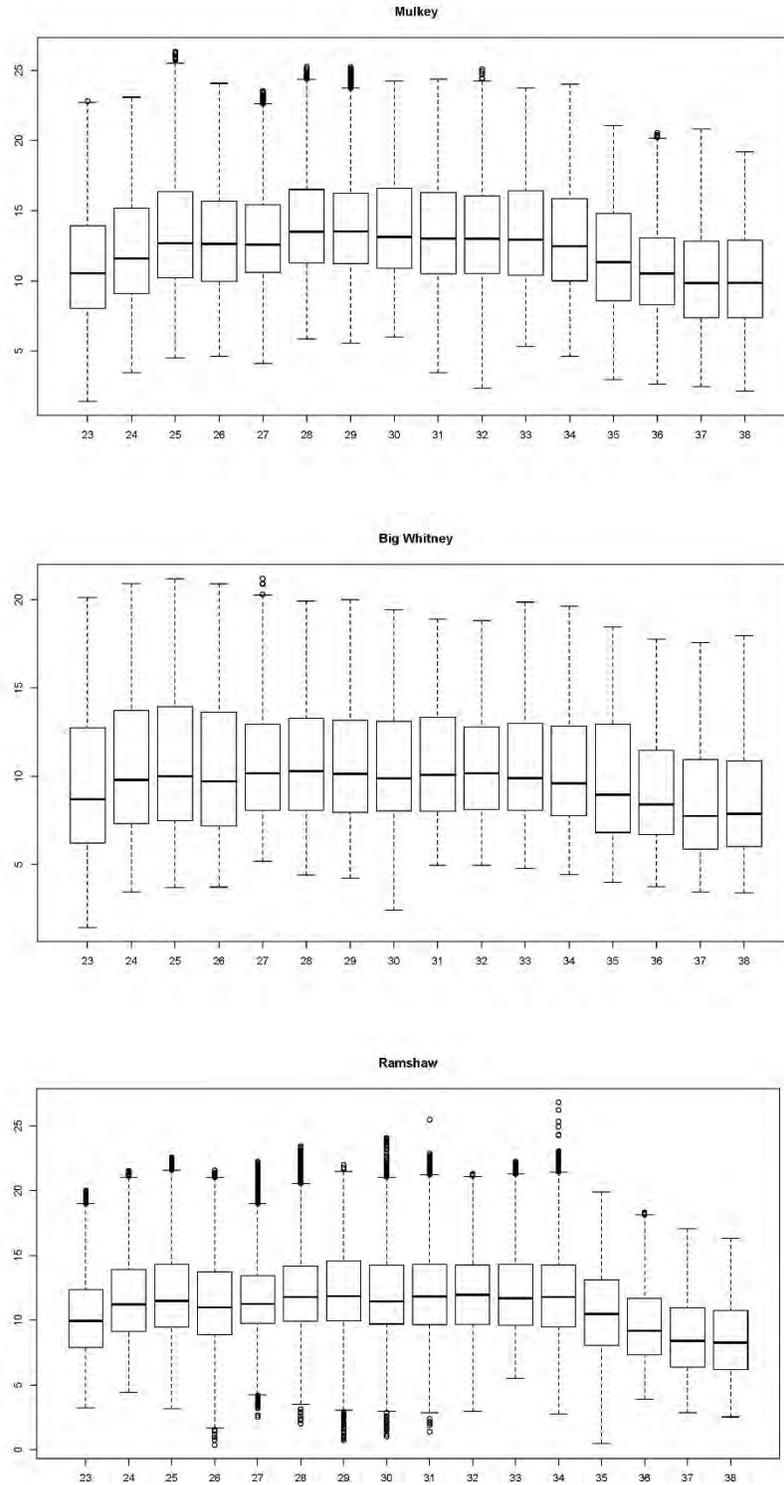
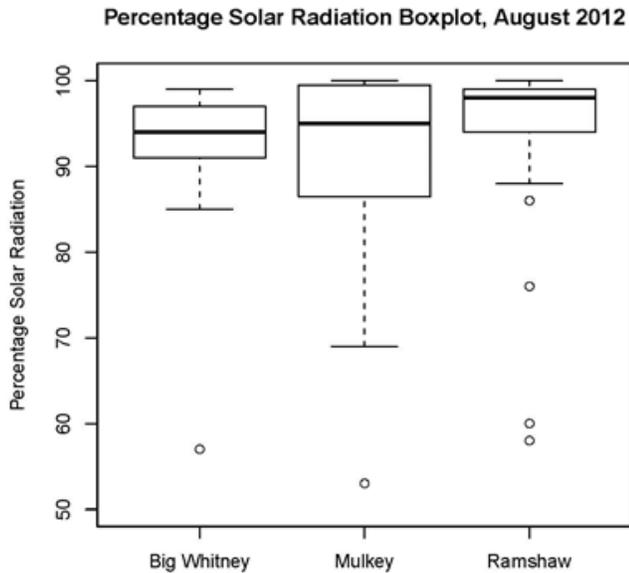


Figure 3 a-c. Boxplots of water temperatures for weeks 23-36 (2008-2013) in Mulkey, Big Whitney, and Ramshaw meadows.



**Figure 4. Boxplots of solar radiation measurements in all three meadows measured in 2012.**

Median solar radiation estimates were high (>90% = 10% shade) for all three meadow streams (Figure 4). The solar radiation estimates (%) in all three streams ranged to 60% (Shading = 40%) in areas with more streamside vegetation.

## DISCUSSION

This is the first documentation of year-round water temperatures in CGT native streams. Water temperature data from 2008 to 2013 highlight several vulnerabilities: water temperatures in some areas of the GTW are already reaching stressful and possibly lethal levels for salmonids (>26°C) (Bjorn and Reiser 1991). These stream areas already are too warm and will not have the resiliency to withstand future increased warming of 1-7°C. The natural conditions of Kern Plateau open meadows combined with reduced streamside vegetation diminish the capacity of these streams to remain cool, and future warming could result in widespread lethal water temperatures.

California Golden Trout inhabit streams with temperatures at critical levels. Past research found Rainbow Trout *Oncorhynchus mykiss* in southern California streams with temperatures up to 28°C, but

trout sought out coolwater seeps and did not use the warmer areas (Matthews and Berg 1997). CGT are extremely abundant throughout the stream (Knapp and Matthews 1995) and inhabit all parts (runs, pools, etc.) of the GTW streams (Matthews 1996). Redband Trout, *Oncorhynchus mykiss gairdneri*, inhabit desert basin streams at mid-elevations (1,600-1,700 m) and may be found in water with temperatures as high as 29°C (Zoellick 1999; Rodnick et al 2004). Redband Trout are considered the most temperature tolerant of the salmonids. However, Meyer et al (2010) reported Redband Trout were more abundant in areas of increased shade and temperature between 10-16 °C and that they steadily declined as mean summer temperature exceeded 16°C. These high temperatures may impact condition and performance of the Redband Trout (Rodnick et al 2004). Perhaps CGT are heat tolerant, but little is known about their thermal preference and in the absence of information it would be prudent to promote management activities that cool the streams.

Climate models predict water temperature will increase 1 to 7°C in the Sierra Nevada (Dettinger 2012; Null et al. 2013) and none of the streams currently have resiliency to withstand increased temperatures. While Golden Trout Creek (Big Whitney Meadow) temperatures were lower than Mulkey Creek and South Fork Kern River (Ramshaw Meadow), Golden Trout Creek would experience stressful levels (>25°C) when temperatures rise. Beschta et al. (2013) reported that climate warming has many similar impacts to overgrazing. They recommended that grazing on public lands especially in wilderness areas be eliminated to help meadow streams recover and become more resilient to climate warming impacts. Because future climate warming could increase water temperatures to lethal levels, the current results stress the importance of continued monitoring and restoration activities that promote stream cooling.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Armour, C. L., D.A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16:7-11.
- Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6, Bethesda, Maryland.
- Belsky, A.J., A. Matzke, and S. Uselman. 1997. Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation*: 54:416-531.
- Beschta, R. L., Donahue, D. L., DellaSala, D. A., Rhodes, J. J., Karr, J. R., O'Brien, M. H., Fleischner, T. L., and Williams, C. D. (2013). Adapting to climate change on western public lands: Addressing the ecological effects of domestic, wild, and feral ungulates. *Environmental Management*, 51:474-491
- Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 In W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, Maryland.
- Dettinger, M.D. 2013. Projections and downscaling of 21st century temperatures, precipitation, radiative fluxes and winds over the southwestern US, with a focus on Lake Tahoe. *Climatic Change* 116:17-33
- Hughes, R. 2014. Livestock Grazing in the West: Sacred Cows at the Public Trough Revisited, *Fisheries*, 39:339, 388.
- Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: A review. *Journal of Range Management* 37:430-437.
- Knapp, R. A., and T. L. Dudley. 1990. Growth and longevity of golden trout, *Oncorhynchus aguabonita*, in their native streams. *California Fish and Game* 76:161-173.
- Knapp, R. A., V. T. Vredenburg, and K.R. Matthews. 1998. Effects of stream channel morphology on golden trout spawning habitat and population structure. *Ecological Applications* 8:1104-1117.
- Knapp, R. A. and K. R. Matthews. 1996. Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: impacts and management implications. *North American Journal of Fisheries Management* 16:805-820.
- Matthews, K.R. 1996a. Golden trout habitat selection and movement patterns in degraded and recovering sites within the Golden Trout Wilderness, California. *North American Journal of Fisheries Management* 16:578-590.
- Matthews, K. R. 1996b. Diel movement and habitat use of the golden trout *Oncorhynchus mykiss aguabonita* in their native habitat on the Golden Trout Wilderness, California. *Transactions of the American Fisheries Society* 125:78-86.
- Matthews, K. R. and N. H. Berg. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology* 49:1-18.
- Null, S. E., J. H. Viers, M. L. Deas, S. K. Tanaka, and J. F. Mount. 2013. Stream temperature sensitivity to climate warming in California's Sierra Nevada: Impacts to coldwater habitat. *Climatic Change*, 116:149-170.
- Pister, E. P. 2008. Restoration of the California golden trout in the South Fork Kern River, Kern plateau, Tulare County, California, 1966-2004, with reference to golden trout creek. California Department of Fish and Game Administrative Report No. 2008-1, Sacramento.
- Platts, W.S. 1991. Livestock grazing. p. 389-424. In: W.R. Meehan (ed), Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19:389-423.
- Rodnick, K.J., A.K. Gamperl, K.R. Lizars, M.T. Bennett, R.N. Rausch, and E.R. Keeley. 2004. Thermal tolerance and metabolic physiology among redband trout populations in south-eastern Oregon. *Journal of Fish Biology* 64:310-335.
- Zoellick, B. W. 1999. Stream temperatures and the elevational distribution of redband trout in southwestern Idaho. *Great Basin Naturalist* 59:136-143.

## REWILDING NATIVE TROUT: OPPORTUNITIES FOR STRONGHOLD DEVELOPMENT THROUGH PORTFOLIO PLANNING

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**Abstract**—We describe a systematic approach to aquatic conservation planning that applies the financial concepts of portfolio management to trout conservation and can be utilized to establish larger stronghold populations. We use the 3-R framework to describe the portfolio of native trout: Representation (genetic, life history, and geographic diversity), Resilience (large populations and large habitat patches), and Redundancy (multiple populations within geographic units). Viewed from this framework, most of the more vulnerable trout taxa have portfolios that inadequately address Resilience, because past management has focused primarily on isolating populations to maintain genetic purity while underemphasizing life history diversity and stronghold development. As the portfolios of these trout are rebalanced with the addition of larger stronghold populations within reconnected stream networks, broader ecological functions and diverse life histories of the trout are restored. These watershed-scale stronghold projects also provide opportunities to protect a broader suite of native fishes within their ecosystems. This rewilding approach also is consistent with climate adaptation strategies that recognize the need for conservation actions to be planned and conducted at a landscape scale capable of providing resistance and resilience to habitats and target populations.

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### INTRODUCTION

Finding divergent perspectives within the field of conservation planning is nearly as old as conservation itself. As the first Chief of the U.S. Forest Service, Gifford Pinchot insisted on balanced conservation and responsible use while John Muir was focused more on strict preservation of larger landscapes. One side has tended to focus more on the conservation and management of places and species while the other looks towards the protection of the larger landscape and charismatic species within those systems. In 1998, Michael Soule and Reed Noss described these divergent perspectives and explored the latter themes in an essay entitled: “Rewilding and Biodiversity.” Their idea for rewilding was the restoration of large core protected areas based on the needs of large carnivores. They argued that these large predators were critical in maintaining the integrity of ecosystems and required large areas of intact habitat with connectivity between the core strongholds.

Now, 15 years after Soule and Noss’s seminal essay, global climate change has made the concept of ‘rewilding’ even more relevant. The rapid rate of environmental change due to global warming is causing a shift in conservation strategies from

preserving pristine landscapes to facilitating the adaptation of species and ecosystems to a changing environment (Groves et al. 2011; Staudinger et al. 2012). While adaptation strategies incorporate a preservation component, they also emphasize connectivity and recognize the potential for altered habitats to serve as corridors between core refugia. The climate adaptation approach recognizes the need for conservation actions to be planned and conducted at a landscape scale capable of sustaining ecological functions, not unlike the emphasis on large carnivores and keystone species advocated by Soule and Noss.

Although both rewilding and climate adaptation approaches are typically applied to terrestrial systems, the concepts of connecting core refugia in a landscape large enough to support ecological functions and keystone species can also be directly applied to aquatic systems. However, conservation planning at this scale for aquatic environments has lagged behind, in spite of the fact that many of the obstacles to large landscape conservation are common to both terrestrial and aquatic systems. One of the reasons for this is the dendritic nature of river systems and the nested nature of watersheds, which require that both the upstream and downstream influences of local

land use and surface and groundwater conditions be considered when developing conservation strategies (Vannote et al. 1980; Fagan 2002). Another challenge in landscape-scale aquatic conservation planning is the lack of comprehensive spatial data on many aquatic species (Williams et al. 2007), thus necessitating the use of surrogates.

In coldwater habitats, native trout provide a biological surrogate for overall aquatic integrity that can serve as the foundation for landscape-scale planning. Their function as a keystone species, serving as both the top predator in the aquatic system as well as prey for a range of terrestrial species (Varley and Schullery 1998; Koel et al. 2005) lends itself well to a rewilding approach. However, recovery programs developed pursuant to the Endangered Species Act for many trout species in the inland West and Southwest have encouraged a management approach that protects populations from invasive nonnative species by isolating them in small stream habitats at the expense of connectivity, diminishing their role as a keystone species. The Apache Trout Recovery Plan, for example, has as its primary recovery objective the establishment of “30 self-sustaining discrete populations” (U.S. Fish and Wildlife Service 2009). While this approach of constructing instream barriers and introducing Apache Trout, *Oncorhynchus apache*, into isolated stream reaches has helped to protect them from hybridization with nonnative Rainbow Trout, *O. mykiss*, it often has prevented Apache Trout from freely moving among the stream network, which historically had enabled them to avoid adverse stream conditions caused by disturbances such as drought or wildfire. Isolation of populations into these small stream reaches may further increase extinction risk by reducing their genetic diversity and ability to adapt to changing environmental conditions (Neville et al. 2006).

This management conundrum over the establishment of isolated trout populations and the trade-offs between protecting genetic integrity and the loss of migratory life history diversity and large interconnected habitat patches is well known (Fausch et al. 2006, 2009). More recently, climate change may be altering these management trade-offs as the isolated populations become more vulnerable to extirpation from climate change induced wildfires, drought, and flooding (Haak et al. 2010; Haak and Williams 2012). Because many of our native trout in the inland West and Southwest are declining and are listed pursuant to

the Endangered Species Act or are being considered for such listing, our ability to understand and quantify such trade-offs is important to managers (Figure 1).

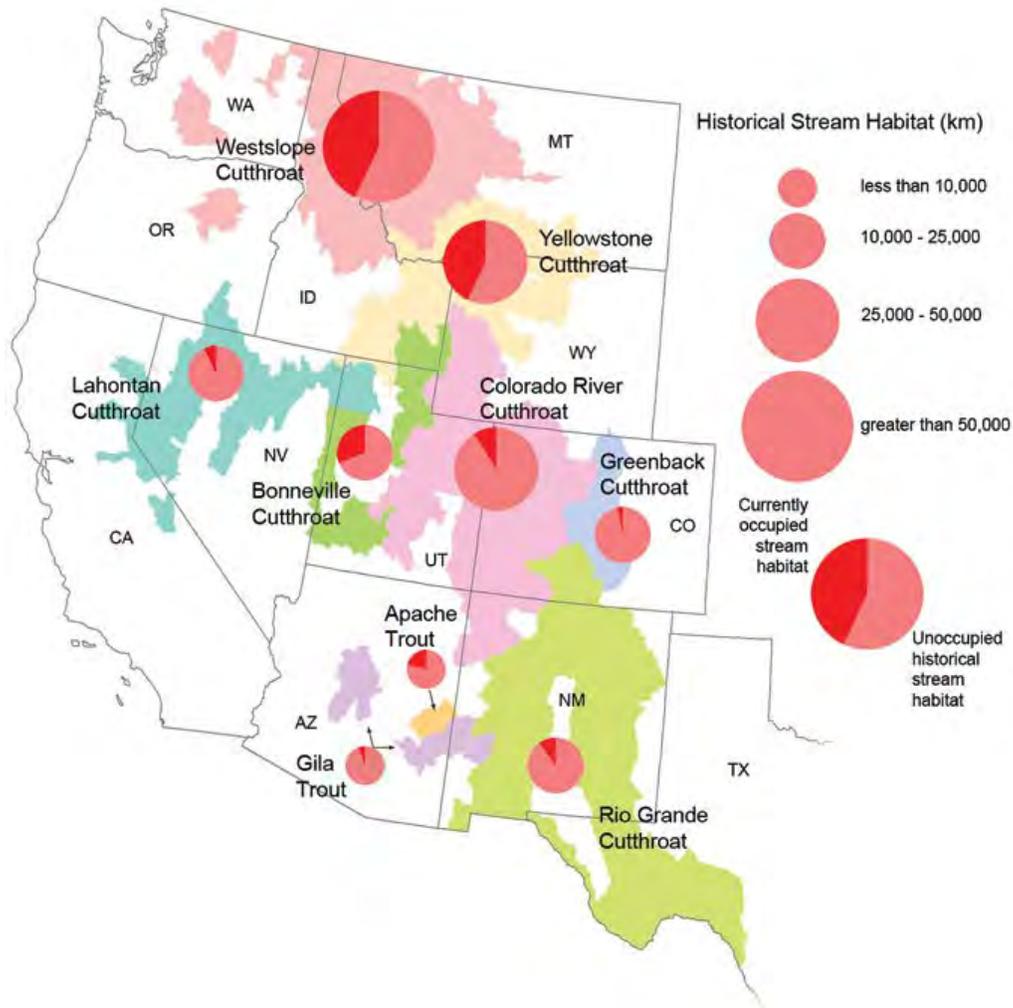
In this paper, we examine the degree to which management changes for native trout in the inland West and Southwest have favored isolation of populations and the reduction in their size compared to historical conditions. We argue that it is important to rebalance their management portfolios with the establishment of larger populations and migratory life histories. Establishment of larger populations will require a watershed-scale approach that will be difficult to achieve but also offers additional opportunities to protect larger fish communities and ecosystem processes (Williams et al. 2011). Rewilding native trout by restoring stronghold populations will increase their resistance and resilience to climate change induced threats such as the increasing frequency and intensity of wildfires, drought, and storm events (Dunham et al. 2002; Haak and Williams 2012).

## METHODS

In order to determine the needs and opportunities for reestablishing large stronghold populations of native trout in the inland West and Southwest, we conducted a portfolio analysis of the existing management conditions. We characterized conservation populations using the 3-R framework of Representation (genetic, life history, and geographic diversity), Resilience (large populations and large habitat patches), and Redundancy (multiple populations within geographic areas) (Shaffer and Stein 2000). The 3-R framework allows us to spatially locate and quantify remaining elements of population diversity. It has been adopted for recovery planning by the U.S. Fish and Wildlife Service (Carroll et al. 2006), and we have applied it previously to native trout populations (Haak and Williams 2012).

### The 3-R Framework

We have expanded on the conceptual approach used by U.S. Fish and Wildlife Service and have developed a spatially explicit, quantitative approach for analyzing the management portfolio of each trout and establishing place-based objectives linked to the 3-R's. We used a GIS (Geographic Information Systems) environment to compile and analyze the population-scale assessment data for nine native trout,



**Figure 1. Comparison of historical and current distributions for seven subspecies of Cutthroat Trout and Apache and Gila trout. The size of the pie chart associated with each trout indicates the amount of historically occupied stream habitat while the dark red “slice” represents the percent of historical habitat that is currently occupied. Data from state and federal agencies and is summarized at [www.tu.org/science/conservation-success-index](http://www.tu.org/science/conservation-success-index).**

including Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi*, Yellowstone Cutthroat Trout *O. c. bouvieri*, Bonneville Cutthroat Trout *O. c. utah*, Lahontan Cutthroat Trout *O. c. henshawi*, Colorado River Cutthroat Trout *O. c. pleuriticus*, Greenback Cutthroat Trout *O. c. stomias*, and Rio Grande Cutthroat Trout *O. c. virginalis* as well as Gila Trout *O. gilae* and Apache Trout *O. apache*. Figure 1 shows the historical ranges for each of these trout. The Cutthroat Trout subspecies occupied a variety of riverine and lacustrine habitats extending from Canada to Mexico while Gila and Apache trout were confined to much smaller drainages in Arizona and New Mexico. Our 3-R analysis for each of these fish uses the most recent

and best available rangewide population data. For Gila Trout, the population data are from 2010 and do not reflect the devastating effects of the 2012 Whitewater-Baldy Fire complex, which was the largest wildfire in known New Mexico history. The full effect of this wildfire on extant populations of Gila Trout is still being assessed (Dave Propst, unpublished data).

Table 1 describes the criteria used for determining whether or not a population contributes to one of the 3-R’s for that trout. For example, populations that are genetically pure contribute to the genetic integrity portion of Representation, while a population occupying at least 27.8 km of stream habitat in a drainage area of at least 10,000 ha in size contributes

**Table 1. Criteria for classifying populations of native trout within the 3-R framework and rangewide objectives for achieving a balanced portfolio. Thresholds for necessary stream length and habitat patch size are from Hilderbrand and Kershner (2000) and Dunham et al. (2002).**

3-R Element	Population Criteria	Portfolio Objectives
Representation 1. Genetic Integrity 2. Life history diversity 3. Geographic diversity	1. Genetically pure populations 2. Migratory populations 3. Peripheral populations	1. Genetically pure populations distributed across historical range. 2. Presence of all historical life history forms. 3. Historical peripheral habitat occupied
Resilience	Occupied stream habitat exceeds 27.8 km and habitat patch size exceeds 10,000 ha	Presence of large inter-connected populations within each major river basin of historical core habitat.
Redundancy	Effective population size of 500 adults and at least 90% genetically unaltered.	Multiple persistent populations present within each sub-basin historically occupied.

to Resilience (Hilderbrand and Kershner 2000; Dunham et al. 2002). Populations that meet the minimum criteria for population persistence (i.e., effective population size of 500 interbreeding adults (Hilderbrand and Kershner 2000)) and are at least 90% genetically unaltered, contribute to Redundancy. See Haak and Williams (2012) for a more detailed discussion of the 3-R analysis. We then summarized rangewide results for each trout according to the number of populations that contribute to each of the 3-R's. A single population may contribute to more than one element, depending on population-specific attributes (e.g., a migratory population in 50 km of stream habitat contributes to the life history diversity component of Representation as well as Resilience).

Table 1 also describes conservation objectives for each of the 3-R's that, if achieved, will contribute to a balanced portfolio. We do not use quantitative measures to determine the balance of a portfolio for each trout but instead apply the concept along a continuum. At one end of the continuum is an 'unbalanced' portfolio characterized by a few small isolated populations in a limited portion of the historical range while at the other end is a 'balanced' portfolio represented by the historical distribution of populations, their sizes, and diversity. Our objectives reflect the historical population and habitat diversity that once characterized inland native trout. We recognize that it may not be feasible to fully restore these trout to their historical conditions. However, we believe that, where possible, restoring the historical diversity that has sustained these fish for millennia improves the 'balance' of the portfolio and will increase the resilience of native trout to environmental change. The 3-R framework provides

a standardized approach for determining where each native trout falls on the continuum between a balanced and unbalanced portfolio.

## RESULTS

We applied the 3-R framework to seven subspecies of Cutthroat Trout and Gila Trout and Apache Trout (Table 2). A north-south gradient of portfolio diversity is evident with the northern subspecies of cutthroat trout (i.e., Westslope and Yellowstone) supporting the most balanced portfolios. The wet environment and large inter-connected river systems have enabled these fishes to retain relatively large migratory populations with over 80% of the currently occupied habitat supporting populations classified as resilient. The relatively low numbers for redundancy are indicative of the management conundrum of isolation versus connectivity with only about one-third of the conservation populations satisfying both the genetics and persistence criteria. The large migratory populations that contribute to redundancy tend to have compromised genetics while the genetically unaltered populations tend to be small and isolated. Overall, there is little difference in redundancy among taxa ranging from north to south.

Moving further south, we find that the percentage of habitat occupied by resilient populations of Bonneville Cutthroat Trout drops significantly from that of Westslope and Yellowstone Cutthroat Trout while genetic integrity, life history diversity and redundancy values are comparable. This may be partially attributable to the presence of a relatively high percentage (24%) of peripheral populations that

**Table 2. Conservation portfolio for species and subspecies of inland native trout. Percentage values represent percent of existing populations that support each element of diversity. INC = incomplete data. \*Portfolio results for Gila Trout are based on 2010 population data. The Baldy-Whitewater fire complex of 2012 has been devastating to Gila Trout recovery efforts. With only 15 populations, no resilience, and a limited geographic distribution, Gila Trout have been highly vulnerable to environmental disturbance such as a wildfire. The full effect of the wildfire on extant populations of Gila Trout is still being assessed at this time (Dave Propst, unpublished data).**

Species or Subspecies	Total Populations	Representation (% of all populations)			Resilient		Redundant (% of all populations)
		Genetic Integrity	Life History	Geographic Diversity	% of all populations	% of occupied habitat	
Westslope Cutthroat	687	63%	13%	7%	13%	88%	36%
Yellowstone Cutthroat	306	74%	22%	12%	20%	84%	32%
Bonneville Cutthroat	164	70%	15%	24%	16%	68%	33%
Colorado River Cutthroat	314	62%	4%	11%	3%	20%	21%
Greenback Cutthroat	34	INC.	20%	INC.	3%	17%	INC.
Rio Grande Cutthroat	121	74%	3%	7%	<1%	7%	20%
Lahontan Cutthroat	58	99%	19%	12%	12%	48%	22%
Gila Trout*	15	100%	0%	27%	0%	0%	33%
Apache Trout	31	100%	0%	45%	6%	21%	42%

tend to be found in smaller systems. Colorado River Cutthroat Trout and Rio Grande Cutthroat Trout have the weakest portfolios with little resilience, very few migratory populations and compromised genetics. Comparisons among species and subspecies should be viewed cautiously, however, as historically available habitat was significantly less for the southern taxa as compared to those from more wetter, northern climates.

The portfolios for the three species protected under the Endangered Species Act, (i.e. Lahontan Cutthroat, Gila, and Apache trout) are comprised of virtually all genetically pure populations as required by the Endangered Species Act. Of the three, Lahontan Cutthroat Trout have the strongest portfolio with the inclusion of several migratory populations, which improves resilience. Gila and Apache trout have virtually no resilience (as defined by the presence of large connected populations) but nearly one-half of the

Apache Trout populations satisfy both the persistence and genetics criteria for redundancy, thus protecting the species from extinction due to a disturbance event such as a wildfire that may result in local population losses.

## BALANCING PORTFOLIOS AND REWILDING NATIVE TROUT

Over the past several decades, native trout in the inland West and Southwest have experienced reductions in their ranges and populations. As their numbers and range have declined, habitats have become fragmented because of the construction of dams, road culverts, and stream diversions. In addition, some management strategies have encouraged isolation by constructing instream barriers to separate native trout from potentially hybridizing species.

Small, fragmented populations are at greater risk of extinction because of habitat limitations as well as demographic and environmental variability (Hilderbrand and Kershner 2000; Rieman and Allendorf 2001). Many populations of native trout have been relegated to smaller, upper elevation streams by degraded downstream habitat and advances from nonnative salmonids. Climate change is likely to exacerbate these threats by increasing environmental variability and reducing suitable water quality and quantity (Poff 2002; Poff et al. 2002). Populations occurring over larger geographic areas, or greater stream lengths, will be more stable and more resistant to local extinction.

Genetic and life history diversity help buffer populations against environmental changes by allowing populations to maintain broad suites of behavioral characteristics, increasing the likelihood that some individuals will be better adapted to novel conditions (Schlosser and Angermeier 1995). Restoring life history diversity, especially migratory forms, serves the dual purpose of maintaining genetic diversity and increasing the ability of a population to explore and colonize habitats that had recovered from earlier disturbance (Dunham et al. 2003; Colyer et al. 2005; Neville et al. 2006). Larger, migratory individuals also have higher fecundities and therefore are better able to resist outside stressors such as nonnative species.

Rewilding native trout favors a reversal of the trend from more fragmented habitats and isolated populations towards a more inter-connected stream network and larger populations. Rewilding helps to rebalance the portfolio of native trout that are lacking fluvial life histories and larger stronghold populations compared to historic conditions. Of course, reconnecting fragmented stream segments into a functional stream network and expanding native trout within this system is not without complications and risks. Chief among concerns are increased risks associated with invasions from nonnative species. Instream barriers may still be needed to separate natives from nonnatives and if new barrier construction is needed, the barrier is likely to be large and more costly because it will be located in a larger main-stem channel. On the other hand, a single larger downstream barrier may be able to replace several smaller upstream ones within a watershed.

## SOME REWILDING SNAPSHOTS

### Lahontan Cutthroat Trout: Maggie Creek Drainage

The Maggie Creek Watershed Restoration Project began in 1993 by the Bureau of Land Management, local ranchers, Newmont Mining Corporation, and TU to restore and reconnect 132 km of stream habitat in the northern Nevada drainage. Heavy livestock use had degraded riparian areas and poorly designed culverts had isolated Maggie Creek from upstream tributaries. Following improvements to livestock management and riparian fencing, habitat recovered. Beavers also were introduced, which further expanded riparian and meadow areas. In 2005, formerly impassible culverts were replaced by culverts of better design, creating one of the largest metapopulations for Lahontan Cutthroat Trout and restoring a migratory life history. Rather than fragmented habitats that supported smaller resident life history forms, larger migratory fish once again reach into tributary streams (Figure 2). The restored habitat, reconnection of stream habitat fragments, and restoration of migratory habitats all increase resistance and resilience to disturbances associated with climate change.



**Figure 2.** Large migratory-size Lahontan Cutthroat Trout now are frequently observed in the Maggie Creek drainage following replacement of culverts and reconnection of Maggie Creek with tributary streams.

## Rio Grande Cutthroat Trout: Rio Costilla

Restoring larger stronghold trout populations requires inter-connected stream habitat and watershed-scale management, which provide more habitat quantity and opportunities to conserve entire fish communities. In the Rio Costilla watershed of northern New Mexico, restoration of a Rio Grande Cutthroat Trout metapopulation is providing habitat for Longnose Dace *Rhinichthys cataractae*, Rio Grande Sucker *Catostomus plebius*, Rio Grande Chub *Gila pandora* and other native species. The project has been a 10-year collaborative effort between the Truchas Chapter of Trout Unlimited, the New Mexico Game and Fish Department, Carson National Forest, private landowners and nonprofit organizations. Upon completion of the project, migratory Rio Grande Cutthroat Trout will be restored to their historical habitat in 240 km of inter-connected streams and 25 lakes, making a significant contribution to a more balanced portfolio for this native trout. Habitat in the Rio Costilla drainage provides a great contrast to most of the smaller, drought-prone habitats that Rio Grande Cutthroat Trout currently occur in. In 2010 and 2011, the majority of streams containing Rio Grande Cutthroat Trout had baseflows of 1 cfs or less (Ziegler et al. 2013).

## Apache Trout: West Fork Black River

Apache Trout are listed as a threatened species pursuant to the Endangered Species Act. Most populations are very small (< 500 adult fish) and are located within headwater streams draining Mt. Baldy in eastern Arizona. The stream populations are vulnerable to drought, wildfires and ash flows that can occur during monsoon rains that follow wildfires in mid-summer. The Arizona Game and Fish Department in conjunction with the U.S. Forest Service and U.S. Fish and Wildlife Service are proposing to establish a large metapopulation for Apache Trout in the West Fork of the Black River in 22.5 km of inter-connected stream habitat. Currently only two of 31 populations are large enough to meet resilience criteria but none is as large as the West Fork Black River would be. This likely would be the first Apache Trout population with sufficient habitat to establish a fluvial life history.

## CONCLUSIONS

We contend that a more balanced portfolio representing a greater diversity of life history types, population sizes, and habitats is more conducive to the long-term survival of native trout and will help spread the risk in an increasingly warm and uncertain future (Haak and Williams 2012). In addition, establishment of large stronghold populations of native trout provides opportunities to conserve entire native fish communities and maintain critical ecosystem functions rather than protect single species in smaller places (Dauwalter et al. 2011; Williams et al. 2011). This large-scale restoration also promotes the broader ecological and keystone roles of native trout in their ecosystem. From an angler perspective, larger habitats and migratory life histories mean larger trout, which are not only valuable from a recreational perspective but have ecological value in resistance to nonnative predators and increased fecundity. In total, we describe these changes as a rewilding of native trout. Fortunately, many agencies are now working to reestablish larger stronghold populations or at least are beginning planning in this direction. We believe there is a strong case for this trend to grow in the future.

## ACKNOWLEDGEMENTS

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## REFERENCES

- Carroll, C., M. K. Phillips, C. A. Lopez-Gonzalez, and N. H. Schumaker. 2006. Defining recovery goals and strategies for endangered species: the wolf as a case study. *BioScience* 56:25-37.
- Colyer, W. T., R. H. Hilderbrand, and J. L. Kershner. 2005. Movements of fluvial Bonneville cutthroat trout in the Thomas Fork of the Bear River, Idaho-Wyoming. *North American Journal of Fisheries Management* 25:954-963.

- Dauwalter, D. C., J. S. Anderson, J. E. Williams, and J. R. Sedell. 2011. Identification and implementation of Native Fish Conservation Areas in the upper Colorado River Basin. *Fisheries* 36:278-288.
- Dunham, J. B., S. B. Adams, R. E. Schroeter, and D. C. Novinger. 2002. Alien invasions in aquatic ecosystems: toward an understanding of brook trout invasions and their potential impacts on inland cutthroat trout in western North America. *Reviews in Fish Biology and Fisheries* 12:373-391.
- Dunham, J. B., M. K. Young, R. E. Gresswell, and B. E. Rieman. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasion. *Forest Ecology and Management* 178:183-196.
- Fagan, W. F. 2002. Connectivity, fragmentation, and extinction risk in dendritic metapopulations. *Ecology* 83:3243-3249.
- Fausch, K. D., B. E. Rieman, M. K. Young, and J. B. Dunham. 2006. Strategies for conserving native salmonid populations at risk from nonnative fish invasions: tradeoffs in using barriers to upstream movement. U. S. D. A. Forest Service General Technical Report RMRS-GTR-174, Fort Collins, Colorado.
- Fausch, K. D., B. E. Rieman, J. B. Dunham, M. K. Young, and D. P. Peterson. 2009. Invasion versus isolation: trade-offs in managing native salmonids with barriers to upstream movement. *Conservation Biology* 23:859-870.
- Groves, C. R., E. T. Game, M. G. Anderson, M. Cross, C. Enquist, Z. Ferdana, E. Girvetz, A. Gondor, K. R. Hall, J. Higgins, R. Marshall, K. Popper, S. Schill, and S. Shafer. 2012. Incorporating climate change into systematic conservation planning. *Biodiversity Conservation* 21:1651-1671.
- Haak, A. L. and J. E. Williams. 2012. Spreading the risk: native trout management in a warmer and less certain future. *North American Journal of Fisheries Management* 32:387-401.
- Haak, A. L., J. E. Williams, D. Isaak, A. Todd, C. C. Muhlfeld, J. L. Kershner, R. E. Gresswell, S. W. Hostetler, and H. M. Neville. 2010. The potential influence of changing climate on the persistence of salmonids in the Inland West. USGS Open-File Report 2010-1236.
- Hilderbrand, R. H. and J. L. Kershner. 2000. Conserving inland cutthroat trout in small streams: how much habitat is enough? *North American Journal of Fisheries Management* 20:513-520.
- Koel, T. M., P. E. Bigelow, P. D. Doepke, B. D. Ertel, and D. L. Mahony. 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. *Fisheries* 30:10-19.
- Neville, H. M., J. B. Dunham, and M. M. Peacock. 2006. Landscape attributes and life history variability shape genetic structure of trout populations in a stream network. *Landscape Ecology* 21:901-916.
- Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions Royal Society of London* 360:1497-1510.
- Poff, N. L., M. M. Brinson, and J. W. Day. 2002. Aquatic ecosystems and global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Pew Center on Global Climate Change, Arlington, Virginia.
- Rieman, B. E. and F. W. Allendorf. 2001. Effective population size and genetic conservation criteria for bull trout. *North American Journal of Fisheries Management* 21:756-764.
- Schlosser, I. J. and P. L. Angermeier. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. Pages 392-401 in J. L. Nielsen, editor. *Evolution and the aquatic ecosystem: defining unique units in population conservation*. American Fisheries Society Symposium 17, Bethesda, Maryland.
- Shaffer, M. L. and B. A. Stein. 2000. Safeguarding our Precious Heritage. In: B.A. Stein, L.S. Kutner, and J.S. Adams (eds). *Precious Heritage: the Status of Biodiversity in the United States*. Oxford University Press, New York.
- Staudinger, M. D. N. B. Grimm, A. Staudt, S. L. Carter, F. S. Chapin III, P. Kareiva, M. Ruckelshaus, and B. A. Stein. 2012. Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services: Technical Input to the 2013 National Climate Assessment. Cooperative Report to the 2013 National Climate Assessment. 296 p. Available at: <http://assessment.globalchange.gov>
- Soule, M. and R. Noss. 1998. Rewilding and biodiversity: complimentary goals for continental conservation. *Wild Earth*. Fall 1998.
- U.S. Fish and Wildlife Service. 2009. Apache trout recovery plan. Second revision. USFWS. Albuquerque, New Mexico.
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130-137.
- Varley, J. D. and P. Schullery. 1998. *Yellowstone Fishes: Ecology, History, and Angling in the Park*. Stackpole Books. Mechanicsburg, Pennsylvania.
- Williams, J. E., A. L. Haak, N. G. Gillespie and W. T. Colyer. 2007. The Conservation Success Index: synthesizing and communicating salmonid condition and management need. *Fisheries* 32:477-492.

Williams, J. E., R. N. Williams, R. F. Thurow, L. Elwell, D. P. Philipp, F. A. Harris, J. L. Kershner, P. J. Martinez, D. Miller, G. H. Reeves, C. A. Frissell, and J. R. Sedell. 2011. Native Fish Conservation Areas: a vision for large-scale conservation of native fish communities. *Fisheries* 36:267-277.

Ziegler, M. P., A. S. Todd, and C. A. Caldwell. 2013. Water temperature and baseflow discharge of streams throughout the range of Rio Grande cutthroat trout in Colorado and New Mexico—2010 and 2011. USGS Open-File Report 2013-1051.

## RESTORING TROUT HABITAT IN DIFFICULT TO ACCESS AREAS USING MOBILE WOOD ADDITIONS

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**Abstract**—The removal of wood from river channels was once a common practice in an effort to reduce flooding and improve transport of timber and other products. River restoration practitioners are increasingly adding large wood into rivers to restore natural channel characteristics and aquatic habitat degraded by these past practices. Most restoration projects use wood in a static manner by anchoring trees and rootwads in place. The use of mobile wood additions—a restoration approach where added wood is allowed to migrate naturally through the channel at high flows—is being pioneered on Nash Stream in northern New Hampshire. While both methods are effective, our implementation and subsequent monitoring shows that mobile wood more closely mimics natural recruitment to, and transport and accumulation within, river systems, and provides a cost-effective method of increasing wood densities in hard-to-reach locations or with limited stands of riparian trees.

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### INTRODUCTION

Wood is a common component in many river systems throughout the world, with forests covering almost one third of the Earth's land surface (Montgomery et al. 2003). Large woody material (LWM) is often the most important structural element in river channels, creating the complex flow hydraulics that can alter channel morphology, increase habitat diversity, and lead to significant sediment storage (Bilby and Ward 1991; Gurnell et al. 2002; Abbe and Montgomery 2003). Large wood within the context of habitat studies on rivers is commonly defined as logs, with or without attached roots,  $\geq 10$  cm in diameter and  $\geq 2.0$  m in length (Schuett-Hames et al. 1999).

The geomorphic function of wood in rivers varies with channel size. In steep headwater streams, individual channel-spanning logs can trap smaller wood, detritus, and sediment to form step-pools that define the channel morphology (Montgomery and Buffington 1997). In mid-gradient rivers, LWM may accumulate into various types of log jams that partly or wholly block the channel and are important for forming and altering the spacing of point bars, meander bends, and other channel features (Abbe and Montgomery 1996). In large, low gradient river systems, rafts of LWM can create hydraulic constrictions that elevate water surfaces upstream,

increase access to floodplains, and create braided or anastomosing channels (Keller and Swanson 1979; Gurnell et al. 2002).

Wood also plays a critical role, both directly and indirectly, in forming and sustaining the habitat necessary for many aquatic organisms (Naiman et al. 2002). Streams with wood in the channel generally have more complex physical habitat (Benke and Wallace 2003), a greater abundance and richness of macroinvertebrates (Bond et al. 2006), and higher fish populations (Flebbe 1999).

Increasingly, LWM is becoming an important component of stream restoration projects to replenish wood that was previously removed by humans for various reasons. The use of wood in restoration projects increases channel complexity and habitat diversity and is important for improving and reconnecting habitat for salmonids and other species of concern (Kail et al. 2007). Wood also has the potential to be used for infrastructure protection such as on-bank stabilization projects.

### STUDY SITE

Nash Stream is a fourth order river, with a watershed area of 115 km<sup>2</sup>, located in northern New Hampshire (Figure 1) and drains into the Upper Ammonoosuc River before reaching the Connecticut

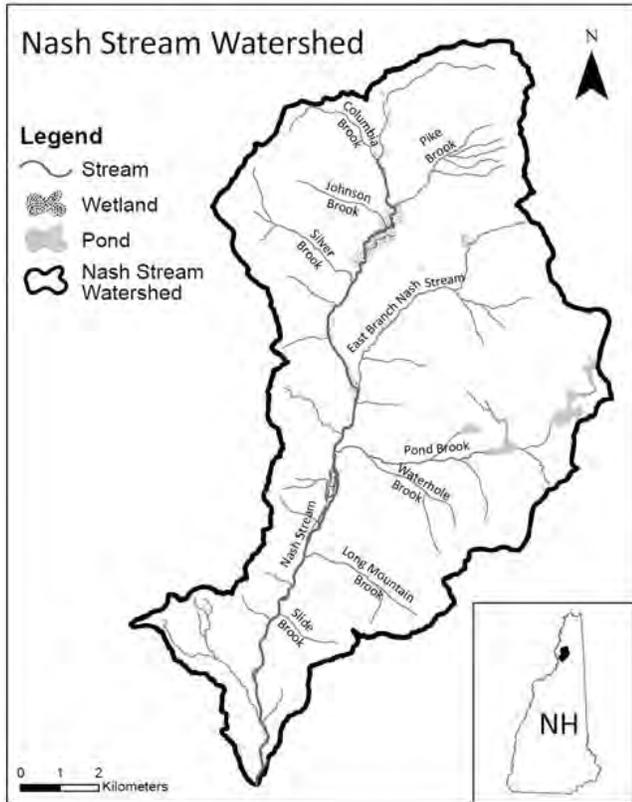


Figure 1. Nash Stream Watershed study area.

River. We conducted our field study in the 15.1-km reach located downstream (south) of the confluence with Silver Brook. Approximately 90% of the watershed is located within the state-owned Nash Stream Forest, and is characterized by glaciated terrain and a mixed conifer and deciduous forest. This provided an appropriate setting for the field study, because the lack of infrastructure greatly simplified the permitting process and allowed for the movement of unanchored wood with little concern for property damage.

The salmonid species native to Nash Stream are Brook Trout *Salvelinus fontinalis* and Atlantic Salmon *Salmo salar*. However, Atlantic Salmon were extirpated from the watershed in the early 1800s due to overfishing, water pollution, and downstream dam construction on the Connecticut River (Moffitt et al. 1982).

Much of the watershed has been a working forest since the 1850s. In 1900, a dam was completed at Nash Bog to provide headwater storage for driving pulp logs during the spring snowmelt to a nearby mill in Groveton, New Hampshire (NHDRED 1995). The log drives ended in the 1930s, but the timber crib

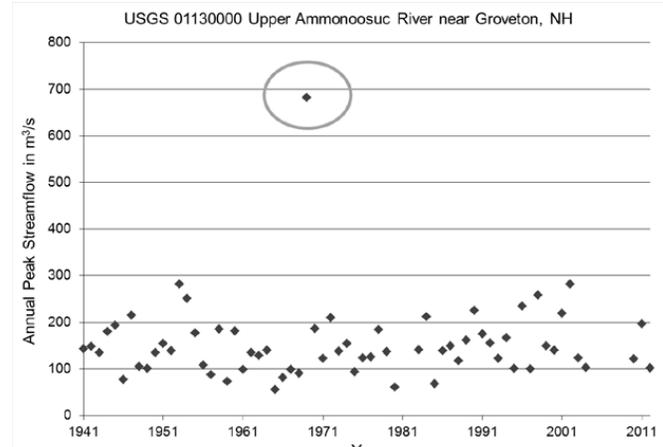


Figure 2. Annual peak streamflow at the USGS Upper Ammonoosuc River gage. The maximum discharge of 682 m<sup>3</sup>/s (circled) resulted from a dam break on Nash Stream.

dam and impoundment at Nash Bog were left intact for recreational use. The dam was 8.9 m high and held back a 90.2-ha impoundment. On May 20, 1969, the dam failed catastrophically following a heavy rainstorm on the remaining snowpack, and was never rebuilt.

The dam failure produced the highest flow ever recorded at the U.S. Geological Service gage on the Upper Ammonoosuc River (USGS 2013a) located 300 m downstream of the Nash Stream confluence (Figure 2). The estimated peak discharge at the USGS gage from the dam break was 682 m<sup>3</sup>/s, a value that is more than two times greater than any other reported peak at this gage and approximately four times greater than the estimated 500-yr recurrence interval peak flow (167 m<sup>3</sup>/s) for Nash Stream (USGS 2013b).

The magnitude of the flood resulted in significant morphological and habitat impacts to Nash Stream including widening of the channel and loss of pools and riparian cover. After the flood, the impacts were further compounded when the channel was straightened and berms were created to reduce future flooding and rebuild the nearby logging road that parallels the stream. In places, the flood stripped bare a swath approximately 100 m wide and more than five times the bank-full channel width. Much of the uprooted riparian forest was deposited up to several kilometers downstream on the floodplain of the Upper Ammonoosuc River.

Many of the bars deposited by the floodwaters consist of boulders up to 2 m in diameter and continue to severely limit lateral channel adjustment. The bars

contain limited fines and organic material and are vertically disconnected from the present river channel due to their height above the streambed. As a result, revegetation rates on these bars are very slow which limits canopy cover over, and wood recruitment into, the stream several decades after the flood.

Given the stream's limited capacity for self-adjustment, Trout Unlimited, Inc. and the New Hampshire Fish and Game Department formed a partnership in 2005 to undertake its restoration. A geomorphic assessment of Nash Stream identified numerous potential treatments for improving geomorphic and habitat function such as boulder clusters and engineered log jams, but many of the restoration options were not viable due to remoteness from the haul road and poor access for heavy machinery. This paper describes a large wood replenishment project that is using unanchored, mobile wood additions (MWA) in which trees with attached roots are strategically placed in specific locations and elevations relative to the bank-full stage.

Because of the uncertainties in the mode, distance, frequency, and benefits of unanchored wood movement, we conducted a study of large wood transport and accumulation at Nash Stream. While a primary long-term objective of our research is to understand how MWA are influencing channel morphology and aquatic habitat for a range of salmonid species, here we specifically report on the general flow conditions during which MWA moved in the first 2 years following implementation, the factors influencing wood movement, and the most likely locations of wood accumulation.

## METHODS

Trees for the MWA were harvested outside the riparian zone near the road or along temporary stream access routes. A 25,000-kg excavator (John Deere 240D) was used to knock over live, whole trees, keeping the rootwads attached, and transport them to locations on the stream where easy access was available upstream of difficult to reach target reaches. Two uniquely numbered, blue anodized aluminum forestry tags were fastened on each tree at breast height with 76-mm aluminum nails. The excavator then placed the trees in the channel oriented parallel to flow and with roots facing upstream. The diameter at breast height (DBH), species, elevation (relative to bank-full), and spatial coordinates were then recorded for each tree placed in the stream.

Three groups of MWA, totaling 48 trees, were installed at five locations along 3.9 km of Nash Stream in 2010 and 2011. The 24 trees of Group 1 were installed in September 2010. The 12 trees of Group 2 were installed in October 2010. The 12 trees of Group 3 were installed in October 2011 (Table 1).

The trees ranged in size from 5 to 34 cm DBH (Figure 3); most fit the definition of large wood by Schuett-Hames et al. (1999). Small diameter trees were intentionally selected for insertion because the primary objective was to ensure their transport to downstream target reaches and avoid overloading the channel with large trees that might impede transport or encourage beaver activity that would preclude or limit the transport of the tagged trees during the study.

**Table 1. Count and location of MWA placements at Nash Stream. River km = river kilometer as measured from the confluence with the Upper Ammonoosuc River. Grp = Group. Bkf = bank-full. River km 14.2<sup>a</sup> = bridge at river kilometer 14.37. River km 14.21<sup>b</sup> = boulder bar at river kilometer 14.20.**

Location	Number of trees					
	Grp. 1	Grp. 2	Grp. 3	At Bkf	< Bkf	Water
14.2 <sup>a</sup>	1	1	1	0	0	3
14.2 <sup>b</sup>	15	4	3	7	4	11
12.4	5	5	5	2	8	5
10.8	3	2	2	0	0	7
10.3	0	0	1	0	0	1

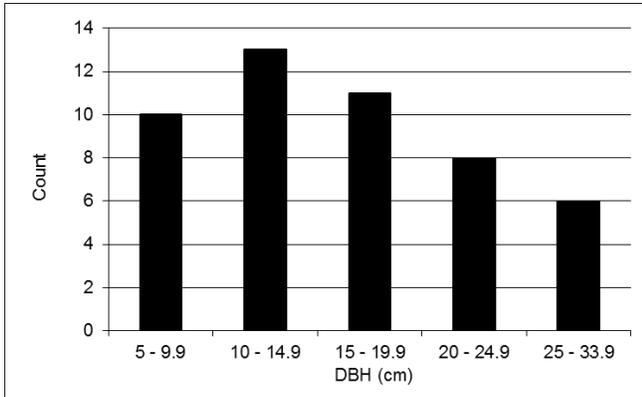


Figure 3. Size range of mobile wood additions to Nash Stream, 2010 and 2011.

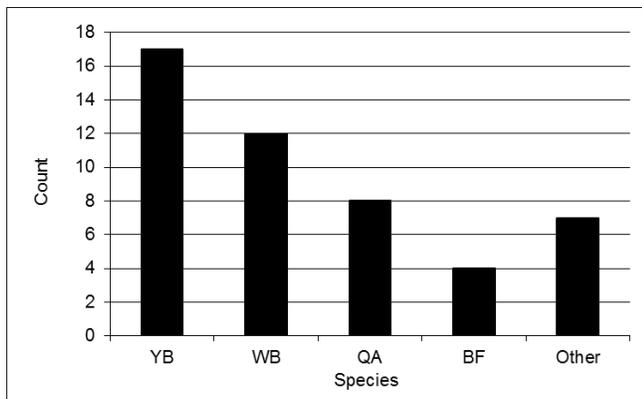


Figure 4. Tree species added to Nash Stream included Yellow birch *Betula alleghaniensis* (YB), White birch *Betula papyrifera* (WB), Quaking aspen *Populus tremuloides* (QA), Balsam fir *Abies balsamea* (BF), and five other species (Other.)

A total of nine tree species were used. The four primary species in descending order of prevalence were: Yellow birch *Betula alleghaniensis* (YB), White birch *Betula papyrifera* (WB), Quaking aspen *Populus tremuloides* (QA), and Balsam fir *Abies balsamea* (BF). Five additional species (Other) were also used: Red maple *Acer rubrum*, Sugar maple *Acer saccharum*, Red spruce *Picea rubens*, Black cherry *Prunus serotina* and Black willow *Salix nigra* (Figure 4).

The trees were deployed at various elevations relative to bank-full to promote release and downstream transport at different flow stages (Figure 5). Twenty-seven trees were placed in the water, 12 were placed on bars at the channel margin, and nine were inserted at bank-full elevation in the active channel.

During three walks of Nash Stream from the upstream-most insertion point to its confluence with



Figure 5. Photo showing MWA were placed at various elevations in Nash Stream to promote transport at different stages during high flow events. Photo by authors.

the Upper Ammonoosuc River between 7 October 2010 and 28 August 2012, in which all observable wood in the bankfull channel and adjacent floodplain was carefully checked for aluminum tags, we recorded the spatial coordinates, elevation relative to bank-full, orientation of roots relative to the bank-full flow direction, and basic geomorphic attributes of the location of each tagged tree during each of the four field visits. We then reviewed the streamflow data from the USGS Upper Ammonoosuc River gage to make an assumption regarding the discharge likely responsible for the transport of the tagged trees.

Based on our experience with the Group 1 trees, in which we are certain that a near bank-full flow moved most of the trees 3 weeks after they were placed into Nash Stream, we assumed that Group 2 and Group 3 trees moved in the first near bank-full or greater event after they were placed into Nash Stream. Whenever possible the field visits were conducted subsequent to known high flow events to determine if the tagged trees moved during those events. Considerable ice forms on Nash Stream during the winter; it is neither possible to locate and positively identify tagged trees during periods of ice nor determine what role ice has played in tree movement.

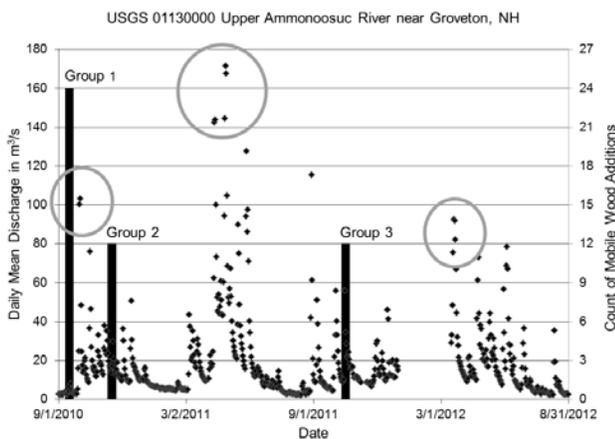
All streamflow values reported in the results are taken from measurements recorded at the USGS Upper Ammonoosuc gage; Nash Stream is un-gaged. The 2-year recurrence interval peak flow (PK2) was derived from USGS StreamStats (USGS 2013b) and is used in this paper as a surrogate for the bank-full

discharge. The PK2 discharge where the wood was installed is approximately 17% of the PK2 streamflow at the USGS gage. Drainage area where the MWA were installed is approximately 10% of the drainage area at the gage (USGS 2013b).

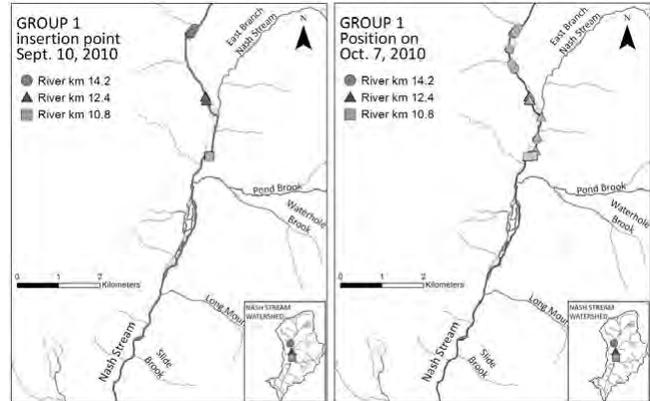
## RESULTS

During the study period, the Upper Ammonoosuc River gauge recorded five near bank-full flow events of greater than  $90 \text{ m}^3/\text{s}$  (USGS 2013a). The maximum discharge was  $171 \text{ m}^3/\text{s}$ . All groups moved at or near the PK2 discharge as measured at the USGS Upper Ammonoosuc River gage ( $140 \text{ m}^3/\text{s}$ ; Figure 6). Estimated PK2 streamflow in the vicinity of where the wood was installed is approximately  $23 \text{ m}^3/\text{s}$  (USGS 2013b).

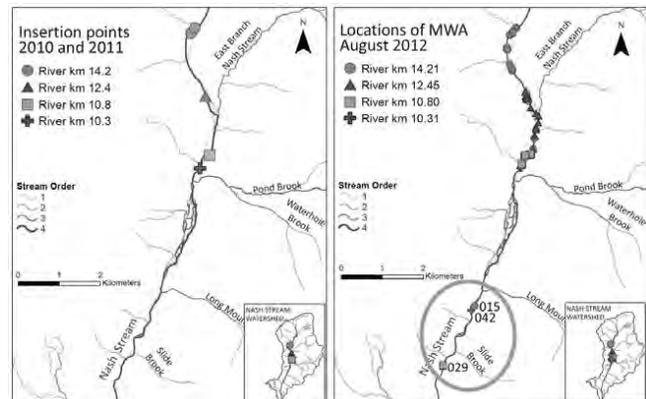
Three weeks after Group 1 trees were placed into Nash Stream, a  $103 \text{ m}^3/\text{s}$  discharge from a very large rainfall event on October 2, 2010, transported most of the trees. Group 2 moved in mid-April 2011 at a discharge of about  $171 \text{ m}^3/\text{s}$ . Group 3 moved in March 2012 at  $93 \text{ m}^3/\text{s}$ . Much of the wood from Group 1 clustered in just a few locations (Figure 7). Similar transport and accumulation patterns were observed for Groups 2 and 3; large discharge events transported MWA downstream where it tended to accumulate in clusters at valley constrictions or expansions and changes in channel slope or planform, such as at meander bends downstream of straightened channel segments.



**Figure 6.** Daily mean discharges for the Upper Ammonoosuc gage. Flows that transported each group of mobile wood are circled.



**Figure 7.** Locations of tagged trees in Nash Stream prior to and after a  $103\text{-m}^3/\text{s}$  discharge.



**Figure 8.** Locations of all three groups of mobile wood in Nash Stream prior to and after transport by high flows. Three trees (circled) moved considerable distances.

Monitoring at the end of the study period in August 2012 showed that 92% of the MWA had dispersed from their original insertion points. Some were transported considerable distances; one 7.6-cm White birch moved 7.8 km (Figure 8). Only 6% of the trees moved more than once; none moved more than twice.

There were several apparent trends in the average distance transported and other factors. The MWA tended to travel farther during higher discharges (Figure 9); however, there was a lot of variability in the distances transported within each Group. The range of transport values was 0.00-2.95 km, 0.02-3.23 km, and 0.00-4.07 km for Groups 1, 2 and 3, respectively. Smaller diameter trees tended to move farther than larger trees (Figure 10).

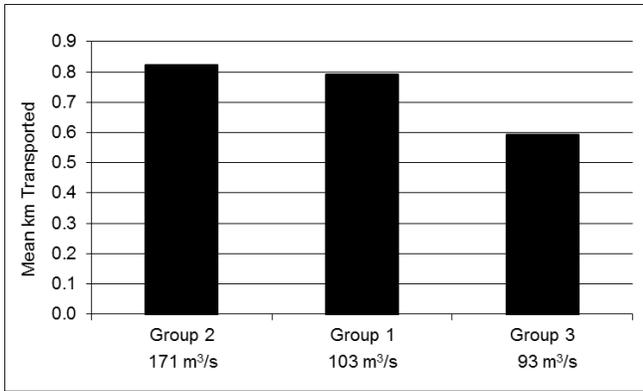


Figure 9. Mean distance that MWA were transported in Nash Stream and daily mean discharge as measured at the Upper Ammonoosuc USGS gage.

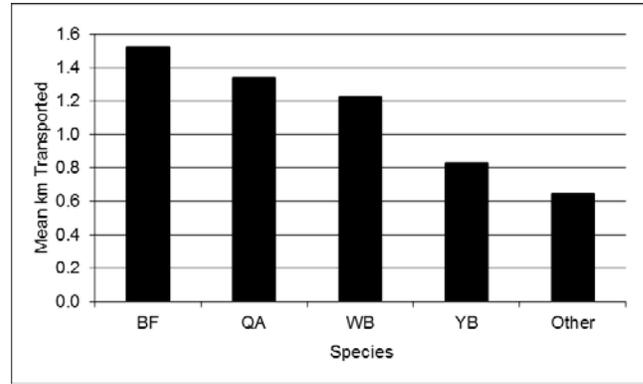


Figure 11. Mean distance trees were transported in Nash Stream and tree species.

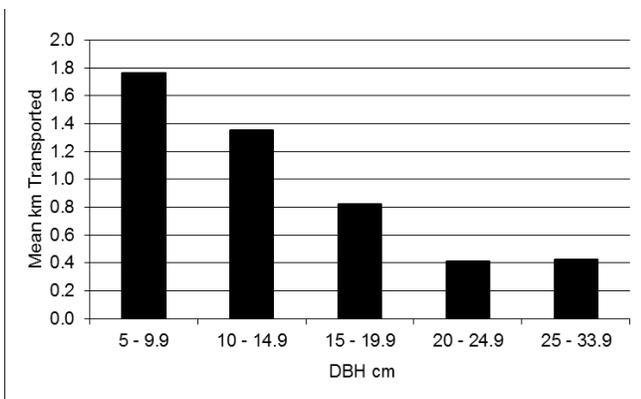


Figure 10. Mean distance trees were transported in Nash Stream and diameter at breast height of the trees.

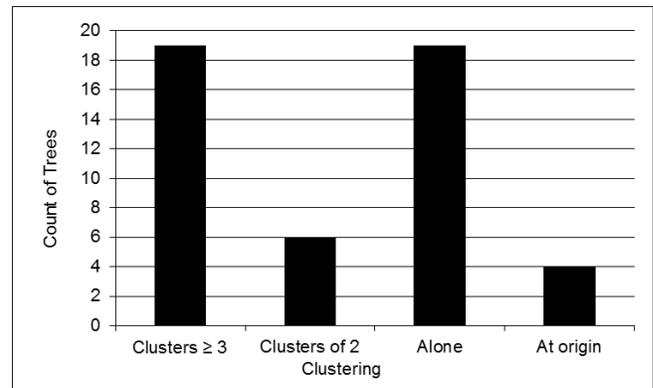


Figure 12. Post-transport clustering of MWA in Nash Stream by end of study period.

We noted that wood density (as reported in Kretschmann 2010) appeared to influence mean transport distance of the trees. Of the four differentiated species, mean transport distance decreased as tree density increased (Figure 11).

Tree elevation relative to bank-full stage at the insertion point was also considered as a possible factor affecting distance transported, but we noted that insertion elevation had no obvious influence on transport distance given that all flows assumed to be responsible for tree movement were at or near the bank-full stage.

By the end of the study period, about half of the trees were deposited with the roots oriented upstream. Nearly half of the trees deposited at bank-full elevation; the rest deposited in the active channel below the bank-full elevation. Slightly more than half

of the trees deposited in clusters of two or more while four trees did not move during this study (Figure 12).

Most of the MWA that accumulated in clusters were found in jams at the apex of a bar or on a meander bend. One jam contained eight tagged trees along with additional naturally recruited material and formed at a location where no wood accumulations were present prior to the deployment of MWA (Figure 13). The jam appears to be stable; several key members are buried parallel to flow in former high flow chutes, and new vegetation is established on some of the earliest material recruited. The LWM comprising the jam is providing cover for a newly-formed adjacent lateral pool. In addition, a large gravel bar forming upstream has narrowed the low flow channel, flow complexity has increased in the general vicinity of the wood jam, and the substrate particle sizes are better sorted.



**Figure 13. Photo of a meander jam in Nash Stream created by accumulated MWA and additional naturally recruited material. Photo by authors.**

## DISCUSSION

These two years of data collected on MWA movements allow for preliminary conclusions regarding the efficacy of MWA as a restoration treatment. We found that MWA work; river systems can transport LWM from accessible insertion points to target restoration reaches where wood accumulations increase channel complexity and create salmonid habitat in hard-to-access locations. The initial transport of the whole trees placed into the bank-full channel was during bank-full or near bank-full flow events, likely because water depth was slightly greater than the buoyant depth of the trees, conditions necessary for the transport of wood (Braudrick and Grant 2001). We suspect that deploying wood at different elevations favorably affects the timing of transport during the rising limb of a flood hydrograph and allows for a greater amount of wood loading at each insertion point.

The distance of wood transport appears to be influenced by several factors including discharge, log diameter, and tree species (density). We found transport distance of the trees used in the MWA was inversely related to tree density. Braudrick and Grant (2000) also reported that log density is an important factor in the transport of wood in rivers with higher density logs requiring a greater water depth to become transported. The shorter transport distances and greater water depth needed to transport higher density tree species may be related to the greater likelihood

that higher density wood will encounter frictional resistance from various channel features such as the streambed (Abbe and Montgomery 2003).

Most trees only move once before becoming lodged in a stable position or clustering in a large meander or apex jam, as occurs naturally (Abbe and Montgomery 2003), or in flume experiments (Braudrick and Grant 2001). We believe that these retention points can be anticipated. Pairs or larger clusters of MWA, in particular, tend to accumulate where there is a marked change in channel morphology. This particularly important attribute of mobile wood transport may allow restoration practitioners to restore functional LWM without the higher costs of constructing specific log structures. It may also provide practitioners some confidence about the likely fate of the wood installed.

In addition, isolated MWA trees that are not part of a larger cluster, result in smaller, and yet still beneficial, effects on channel complexity and salmonid habitat. They also increase diversity of flow regimes and provide some sorting of substrate when they are partly or wholly submerged. When resting at the bank-full elevation, they can provide cover for pre-existing deep water habitat or create the potential to recruit additional LWM. Isolated MWA also have the potential to be mobilized during future high flow events and transported downstream to become part of a larger cluster.

We believe these findings have several practical applications. Knowing that wood with differing densities tends to move different distances before being deposited in a stable position, lower density trees like Balsam fir might be the species of choice if the target restoration area is far from the insertion point whereas higher density wood such as White birch might be a better choice if the target area is close by. Furthermore, given that wood placed at lower elevation in the channel likely moves before wood staged closer to the bank-full elevation, higher density wood could be placed lower in the channel and lower density wood closer to the bank-full stage if the desire is to form log jams close to the insertion point. In contrast, if the restoration objective is to have isolated pieces of wood distributed over a longer length of stream, then placing lower density wood lower in the channel would be more effective as that would more likely permit the first pieces to move farther downstream without being retained by higher density

wood that would move later during the high flow event given their position closer to bank-full.

Wood insertion points can be prioritized based on the knowledge that wood tends to accumulate in areas of rapid geomorphic change such as at valley constrictions, slope breaks, and changes in channel planform. Careful geomorphic mapping can be used to identify areas where wood is likely to accumulate and then decisions made regarding the best location to insert trees as part of a MWA restoration project. While adding wood anywhere on streams where wood has been removed by past human activities is likely to be beneficial, careful study of geomorphic conditions and the patterns of wood movement and accumulation will lead to even greater benefits with less effort and a lower likelihood of unintended damage to adjacent infrastructure.

We suggest that wood used for restoration need not always be anchored, that its movements are largely predictable and stable after the initial transport, and that mobile wood additions are a cost effective tool to create habitat and channel complexity. Our results are consistent with a passive approach to in-stream wood restoration in which it is the process of wood recruitment that is restored (Kali et al. 2007). While MWA is a treatment best suited to watersheds with limited infrastructure like Nash Stream, further research into the patterns of wood movement and accumulation may increase the confidence of restoration practitioners to attempt MWA in a wider array of settings and environments.

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## REFERENCES

- Abbe, T. B., and D. R. Montgomery. 1996. Interaction of large woody debris, channel hydraulics and habitat formation in large rivers. *Regulated Rivers Research & Management* 12:201–221.
- Abbe, T. B., and D. R. Montgomery. 2003. Patterns and processes of wood debris accumulation in the Queets river basin, Washington. *Geomorphology* 51:81–107.
- Benke, A. C., and J. B. Wallace. 2003. Influence of wood on invertebrate communities in streams and rivers. Pages 149–177 in Gregory, S. V., K. L. Boyer, and A. M. Gurnell, editors. *The ecology and management of wood in world rivers*. American Fisheries Society Symposium 37, Bethesda, Maryland.
- Bilby, R. E., and J. W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Sciences* 48:2499–2508.
- Bond, N. R., S. Sabater, A. Glaister, S. Roberts, and K. Vanderkruk. 2006. Colonisation of introduced timber by algae and invertebrates, and its potential role in aquatic ecosystem restoration. *Hydrobiologia* 556:303–316.
- Braudrick, C. A., and G. E. Grant. 2000. When do logs move in rivers? *Water Resources Research* 36:571–583.
- Braudrick, C.A., and G. E. Grant. 2001. Transport and deposition of large woody debris in streams: a flume experiment. *Geomorphology* 41:263–283.
- Flebbe, P.A. 1999. Trout use of woody debris and habitat in Wine Spring Creek, North Carolina. *Forest Ecology and Management* 114:367–376.
- Gurnell, A. M., H. Piégay, F. J. Swanson and S. V. Gregory. 2002. Large wood and fluvial processes. *Freshwater Biology* 47:601–619.
- Kail, J., D. Hering, S. Muhar, M. Gerhard, and S. Preis. 2007. The use of large wood in stream restoration: experiences from 50 projects in Germany and Austria. *Journal of Applied Ecology* 44:1145–1155.

- Keller, E. A., and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. *Earth Surface Processes* 4:361–380.
- Kretschmann, D. E. 2010. Mechanical properties of wood. Chapter 5 in Ross, R. J., editor. *Wood handbook: wood as an engineering material*. General Technical Report FPL-GTR-190. U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin.
- Moffitt, C. M., B. Kynard, S. Rideout. 1982. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. *Fisheries* 7(6):2–11.
- Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin* 109:596–611.
- Montgomery, D. R., B. D. Collins, J. M. Buffington, and T. B. Abbe. 2003. Geomorphic Effects of Wood in Rivers. Pages 21–47 in Gregory, S. V., K. L. Boyer, and A. M. Gurnell, editors. *The ecology and management of wood in world rivers*. American Fisheries Society Symposium 37, Bethesda, Maryland.
- Naiman, R. J., E. V. Balian, K. K. Bartz, R. E. Bilby, and J. J. Latterell. 2002. Dead wood dynamics in stream ecosystems. Pages 23–48 in *Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests*. USDA Forest Service General Technical Report PSW-GTR-181, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.
- NHDRED (New Hampshire Department of Resources and Economic Development). 1995. *Nash Stream Forest Management Plan*. NHDRED, Concord, New Hampshire.
- Schuett-Hames, D., A. E. Pleus, J. Ward, M. Fox, and J. Light. 1999. *TFW monitoring program method manual for the large woody debris survey*. NW Indian Fisheries Commission Technical Report TFW-AM9-99-004.
- USGS (U.S. Geological Survey). 2013a. *Peak Streamflow for New Hampshire*. [http://nwis.waterdata.usgs.gov/nh/nwis/peak/?site\\_no=01130000&agency\\_cd=USGS](http://nwis.waterdata.usgs.gov/nh/nwis/peak/?site_no=01130000&agency_cd=USGS). Accessed July 30, 2013.
- USGS (U.S. Geological Survey). 2013b. *New Hampshire StreamStats*. [http://water.usgs.gov/osw/streamstats/new\\_hampshire.html](http://water.usgs.gov/osw/streamstats/new_hampshire.html). Accessed July 30, 2013.

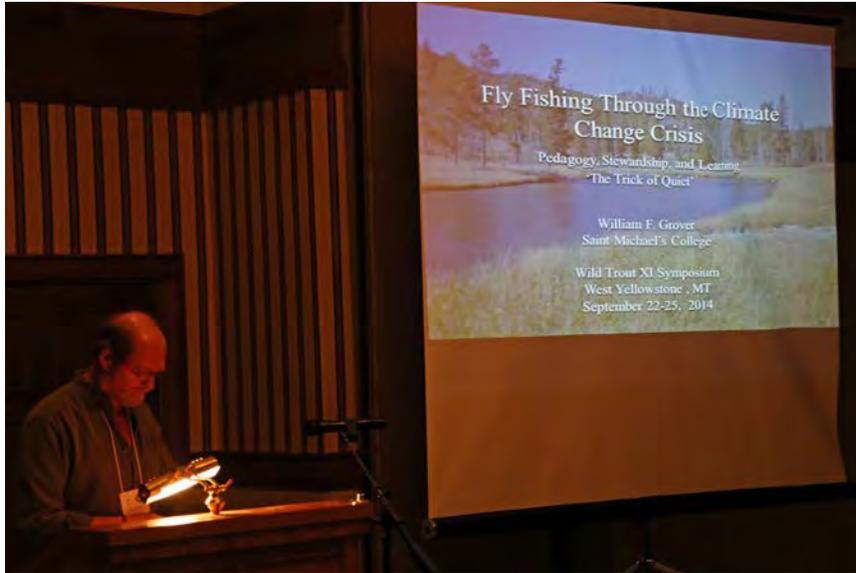


Photo courtesy of Eric Stark.

# Session 2

## Wild Trout Socioeconomics





## LOOKING BACK AT WILD TROUT: THE HISTORY OF “WILD”

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As the Wild Trout Symposium prepares to celebrate its fortieth year in 2014, it offers us a nice time to look back at the history of wild trout. At the first symposium, two fisheries biologists attacked wild trout management as a standalone management technique, arguing that ending catchable-sized trout stocking entirely was an idea of “some elitist trout fishermen and a few fishery biologists” (Wiley and Mullan 1975). While the authors correctly pointed out that wild trout management was not suitable for all fisheries, they overlooked a much longer and expansive history of wild trout ethics and management that went beyond a handful of elitist anglers and biologists. I address this history with more depth in my forthcoming book from the University of Washington Press, but here I will attempt to outline some of the broad changes in American conceptions of nature and the wild as well as the changing ideals and techniques of anglers and fisheries managers in the twentieth century. I will then explain what we may learn from this history.

During the premodern and early modern time periods before about 1800 AD, Europeans held dramatically different views of nature, believing that wild landscapes and wild creatures needed to be tamed. Indeed, the northern European roots of the word wilderness translate to the “place of wild beasts” (Nash 1982). In the Middle Ages, Europeans saw forests as scary, dark places and peasants rarely ventured far from their small villages (Manchester 1993). The original fairy tales emerged not as fun, Disneyfied stories, but as violent and bawdy tales over food, family size, and the ever-present threats of nature. The harsh tales had few happy endings (Stilgoe 1982, Darnton 1984). As they colonized the Americas, Europeans brought these traditions with them; one pilgrim leader, William Bradford, later wrote that the land that lay before them was “but a hideous and desolate wilderness, full of wild beasts and wild men” (Quoted in Nash 1982). Within the Euro-american cultural tradition, then, the idea of wild was not celebrated. Nature and its creatures remained a place to be transformed into civilization—or avoided

entirely. This concept of nature changed when the rise of industrial capitalism and nation-states ushered the world into the modern era.

In response to this new industrialized, modern world in the nineteenth century, many Americans began to see the wild qualities of nature in a more positive light. Influenced by Romanticism, evangelical revivalism in the wake of the Second Great Awakening, and nationalism, many Americans connected nature to God, redefining the sublime to appreciate the awe of wild landscapes (Novak 1980). The growing leagues of leisure class anglers also held sentimental views of nature. One sporting writer liked that fly fishing took place “amongst the most picturesque panorama designed by nature” (Fitzgibbon 1853). Within this shift, the growing middle class both benefitted from the exploitation of nature and used it as a place for play; they increasingly headed outdoors to spend their leisure time and money on recreational activities (Merchant 1989, see also Schmitt 1969). Holding a sort of collective amnesia in regards to industrialization, urbanization, and environmental change, the conception of wild nature shaped angling and recreational experiences into the twentieth century.

In the industrial age, Americans also looked for solutions to environmental degradation and used hatcheries to manufacture fish to address declining fish populations in the wake of industrial pollution as well as provide food for an expanding population. Hatcheries became incorporated into the trout conservation agenda for fish agencies, but their use later largely shifted to providing sport for anglers on inland waters. Few anglers and fisheries managers questioned the growing use of hatcheries, besides some often-quoted voices in the wilderness like Myron Reed, the Denver angler and socialist preacher who lamented in the late-nineteenth century that “This is the last generation of trout fishers. The children will not be able to find any. Already there are well-trodden paths by every stream in Maine, New York, and in Michigan. I know of but one river in North America by the side of which you will find no paper collar or other evidence of civilization. It is the Nameless River.

Not that trout will cease to be. They will be hatched by machinery and raised in ponds, and fattened on chopper liver, and grow flabby and lose their spots” (quoted in Halverson 2010). While Reed’s concern for the unnaturalness of trout and trout streams represented a small minority in this era, the mindset of recreational anglers who valued a pristine outdoor experience proved central to the later shift to wild trout values and management.

During the first half of the twentieth century, the use of hatcheries on trout streams continued to grow. After World War II, fisheries managers matched the increase of anglers by expanding hatcheries even further and raising the amounts of catchable-sized trout that they planted. At the same time, the quiet rise of ecology profoundly altered the western world’s ideas of nature, bringing with it criticisms of modern scientific management. As ecologists rethought their connections to nature, many anglers made catch-and-release a central part of the sport. In speaking of the sea change needed for a more ethical and ecological concern for nature, Aldo Leopold (1949) once said, “Perhaps such a shift of values can be achieved by reappraising things unnatural, tame, and confined in terms of natural, wild, and free.” Leopold knew that the concept of “wild” could only exist as a dichotomy that compared wild to domesticated, or civilized, or hatchery, or tailwater. No wonder then, in the midst of postwar put-and-take stocking that planted millions of catchable-sized trout each year, ecologists and anglers started to denounce hatchery trout and other modern fisheries management techniques.

The ecological focus may not have entirely transform scientific thinking and management, but did erect a framework for criticisms of hatcheries. The ecological viewpoint conceptualized the environment as a biotic community that included humans as both a member of the community and its moral protector (see Worster 1994 for more on the history of ecology). Leopold (1949) promoted sporting values that brought people closer to nature and wildlife, and had ingrained ethical considerations as a “sport.” He believed the manipulation of natural systems created second-rate aesthetics and poor management practices that ignored environmental degradation:

Consider, for example, a trout raised in a hatchery and newly liberated in an over-fished stream. The stream is no longer capable of natural trout production. Pollution has fouled its waters, or deforestation and

trampling have warmed or silted them. No one would claim that this trout has the same value as a wholly wild one caught out of some unmanaged stream in the high Rockies. Its esthetic connotations are inferior, even though its capture may require skill...several over-fished states now depend almost entirely on such manmade trout. All intergrades of artificiality exist, but as mass-use increases it tends to push the whole gamut of conservation techniques toward the artificial end, and the whole scale of trophy-values downward (Leopold 1949).

From this viewpoint, hatcheries could never provide quality fishing experiences, in large part, because they failed to address important conservation issues. Leopold voiced a growing concern from anglers and new generations of fisheries biologists.

In the twentieth century, angling culture also provided a foundation for wild trout. While catch-and-release has an extended history, it became an ethos to growing numbers of anglers, particularly fly fishers by the 1970. Purposefully releasing fish dates back centuries to both the sporting ideals of the English leisure class and the more practical consideration of all anglers that small fish were often not worth the effort to clean or were too small to eat. Above all, ethics defined sporting values over time and place. When British angler Humphry Davy (1832) warned in the early nineteenth century of “an end to the sport in the river” if fellow anglers kept too many fish, he extolled the virtues that remained surprisingly static over the years. Master fly fisher Lee Wulff (who else could tie a size 28 fly—smaller than a pencil tip—with no vise?) helped popularize the concept of catch-and-release fishing among mid-twentieth century Americans in his *Handbook of Freshwater Fishing* (1939) as well as his other writings. In the book, Wulff observed a blossoming catch-and-release sentiment: “There is a growing tendency among anglers to release their fish, returning them to the water in order that they may furnish sport again for a brother angler. Game fish are too valuable to be caught only once” (Wulff 1939). In that last sentence, the oft-repeated words of the value of game fish defined the fly fishing ethos for many of its twentieth-century practitioners.

The move to wild trout also modified some fly fishing practices. Doug Swisher’s and Carl Richard’s *Selective Trout* (1971) pioneered a new fly fishing philosophy, arguing that fly fishers needed better patterns to trick trout that had become more selective

with catch and release. The authors conducted studies on Michigan's Au Sable River that formed the basis of the book, which reads as part fly-tying manual, part entomology textbook. After meticulously collecting, categorizing, and photographing insects, they developed new fly patterns designed to more accurately imitate mayflies and other insects. The book transformed dry fly fishing with the simple, no-hackle patterns, quickly gaining popularity across the United States. Like Swisher and Richards, many anglers saw wild trout as harder to catch, enjoying the challenge.

Many of the same anglers who championed wild trout ethics formed new conservation groups like Trout Unlimited and the Federation of Fly Fishers in the 1960s, institutionalizing catch-and-release and wild trout ethics. These organizations found growing force as the modern environmental movement coalesced in the 1960s and 1970s. Anglers also used the conservation groups to lobby state agencies for more wild trout opportunities. Ennis, Montana, fly fisherman Dick McGuire, for instance, complained in 1960 to the Montana Fish and Game Department about the declining fishing on the upper Madison River. McGuire blamed the stocking of catchable-sized rainbows, stating there was "only one reason for the poor fishing...the planting program" (cited in Vincent 1972). His concern for wild trout and wild rivers prompted McGuire and others to later found the Southwestern Montana Fly Fishers, a club affiliated with the Federation of Fly Fishers (Brooks 1979). By the decade's end, scientific studies proved McGuire right. Resting on the foundation laid by the rise of ecology and catch-and-release fishing and strengthened by the ideals imparted by Trout Unlimited and the Federation of Fly Fishers, wild trout ethics and management gained ground in the 1960s and 1970s.

Two agencies led the way in wild trout management: the National Park Service and Montana Fish, Wildlife and Parks. From the 1930s to the 1950s, the National Park Service put in place progressive management policies such as including native and nongame fish in management plans and refusing to stock catchable-sized trout. By 1960, the federal agency entirely shifted their focus to restoring native fisheries by regulating catches with more restrictive creel limits (Wallis 1960). Conversely, Montana Fish, Wildlife and Parks pragmatically changed their policies in response to a pathbreaking examination

of put-and-take trout stocking. From 1967 to 1971, Montana Fish, Wildlife and Parks biologist Dick Vincent conducted his now-infamous study on the Madison River that led to a wholesale shift to wild trout management on all Montana rivers starting in 1972 and complete by 1975. While earlier studies only showed the inefficiency and high costs of stocking catchables, Vincent's work definitively demonstrated the environmental tolls of the reliance on hatcheries. After ending stocking of catchable rainbows in 1969, the wild trout population in the popular Varney section exploded. In two years, the wild trout population had grown by 180 percent and continued to grow in the years following (Vincent 1975). Wild trout proved wildly successful in Montana. Both Montana Fish, Wildlife and Parks and the National Park Service set important precedents in wild trout management. More importantly, the wild trout era also brought more attention to healthy habitats, a goal that all agencies and conservation groups undertook.

After surveying some of the major changes in American ideas of nature that brought forth wild trout ethics and management, I think we may consider four lessons from this history. First, the idea of "wild" is constantly changing. Fisheries managers and conservation organizations have difficult jobs, often connected to the larger political climate and diverse constituencies of anglers. As such, their objectives sometimes seem unclear to the larger population or are obscured by an uninformed public. Therefore, these groups might clarify their goals and objectives to the public. Is the goal wild or native? Is it nativeness or biodiversity? How are these concepts defined? Does your constituency understand the different uses and consequences of hatcheries and wild trout management? Second, the idea of "wild" always exists as a binary concept. In other words, we can only have wild if we have civilized. It would help to anticipate future threats to wild fisheries from civilization, the other side of the dichotomy (energy development, urban growth and regulations, agriculture including pesticide use and irrigation, climate change, and other sources of pollution that you all deal with on a day-to-day basis). Third, wild trout ethics and management have not been fully realized. Clearly, practical reasons remain for the use of hatcheries and fish stocking. With that said, the long history of hatcheries serves as a warning about the hubris that accompanies human manipulation of nature. Finally,

wild trout meant wild rivers. In their fights to save rivers and fish, anglers and fisheries managers realized the importance of habitat protection. This wildness played a significant role in the appreciation of wild trout. Echoing nineteenth-century romantics, Butte conservationist George Grant cherished the experience of fishing the nearby Big Hole River for over fifty years: “The fascination or allure of this unusual river was not merely in the pursuit or killing of its wild trout, or later in the taking and releasing of them, but equally so in the appreciation of nature’s contribution to the pleasures of man’s existence...Few men have ever been so rich” (Grant 1975). Can these wild trout experiences be sustained for coming generations? As we continue to conserve wild trout and respond to futures challenges, as a historian, I also believe that preserving rivers and fish means knowing the past as much as the rivers we love.

## REFERENCES

- Brooks, C. E. 1979. *The living river: a fisherman’s intimate profile of the Madison River watershed—its history, ecology, lore, and angling opportunities*. Nick Lyons Books, Garden City, New York.
- Darnton, R. 1984. *The great cat massacre and other episodes in French cultural history*. Basic Books, New York.
- Davy, H. 1832. *Salmonia: or days of fly fishing in a series of conversations with some account of the habit of fishes belonging to the genus Salmo*. 3rd ed. John Murray, London. Available at: <http://www.archive.org/detailssalmoniaordaysof1832davy> (December 2010).
- Fitzgibbon, E. 1853. *A handbook of angling: teaching fly-fishing, trolling, bottom-fishing, and salmon-fishing: with the natural history of river fish, and the best modes of catching them*. 3rd ed. Longman, Brown, Green, and Longmans, London.
- Grant, G. F. 1975. *Confessions of an addict*. River Rat. Montana Trout Unlimited, Butte.
- Halverson, A. 2010. *An entirely synthetic fish: how rainbow trout beguiled America and overran the world*. Yale University Press, New Haven.
- Hays, S. P. 1987. *Beauty, health, and permanence: environmental politics in the United States, 1955-1985*. Cambridge University Press, New York.
- Leopold, A. 1949. *A Sand County almanac and sketches here and there*. Reprint 1989. Oxford University Press, New York.
- Manchester, W. 1993. *A world lit only by fire: the medieval mind and the Renaissance, portrait of an age*. Little, Brown, New York.
- Merchant, C. 1989. *Ecological revolutions: nature, gender, and science in New England*. University of North Carolina Press, Chapel Hill.
- Nash, R. 1982. *Wilderness and the American mind*. 3rd ed. Yale University Press, New Haven.
- Novak, B. 1980. *Nature and culture: American landscape and painting, 1825-1875*. Oxford University Press, New York.
- Oelschlaeger, M. 1991. *The idea of wilderness: from prehistory to the age of ecology*. Yale University Press, New Haven.
- Schmitt, P. J. 1969. *Back to nature: the arcadian myth in urban America*. Oxford University Press, New York.
- Stilgoe, J. R. 1982. *Common landscape of America, 1580 to 1845*. Yale University Press, New Haven.
- US Department of Health, Education, and Welfare. 1962. News release. US Department of Health, Education, and Welfare, Washington, DC.
- Vincent, E. R. 1972. The catchable trout. *Montana Outdoors* 3: 24-29.
- Vincent, E. R. 1975. Effect of stocking catchable trout on wild trout populations. Pages 88-91 in Willis King, editor. *Proceedings of the wild trout management symposium*. Trout Unlimited. Available: <http://wildtroutsymposium.com/proceedings-1.pdf> (July 2013).
- Wallis, O. L. 1960. Management of sport fishing in national parks. *Transactions of the American Fisheries Society* 89: 234-238.
- Wiley, R. W., and Mullan, J. W. 1975. Philosophy and management of the Fontenelle Green River tailwater trout fisheries. Pages 28-31 in Willis King, editor. *Proceedings of the wild trout management symposium*. Trout Unlimited. Available: <http://wildtroutsymposium.com/proceedings-1.pdf> (July 2013).
- Worster, D. 1994. *Nature’s economy: a history of ecological ideas*. 2nd ed. Cambridge University Press, New York.
- Wulff, L. 1939. *Lee Wulff’s handbook of freshwater fishing*. J. B. Lippincott, New York.

## A PLAUSIBLE EXPLANATION FOR LAPSED TROUT FISHING PARTICIPATION IN WISCONSIN

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**Abstract**—From 2000 to 2011, sales of Wisconsin’s inland trout stamp remained relatively stable. Despite this stability, Wisconsin Department of Natural Resources regional biologists and administrators continue to hear from trout anglers that regulations for inland trout fishing are too numerous and too complex; the result being that regulations are driving anglers away from the sport and hindering the initiation of new anglers. To help inform Wisconsin’s fisheries management program on reasons for lapsed participation in inland trout fishing, we conducted a mail survey of anglers who did not purchase the inland trout stamp for three consecutive years (2009-2011) but who had been “dedicated” holders by purchasing the stamp the previous five consecutive years (2004-2008). Survey questions addressed aspects of recreation participation and trout management which may contribute to angler drop-out. After a maximum of three contacts and correcting for non-sample bias, 498 of the 800 (68%) surveyed anglers returned usable questionnaires. Initial results indicate that while regulations were cause for some anglers to cease their participation, they were not the most influential reason, and significantly less influential than restraining factors such as time constraints. Management implications are presented as a plausible model illustrating a prescription to curb lapsed participation in trout fishing.

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### INTRODUCTION

This paper builds upon the work of Fedler and Ditton (2001) and Sutton et al. (2009) by exploring likely reasons dedicated Wisconsin inland trout anglers stopped participating in trout fishing. Despite stable sales of the inland trout stamp between the years 2000 and 2011, Wisconsin Department of Natural Resources (WDNR) administrators regularly heard from anglers that they were dropping out of trout fishing, and recruitment of new anglers was being hindered because fishing regulations are too numerous and complex. (For review of the regulations see [dnr.wi.gov/topic/fishing/documents/regulations/TroutRegsText1314.pdf](http://dnr.wi.gov/topic/fishing/documents/regulations/TroutRegsText1314.pdf)). The WDNR’s attention to such anecdotes is not surprising. It’s easy for decision-makers to be biased by anecdotal input because the stories can be more vivid, more emotional and easier to process as compared to statistical data, thereby leading decision-makers to overweight anecdotal relevance (Wainberg et al. 2010). Tinbergen’s cautionary observation that “many anecdotes make a

statistic” reflects the common misinterpretation that anecdotes are data (Kruuk 2002; Kerasote 2013). They are not; the plurality of anecdote is not data (Novella 2008). Noted social psychologist Kurt Lewin put it this way: “...the importance of a case, and its validity as proof, cannot be evaluated by the frequency of its occurrence” (Lewin 1935).

Few studies have explored the influence of fishing regulations on continued participation or as barriers to initiation, and those that have found them to be weak constraints (Responsive Management 1995, 2012b; Fedler and Ditton 2001; Sutton et al. 2009). Recent findings from Wisconsin found that 12% of active trout anglers said they spend less time trout fishing now than in past years due to regulations (WDNR 2013b). On the other hand, numerous studies of lapsed anglers have for the past 20 years identified allocation of time as the most frequently cited primary constraint to fishing (Responsive Management 1995; Sutton et al. 2009; Responsive Management 2012b) or as the “most important reason for quitting fishing” (Fedler

and Ditton 2001). Further, studies of current anglers found that time was the most important constraint to fishing more often (Ritter et al. 1992; Responsive Management 1999; Fedler and Ditton 2001). Most recently, the Wisconsin study found that 20% of active trout anglers reported spending less time trout fishing now than in past years due to unavailable time (WDNR 2013b).

## METHODS

*Data collection*—Data were generated from a questionnaire mailed to Wisconsin residents who previously held a Wisconsin inland trout stamp. A lapsed trout angler was defined as someone who was at least 21 years old, and who had not purchased the stamp for the three consecutive years (2009 through 2011) but had been a “dedicated” holder by purchasing the inland trout stamp the five consecutive previous years (2004 through 2008). From these criteria, 2,268 lapsed anglers were identified. A screening letter was mailed to the identified population to verify current mailing addresses and after three weeks, 290 non-deliverable letters (including deceased) were purged from the population, resulting in 1,978 viable addresses. A random selection of 800 lapsed trout anglers was drawn from this list.

Survey design and administration followed a modified version of the procedures outlined by Dillman (2000). The questionnaire was pre-tested on six lapsed trout anglers; revisions were subsequently made resulting in a six-page questionnaire. From the sample of 800 lapsed trout anglers, 71 were eliminated as non-sample (returned as non-deliverable). This is a high number of non-sample questionnaires, but perhaps not surprising given that mortality is one explanation for lapsed participation. Useable questionnaires were returned by 498 lapsed trout anglers for a response rate of 68 percent. All mailings originated from and were returned to the WDNR. Data entry and analysis was performed using SPSS version 19.0 (IBM 2010). The study has a margin of error of +/- 3%.

For this study, 27 influences on lapsed participation were presented in a table organized by themes. Using a six-point Likert-type scale, respondents were asked to indicate how much influence, if any, each item had on why they stopped trout fishing. The influences were based in-part on

fishing constraints investigated in other studies (Fedler and Ditton 2011) but were expanded and modified to better apply to trout fishing in Wisconsin and to specifically address the anecdotal input received by WDNR personnel. Although influence themes were predetermined, a factor analysis was performed on the 27 items to determine if they were measuring the previously determined themes (Vaske 2008).

After rating each of the possible influences for lapsed participation, respondents were asked to rank the importance of the seven major themes. A ranking of one was recorded as the most important influence on their lapsed participation; a ranking of seven was recorded as the least important influence. Lower mean scores, therefore, indicate greater influence. Lastly, respondents were asked to indicate the likelihood of returning to trout fishing in Wisconsin. This was explored by asking: “If the item you listed as number 1 in the previous question was remedied (it was no longer a problem for you) how likely is it that you would start trout fishing again in Wisconsin?” The question was measured with a five-point Likert-type scale where “Not at all likely” was coded as 1, “Unsure” was coded as 3 and “Very likely” was coded as 5.

## RESULTS

Presentation of the 27 possible influences is intended to uncover any items which exert a moderate or great amount of influence on lapsed participation for a majority of lapsed trout anglers (Table 1). Overall, no single item had an alarming influence on lapsed participation. Not one of the 27 influences resulted in a mean score of “moderate influence” or greater. The highest mean score was 2.5 (between “little” and “moderate”) for “work or household responsibilities.” Seven of the 27 items resulted in ratings of “moderate” to “great” for 40% or more of the lapsed anglers, which resulted in mean scores of at least 2.0. The items which hold potential to exert the strongest influence on desertion from trout fishing included: “work or household responsibilities” (55% reported “moderate” to “great” influence; 2.5 mean score), “other activities enjoyed more” (50% reported “moderate” to “great” influence; 2.2 mean score), “not enough trout to catch” (48% reported “moderate” to “great” influence; 2.1 mean score), “not enough large trout” (44% reported “moderate” to “great” influence;

2.0 mean score), “regulations vary along the course of a stream or are different for multiple streams in the same area” (44% reported “moderate” to “great” influence; 2.1 mean score), “number of regulations” (43% reported “moderate” to “great” influence; 2.0 mean score) and “trout stamp/license became too costly” (41% reported “moderate” to “great” influence; 2.0 mean score).

Respondents were subsequently asked to rank the seven themes in order of importance for why they no longer participate in inland trout fishing. Time constraints, cited by more than one-third (35%) of the lapsed anglers, was the primary reason they stopped participating (Table 2). The mean score of 3.0 is to the left of the 7-point scale midpoint, indicating a degree of importance. Further, while inland trout regulations were cause for some anglers to break their participation, it was not the primary reason, and less important (less influential) than time constraints. The state’s inland

trout regulations were cited by 12% of lapsed trout anglers as the primary reason they no longer trout fish in Wisconsin. The mean score was 3.9, indicating a midpoint measure on the 7-point scale.

Trout fishing on a stream or river is a physical activity. As an angler ages, wading a stream or traversing rough terrain may become difficult or insurmountable. It is no surprise that the respondents’ age, health (and secondarily status of fishing companions) influenced lapsed participation. This was the second most frequently cited reason (21%) that lapsed anglers no longer participate. Yet the mean score of 4.2, while at the midpoint of the 7-point scale, is deceptively high. This is attributed to almost 40% of the respondents reporting that their age, health, or companions had little to do with their lapsed participation (i.e., ranked sixth or seventh, essentially saying it was not an influence for younger respondents in good health).

**Table 1. Possible influences on lapsed participation in trout fishing (mean score and percent responding moderate to great influence). Mean scores are based on a 6-point scale where 0=no influence or not applicable, 1=very little influence, 3=moderate influence and 5=great influence.**

Possible influence	Mean	Moderate to Great (3-5)	Possible influence	Mean	Moderate to Great (3-5)
<b>Regulations</b>			<b>Time constraints</b>		
Regs. vary along the course of a stream or are different for multiple streams in same area	2.1	44%	Work or household responsibilities	2.5	55%
Number of regs.	2.0	43	Other activities I enjoy more	2.2	50
Overall complexity of regs. and seasons	1.8	36	Time spent with children	1.6	34
Difficulty understanding regs.	1.7	35	Travel distance – takes too much time	1.5	29
Regs. are not clearly posted at access sites	1.6	32	<b>Fish preferences</b>		
Regs. did not allow me to keep trout during early spring catch-release season	1.0	13	Prefer to catch or eat other fish	1.8	38%
Regs. prevented me from fishing the way I wanted to	1.0	18	<b>Age, health, companions</b>		
<b>Quality of trout fishery at favorite trout water</b>			Health issues or too old to get around fishing	1.2	26%
Not enough trout to catch	2.1	48%	Companions stopped fishing or moved away	1.1	24
Not enough large trout	2.0	44	<b>Access to and conditions of trout streams</b>		
Too many small trout	1.8	35	Stream habitat became degraded or difficult to fish	1.7	36%
Favorite water no longer stocked with trout	1.5	31	Not enough public access or I lost access via private land	1.5	32
Wild trout no longer present	1.4	29	Overcrowded with other stream users	1.2	23
Type of trout I prefer to catch no longer present	1.1	20	I was harassed by other users or by landowners	< 1	9
Trout fishing is better in other states or Canada	1.0	17	<b>Expenses</b>		
			Trout stamp/license became too costly	2.0	41%
			Other fishing expenses became too costly	1.3	24

**Table 2: Ranking of seven influential themes on lapsed inland trout fishing. Mean ranking is based on a 7-point scale where a ranking of 1=most important and 7=least important.**

Possible influences	Mean	Ranked 1 <sup>st</sup> (%)
Time constraints	3.0	35%
Access to and conditions of trout streams	3.7	7
Quality of fishery of favorite trout water	3.8	13
Regulations	3.9	12
Expenses	4.1	6
Age, health and companions	4.2	21
Fish preferences	4.5	5

The quality of the trout fishery at the respondents' favorite trout water was cited as the most important reason for lapsed participation by approximately one lapsed angler in eight (13%). Poor stream access and stream conditions explained lapsed participation for 7% of the respondents. Expenses related to inland trout fishing as well as preferences to catch and eat fish other than trout were important reasons for some lapsed trout anglers, but less so relative to other reasons. Approximately one lapsed trout angler in 20 reported that expenses (6%) and preferences for other fish (5%), respectively, were primary reasons they no longer fish for inland trout in Wisconsin.

Following the ranking question, the respondents were asked to consider a hypothetical situation of returning to trout fishing, if their primary constraint was remedied. Results indicate the majority of lapsed anglers would return. Two-thirds (67%) of the lapsed anglers reported that if the primary reason they no longer trout fish was to disappear, they would be somewhat likely (31%) or very likely (36%) to start trout fishing again. Slightly more than one lapsed angler in ten (12%) is unlikely to start trout fishing again and one-fifth (20%) were uncertain of their future participation.

While the results are encouraging, they must be considered relative to the possibility or eventuality that an issue can or will be remedied. In other words, some reasons for lapsed participation cannot be or are unlikely to be remedied (e.g., debilitating health, old age, preference for fish). But what about the explanations for lapsed participation which can be addressed (e.g., regulations, stream conditions, quality) or are likely to change in a respondent's life (e.g.,

children are grown, diminished household or work responsibilities)?

Although hypothetical, results indicate that if the primary issue which prompted a trout angler's departure was remedied, a majority of those anglers would start trout fishing again. Of the lapsed trout anglers who ranked the poor quality of their favorite trout fishery as the primary reason they stopped fishing, more than eight in ten (83%) indicated that they would likely return if the quality improved. Similarly, about three-fourths (74%) of the lapsed anglers indicated that they would likely return if their primary constraint of regulations were simplified or allowed them to fish the way they preferred and two-thirds (67%) of the lapsed anglers indicated that they would likely return if the primary constraint of access and conditions improved. A final noteworthy observation is the high percentage (74%) of lapsed anglers who would likely start trout fishing again if their current time constraints improved. This finding perhaps holds real potential for returned participation when family and work responsibilities diminish and if interest in competing activities wane.

Returning to the factor analysis, results largely confirmed the predetermined themes though a few exceptions were noted. Items which had factor loadings of 0.50 and greater were considered meaningful. Items with loadings of 0.35 to 0.49 were also included if they seemed to fit conceptually. One of the four items within "Access to and conditions of trout streams" had a weak loading within the theme but a strong loading within "Quality of trout fishery in favorite trout water." Further, two of the seven items within "Regulations" had weak loadings but stronger loadings on their own.

## DISCUSSION AND MANAGEMENT IMPLICATIONS

Previous studies identified time allocation as the most likely constraint to fishing participation (Responsive Management 1999; Fedler and Ditton 2001; Sutton et al. 2009; Responsive Management and Southwick Associates 2012a, b). Results of this study confirm those findings; how lapsed anglers choose to allocate their time is the primary reason they stopped participating in inland trout fishing.

A motivation for the conduct of the research was to either confirm or refute the regular anecdotal input that the complexity and number of Wisconsin's trout regulations were driving anglers away from participation. We found that although the regulations were cause for some anglers to break their participation, they were far from the most influential reason, and notably less important (less influential) than time constraints. Likewise, other management-oriented reasons including the quality of the anglers' favorite trout fishery as well as stream accessibility and condition were considerably less likely than time constraints to be cited as the primary reasons for lapsing. It should be recognized, however, that while active management such as habitat improvement and regulation simplification can lead to more quality opportunities and more satisfying experiences on select waters, uncontrollable events such as drought, climate change, and private landowner practices may influence perceptions of quality and overall satisfaction on a larger scale. It should also be recognized that many inland streams in Wisconsin have limited potential to produce quality or trophy size trout. Opportunities to fish for other species which provide more frequent action as well as meals are available throughout the state and may in-part explain a lapsed angler's preference for other fish.

Given that these lapsed anglers had once been dedicated participants, it was not surprising that the majority of them indicated they would likely return to trout fishing if the primary cause for lapsing was remedied. Fedler and Ditton (2001) similarly found that approximately one-half of their inactive and recently lapsed anglers indicated they were likely to fish again. Given this finding, the question the Wisconsin DNR must ask itself is what can be done to invigorate lapsed anglers to pick-up their rods and reels and head to their favorite (or closest) trout waters? While some

recommendations for renewed participation have included targeted outreach and communication efforts as well as fostering the social interactions of fishing (Fedler and Ditton 2011), other research suggests an approach aimed at actions under direct management control might be most effective (Sutton et al. 2009). We believe the implications of this research align with the latter perspective. We follow the premise that constraints on time is not defined as "not having enough time," but rather the lapsed trout angler has chosen to allocate his or her time in specific ways such that trout fishing is no longer a priority (i.e., time is no longer allocated for fishing) (Fedler and Ditton 2001; Responsive Management and Southwick Associates 2012a, b). Our interpretation of the data is that if the trout fishing experience (access, quality and regulations) is less than satisfactory, the value of the experience relative to the investment is diminished; and if the investment is not worth the experience, then allocation of time for the experience also diminishes.

To foster a re-allocation of time so that trout fishing becomes and remains a recreation priority, we suggest a focused attention on the three influences that are responsive to WDNR management and policies; access to and conditions of trout streams, the quality of trout waters, and trout fishing regulations. If these potential influences on lapsed participation were remedied (i.e., access to and conditions of streams improved through increased funds from the stewardship acquisition program, quality of trout waters improved, and regulations were simplified), then two hypotheses emerge: (1) the influence of fishing-related expenses on lapsed participation would diminish because the value of the experience would increase (i.e., the fishing experience becomes worth the expense); and (2) time constraints as a barrier to participation would diminish and time would once again be allocated for trout fishing. While this interpretation is neither a quick nor simple fix, we believe it points to a prescription to curb lapsed participation in trout fishing.

*Future studies*—Results from this study have implications for future research. The proposed hypotheses could be tested using path analysis by drawing another sample that includes both lapsed and current anglers, with current license buying as the dependent variable. Further, future modeling would permit us to explore the potential influences of angler demographics, socialization traits (e.g., initiation age,

socialization agent), and preferred fishing methods (e.g., live bait versus artificial lures and flies) on continued participation. Rather than working with predetermined themes, factor loadings would identify the related influences; Cronbach's alpha would then test for the creation of additive scales which could uncover situations where a number of factors with smaller influence on angler drop-out add up to be important (Vaske 2008; Holsman 2012).

## ACKNOWLEDGEMENTS

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## REFERENCE

- Dillman, D. A. 2000. Mail and internet surveys: The tailored design method. Wiley, New York.
- Fedler, A. J., and R. B. Ditton. 2011. Dropping out and dropping in: A study of factors for changing recreational fishing participation. *North American Journal of Fisheries Management* 21:283-292.
- Holsman, R. H. 2012. Deer camp waning: Why middle-aged gun deer hunters are dropping out. Internal report to the Wisconsin Department of Natural Resources. Madison.
- IBM Corporation 2010. IBM SPSS statistics for windows, version 19.0. Armonk, New York.
- Kerasote, T. 2013. Pukka's promise: The quest for longer-lived dogs. Houghton Mifflin Harcourt, New York.
- Kruuk, H. 2002. Hunter and hunted: Relationships between carnivores and people. Cambridge University press, New York.
- Lewin, K. 1935. A dynamic theory of personality. McGraw-Hill, New York.
- Novella, S. 2008. The role of anecdotes in science-based medicine. Available at <http://www.sciencebasedmedicine.org/the-role-of-anecdotes-in-science-based-medicine>.
- Responsive Management 1995. Factors related to hunting and fishing participation in the United States: Phase IV quantitative analysis. Prepared for the U. S. Fish and Wildlife Service, Division of Federal Aid, Arlington, Virginia.
- Responsive Management 1999. The future of fishing in the United States: Assessment of needs to increase sport fishing participation. Prepared for the International Association of Fish and Wildlife Agencies, Arlington, Virginia.
- Responsive Management and Southwick Associates 2012a. Why do anglers sit on the fence about going fishing? A study of why they do and don't fish and what will get them on the water. Prepared for the American Sportfishing Association, Arlington, Virginia.
- Responsive Management and Southwick Associates 2012b. Understanding activities that compete with recreational fishing. Prepared for the American Sportfishing Association, Arlington, Virginia.
- Ritter, C., R. B. Ditton, and R. K. Riechers. 1992. Constraints to sport fishing: Implications for fisheries management. *Fisheries* 17(4): 16-19.
- Sutton, S. G., K. Dew, and J Higgs. 2009. Why do people drop out of recreational fishing? A study of lapsed fishers from Queensland, Australia. *North American Journal of Fisheries Management* 34:443-452.
- Vaske, J. J. 2008. Survey research and analysis: Applications in parks, recreation and human dimensions. Venture Publishing, State College, Pennsylvania.
- Wainberg, J., T. Kida, and J. F. Smith. 2010. Stories vs. statistics: The impact of anecdotal data on professional decision making. Available at SSRN: <http://ssrn.com/abstract=1571358> or <http://dx.doi.org/10.2139/ssrn.1571358>
- WDNR (Wisconsin Department of Natural Resources). 2013a. Guide to Wisconsin trout fishing regulations 2013-2014. Available at <http://dnr.wi.gov/topic/fishing/documents/regulations/TroutRegsText1314.pdf>
- WDNR (Wisconsin Department of Natural Resources). 2013b. Internal departmental survey data. Madison.

## WILD TROUT AND THE DRIFTLESS AREA: AN EXPANDING DRAW FOR ANGLING TOURISM

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**Abstract**—As watershed restoration efforts across the unglaciated, or “Driftless” area of the Upper Mississippi basin have expanded in the last decade, traveling anglers focusing on wild trout fisheries have shown preferences for restored waters with assured public access over stocked fisheries. Attendant to this increased use of primarily wild trout fisheries has come recognition of the significant economic impact of recreational anglers across the region in the form of new businesses catering to them.

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### INTRODUCTION

Every summer weekend, over a half million people migrate into rural areas of the unglaciated, or “Driftless”, area of the Upper Mississippi basin. They bike, hike, ride horses, search for fossils, geocache—and they fish for trout. In southwestern Wisconsin, southeastern Minnesota and northwestern Iowa, their preferences for recreational activities are changing the landscape as well as the populations of streams.

Since the 1990s, tourism across area has expanded and changed as the area has developed external recognition and come to offer more recreational amenities. In a 1999 study, for example, researchers found the number of anglers fishing in the Kickapoo River Valley of Wisconsin had doubled since a comparable 1994 study and the number of non-local versus local anglers had shifted from equal numbers to three-to-one non-local anglers (Anderson 2001). More recognition of opportunities to pursue the region’s expanding populations of wild Brown Trout *Salmo trutta* and native Brook Trout *Salvelinus fontinalis* are among the drivers of this growth.

Media articles, videos, and expanded attention in the population centers adjacent to the region and nationwide are bringing in more recreationists. Articles in The New York Times, Minneapolis Star-Tribune, and specialized fishing magazines join commercial videos such as “Heart of the Driftless”, e.g., in getting the word out.

An active segment of the real estate market across the region has developed to meet the demands of people who come to see the area and then start looking for a cabin or other second home up in the coulees. Another segment features cabins for rent, from bare

bones log structures to first-class accommodations and bed-and-breakfast inns.

This attention has accompanied expanded development of restoration programs for the area’s many trout streams, part of it due to the increasing capacity of Trout Unlimited and its partners in the Driftless Area Restoration Effort (DARE) to restore coldwater systems across the region. In Wisconsin, Minnesota, and Iowa, expanded restoration has meant improved wild trout fisheries and expanded public access to streams. One tenet of the DARE program has been that restoration dollars will only be committed to stream reaches where the public has guaranteed legal public access. As a result, all three states, or alternately other governmental or private entities, have expanded their efforts to obtain fishing easements or purchase streamside lands in fee title.

### What is the Driftless Area?

The Driftless Area was not flattened by the Wisconsin Glacial Era of 80,000-10,000 B.C.E., as the glaciers ground down the nearby landscapes of western Minnesota, the Dakotas, northern and eastern Wisconsin and most of Illinois. Instead, the Driftless Area’s limestone-sandstone ridges remain and loom 300 to 600 ft over the bottomlands where spring-fed creeks flow into the region’s major river systems.

Early geologists traveling in this region found that its soils did not contain the gravel, rocks, and boulders, or “glacial drift”, which glaciers scatter when they grind down landscapes. Soft loess soil blown in by wind from the prairies to the west overlaid ridgetops and hillsides. This 24,000-mi<sup>2</sup> area of southwest Wisconsin (24 counties), southeast

Minnesota (17 counties), northeast Iowa (13 counties), and northwest Illinois (3 counties) remains some of the most arresting topography in the western Great Lakes and northern Great Plains. Its underlying karst bedrock, named after the limestone-rich Karst region of Hungary, produces a fertile water chemistry in the over 600 spring creeks that flow through its valleys. Stream temperatures are ideal for trout and water quality is good.

### Historic Resource Challenges

Widespread European settlement of the region led to land use changes that dramatically changed the Driftless Area. Wooded hillsides were logged off and heavily grazed. Deep-rooted prairie plants were plowed under and replaced with shallow-rooted farm crops such as wheat and oats. Soon, the soft loess soil washed down onto valley floors, creating a thick blanket of sediment. Widespread gully erosion showed up on pastured hillsides, bringing more and more soil into valleys and eventually the Mississippi River. “By the 1930s, it was apparent that the topsoil of the Driftless Area was slipping seaward” to the Gulf of Mexico,” wrote Prof. Aldo Leopold. Photographs from area historical societies illustrate the erosion, for example, one from the Vernon County Historical Society showing a 6-ft man standing at the base of a 60-ft deep gully. Erosion led to flooding of communities, and more than one village had to be moved completely after dozens of floods made it hard to get into the first floors of buildings (see, e.g., Beaver, Minnesota). Over time, the erosional losses developed into a regional resource crisis.

In the 1930s, agricultural production experts and academics like Prof. Leopold decided it was time for action. The new federal Soil Erosion Service, a forerunner of the U.S. Department of Agriculture’s present Natural Resources Conservation Service, began a project in 1935 in Coon Valley, Wisconsin, using Work Projects Administration and Civilian Conservation Corps personnel. They stabilized streambanks, built concrete water retention structures in dry runs, installed contour strips, and reforested denuded hillsides. Soil conservation efforts have continued since across the region, though the present boom in corn and soybean prices has hindered some soil erosion practices.

Trout conservation in the region suffered with the land. In 1957, Wisconsin’s top fisheries expert

concluded that because of poor land use practices, it was likely that trout fishing in the Driftless Area would end in the near future. Other agency personnel, anglers, and other conservationists, however, didn’t accept that death warrant. They worked to develop restoration techniques that would hinder soil erosion, limit sedimentation, and recreate trout habitat. The development of Wisconsin’s Inland Trout Stamp program in 1977 made stamp revenues available for habitat work alone.

A brief comparison of the trout resources in the three states is instructive. Trout stamps sold in Wisconsin (192,000 last year) and Minnesota (82,000) produce revenue for habitat work, while revenues from Iowa trout stamps (39,000) go to support that state’s hatcheries and stocking programs. Driftless Area trout stream miles range from approximately 3,000 in Wisconsin to 750 in Minnesota and 350 in Iowa. However, numbers of stream miles are increasing in all three states with restorative efforts, and the number of streams with identified populations of naturally-reproducing wild trout is increasing each year as well.

### Focus on Wild Trout in Wisconsin, Minnesota and Iowa (WI, MN and IA)

As habitat restoration has progressed across the 3 Driftless States (WI, MN and IA) where trout are managed by state conservation agencies, more attention has focused on wild trout. In the Wisconsin Driftless streams, fewer trout are being stocked each year and more of them are fingerlings from feral Brown Trout and Brook Trout stock. Only 75,000 trout were stocked in Wisconsin Driftless waters in 2012: 24,600 Brown Trout, 47,100 Brook Trout and 6,600 Rainbow Trout *Oncorhynchus mykiss*. (Rainbow Trout were stocked primarily in waters such as ponds with no natural trout reproduction.) The transition is complete in areas with older, more established habitat restoration, as naturally reproducing trout become the bulk of the fish population. Where habitat restoration programs are new or yet to be established, fish managers still rely on supplementing wild populations with some hatchery fish. But as spawning success increases in restored waters, stocking is being reduced or eliminated entirely. Minnesota’s 2012 stocking figures from its three Driftless Area trout hatcheries were not available at the time of this writing. As of 2006, however, Minnesota stocked 55,000 Rainbow Trout in its Driftless Area streams. Snook 2006. In

Iowa, while over 258,000 catchable sized domestic Rainbow Trout were stocked in streams, about 159,000 fingerling wild Brown Trout were stocked in one popular stream and 2,500 wild Brook Trout were stocked in another in a trial program aimed to restore a strain as close to native as exists in that state. In plain terms, Wisconsin's habitat restoration program and focus on wild and native trout are longer-established and in line with angler preferences, while in Iowa there is less habitat work, less trout water, and more emphasis on harvesting catchable sized hatchery Rainbow Trout, even as Brown Trout populations are doing well in the same waters.

### Anglers' Preferences (Wisconsin and Minnesota Creel Surveys)

Anglers surveyed in Wisconsin and Minnesota trout streams in recent years reported they favor streams with restored habitat and unquestioned legal access allowing them to walk along streambanks. Many of these streams are quite small and often silty, and wading may be difficult and murk-producing. Along the Root River, one of southeastern Minnesota's premier trout watersheds, a Minnesota Department of Natural Resources (MN DNR) survey in 2006 revealed anglers in that watershed angled for Brown Trout (39%) more than the stocked Rainbow Trout (7%), which do not reproduce in that area. They reported that almost 40% of anglers in the watershed were satisfied fishing for any trout species. The Root River watershed appears to be an area where more anglers fish close to home, in contrast to the Timber Coulee watershed described below. In the Root, over 52% of anglers were local residents, while 40% traveled 50-100 miles to reach the stream they fished, most likely from the Twin Cities to the north (Snook and Dieterman 2006).

Academic researchers strive mightily to assess what it takes to make a natural setting into a recreational draw. One good definition of the core problem comes from "Economics of Outdoor Recreation": "There is nothing in the physical landscape or features of any particular piece of land or body of water that makes it a recreation resource; it is the combination of the natural qualities and the ability and desire of man [sic] to use them that makes a resource out of what might otherwise be a more or less meaningless combination of rocks, soil and

trees" (Clawson 1966 cited in Dissert and Marcoullier 2012). Others see tourism as requiring a complex combination of amenities, publicly owned recreation sites and privately offered hospitality services that provide opportunities for leisure experiences to satisfy the needs and desires of travelers (Kreutzwiser 1989 cited in Dissert and Marcoullier 2012). Dissert and Marcoullier (2012) observe, "The value of natural amenity endowments (e.g., forest, water, wildlife, geologic resources, etc.) is clearly seen as integral to the rural tourism product." How does this relate to the lure of wild and native trout to visiting anglers?

First, wild and native trout can be perceived as a valued amenity by anglers, who will favor wild trout over stocked trout if they know the difference. A recent Wisconsin Department of Natural Resources (WI DNR) survey of trout anglers in Wisconsin asked them whether they favored fishing for wild fish compared to stocked trout. By a three to one margin (61 to 18%), they said they preferred to fish streams where wild trout were present, compared to streams where stocked trout were present. A significant number (14%) said they simply preferred not to fish for hatchery trout (Petchenik et al. 2012).

Second, anglers in Wisconsin report they will drive significant distances to fish streams inhabited by wild trout, rather than hatchery trout. Near Coon Valley, Wisconsin, lies Timber Coulee, often cited as one of the Midwest's premier trout fisheries. Its trout population is made up primarily of Brown Trout, naturally reproducing within the larger Coon Creek system. While some hatchery fish make it into parts of the Coon Creek system, they are fingerlings from feral brood stock Brown Trout. Seventy-nine percent of Timber Coulee anglers in a recent angler survey, conducted by WI DNR employees in 2008, reported they drove over 50 mi to fish there (Mitro et al. 2008). In that survey, researchers compared 1984 and 2008 creel surveys on the same reach of stream, and found that the fishery had become essentially catch-and-release, harbored larger fish despite a regulation in 2008 that allowed harvest of five fish under 12 in, and anglers had become predominantly fly-fishers. Anecdotally, license plate surveys at parking sites on both Timber Coulee and the nearby West Fork of the Kickapoo now reveal a wide variety of states represented on these streams, with a great number of Wisconsin and Illinois plates, a significant group

of Minnesota and Iowa plates, and an increasing number of plates from across the nation. In contrast, an earlier creel survey on the same reach of Timber Coulee, conducted by the late Robert Hunt for WI DNR in 1984, showed that 89.5% of anglers traveled 24 mi or less to fish the stream at that time. According to former fisheries managers, angling in the 1980s on Timber Coulee relied much more on hatchery-produced trout than in the past two decades (D. Vetrano, personal communication).

Third, anglers appear to be responding not only to significant numbers of wild trout they can pursue in these fisheries, but to the burgeoning number of amenities available to them in those areas. Cottages, bed-and-breakfast inns, lodges, guides, and fly shops are becoming more readily available in central areas of the Wisconsin and Minnesota Driftless Areas, as fewer and fewer hatchery trout are being stocked in these streams. An experienced operator of a bed and breakfast in the Wisconsin Driftless Area told this writer that while anglers didn't make up a majority of her business, they constituted a reliable fraction of about 20%, year in and year out (M. Cimino pers. commun.) Her business strategy was to continue to court these anglers in markets a drivable distance from her site. As a result, many drive from Chicago or Milwaukee to spend weekends at her inn, some 4 to 5 h away, on a regular basis during the open trout season. While pursuing their sport, trout anglers spend significant money in these areas. A 2008 study of the economic impact of recreational angling in the Driftless Area, commissioned by Trout Unlimited, found that over \$1.1 billion was spent annually by trout anglers in the region (Hart 2008).

## CONCLUSION

As more and more waters across the Driftless Area are restored to healthier fisheries, stocking has been reduced and wild trout are primarily the catch of the day. In areas with less restoration, more stocking is done and fewer travelers are reported. However, more than ever, anglers are willing to drive to fish in high-quality, regionally-significant trout fisheries. Other amenities of tourism are expanding with an aim of attracting these traveling anglers, and are providing

opportunities for more tourism spending in these areas. Further research can compare the availability of accessible trout fisheries populated by wild trout within the region with other fisheries which lack quality trout habitat for wild fish.

## REFERENCES

- Anderson, A., Hewitt, L., and Marcoullier, D. 2001. Canoeing and angling in southwestern Wisconsin. Board of Regents of the University of Wisconsin System, Madison, Wisconsin.
- Cimino, M. co-owner of Westby House bed & breakfast. personal communication.
- Clawson, M., and Knetsch, J.L. 1966. Economics of Outdoor Recreation. Johns Hopkins Press, Baltimore, Maryland.
- Dissert, J., and Marcoullier, D. 2012. Rural tourism development and the experience-scape. *Tourism Analysis*, Vol. 17, 691-704.
- Erickson, J. 2012. Iowa's spring creek paradise: exploring the driftless region along the great river. *Fly Fisherman magazine*. October-December 2012.
- Hart, A. 2008. The economic impact of recreational trout angling in the Driftless Area. Northstar Economics, Middleton, Wisconsin.
- Leopold, A. 1949. *A Sand County Almanac*. Oxford University Press, Oxford, England.
- Mueller, R. 2000. *Fly-fishing midwestern spring creeks: an angler's guide*. Mueller Publications. Appleton, Wisconsin.
- Mitro, M., J. Weeks, and D. Vetrano. 2008. Trout angling on Timber Coulee Creek: a comparison of creel surveys from 1984 and 2008, Wisconsin Department of Natural Resources, Madison, Wisconsin. Manuscript in draft form.
- Petchenik, J., M. Mitro, M. Engel, and R. S. Stewart. 2012. Wisconsin angler preference survey. Wisconsin Department of Natural Resources, Madison. Manuscript in draft form.
- Snook, V., and D. Dieterman. 2006. A roving creel survey of selected southeast Minnesota trout streams—2006. Minnesota Department of Natural Resources, St. Paul.
- Thompson, R. 2012. *Heart of the Driftless*. Thirdyearflyfisher Productions, Chicago, Illinois.
- Trout Unlimited. 2005. *The Midwest's Driftless Area: Landscape of Opportunities*. Arlington, Virginia.
- Vetrano, D. Wisconsin Department of Natural Resources fisheries biologist, personal communication.

## FLY FISHING THROUGH THE CLIMATE CHANGE CRISIS: PEDAGOGY, STEWARDSHIP, AND LEARNING ‘THE TRICK OF QUIET’

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**Abstract**—In the face of the rapidly accelerating threats of global climate change, environmentalists, scientists and others have suggested the need for species diversity, habitat restoration, reduction of non-climate stressors, changes in angling regulations and a host of other steps to enhance the likelihood of sustaining wild trout populations in a warming world. All of these are worthy goals. But what role can anglers themselves play in the fight for fundamental policy changes to slow the advance of climate catastrophe? Is increasing educational awareness enough? Or must fly fishers themselves get more “political?” For a decade I have been teaching a First Year Seminar on the literature and craft of fly fishing at Saint Michael’s College in Vermont. This paper will explore my experiences as a teacher of fly fishing’s history and traditions and suggest that the rich literature and hallowed practices of fly fishing offer a framework for understanding the responsibilities we face in an environmentally catastrophic world. From Dame Juliana Berners to Izaak Walton, Aldo Leopold to Wallace Stegner, John Gierach to Howell Raines, the embrace of wilderness and fly fishing as a metaphor for spiritual sustenance have been touchstones for those who would pursue trout and preserve their environs. In his seminal 1960 “Wilderness Letter,” Stegner makes a passionate call for the “spiritual refreshment” nurtured by engagement in the natural world. He quotes an observation by Sherwood Anderson, that early Americans in the fields and forests, on the prairies and the plains naturally got “a sense of the bigness outside themselves.” According to Anderson, “They had learned the trick of quiet.” Fly fishers live for that sense of bigness; they revel in the trick of quiet. Yet, the irony of the 21st century fly fisher may be that learning the trick of quiet now requires us to make a lot of noise.

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“Sixty million disorganized fishermen are being hornswaggled by highly organized and greedy elites... We really ought to get together.” —Thomas McGuane

### INTRODUCTION

In his book *Fly Fishing Through the Midlife Crisis* (1993), journalist and former *New York Times* editor Howell Raines offers a plea for us to lead balanced lives as a way to navigate the troubled waters of this life passage. He conveys this message through his own maturing approach to fishing as his “Redneck Way” was transcended by “Blalock’s way”—fishing for meat is supplanted by rising above the need to catch fish in order to achieve spiritual depth. Balance can be achieved by leading meaningful lives (he covered some of the most important political figures of the twentieth century) while also seeking the immense joys of pursuing trout in the beautiful places they inhabit.

Raines’s embrace of the spiritual side of fly fishing is hardly a new story, nor is the call for balance. Going back at least as far as Dame Juliana Berners’s 1496 essay “A Treatyse of Fysshynge with an Angle”

and selections from Izaak Walton’s 1653 classic *The Compleat Angler*, writers have explored the confluence of spirituality, ethics and balance inherent in fishing in general and fly fishing in particular. Berners and Walton both claim that fishing can lead to personal self-improvement. Berners recommends the pursuit of fish “for your solace and to promote the health of your body and specially of your soul.” She urges her readers to not be greedy by taking too many fish or destroying the environment while practicing the art, for a lack of balance and perspective “could easily be the occasion of destroying your own sport and other men’s also.” In early form, she endorses an ethic of environmental stewardship. Walton, too, views fishing as a way to appreciate the natural world. He touts the quiet, contemplative nature of fishing, promoting joyful embrace of nature—being alive and aware—and the thoughtful, peaceful civility that enhances human

interaction. Commenting in an Introduction to a modern edition of Walton, Thomas McGuane observes that

[L]earned, equitable Izaak Walton, by demonstrating how watchfulness and awe can be taken within from the natural world, has much to tell us—that is, less about how to catch fish than about how to be thankful that we *may* catch fish. He tells us how to live (p. 15).

McGuane hopes Walton's 17<sup>th</sup> century call for humans to overcome their alienation from nature will resonate in our day, when it is even more essential than ever given the grave challenges of global climate change. Channeling Berners, Robert Hughes (1999) puts the case for a balanced engagement with nature more bluntly: "There is no defensible ethic or esthetic of angling that doesn't canter on moderation" (p. 117).

## THE FLY FISHING SEMINAR: A RIVER RUNS THROUGH IT

Balance, moderation, environmental stewardship, spiritual renewal in the natural world—all of these desirable qualities merge in the work of novelist and environmentalist Wallace Stegner. In his classic 1960 "Wilderness Letter" Stegner offers a spirited defense of "The wilderness idea." He concludes by suggesting that wilderness "can be a means of reassuring ourselves of our sanity as creatures, a part of the geography of hope, echoing the passionate earlier calls of hope and salvation in Henry David Thoreau and John Muir (Allen 2013). Stegner goes on to make an impassioned case for the restorative power of wilderness as a natural place for "a civilized man who has renewed himself in the world." Illustrating the "spiritual refreshment" nurtured by engagement in the natural world, he quotes an observation by Sherwood Anderson, that early Americans in the fields and forests, on the prairies and the plains naturally got "a sense of the bigness outside themselves." According to Anderson, "They had learned the trick of quiet." Fly fishers live for that sense of bigness; they revel in the trick of quiet.

But what does it mean to learn the trick of quiet in the 21st century? In the face of the rapidly accelerating

threats of global climate change, environmentalists, scientists and others have suggested the need for species diversity, habitat restoration, reduction of non-climate stressors, changes in angling regulations and a host of other steps to enhance the likelihood of sustaining wild trout populations in a warming world. All of these are worthy goals discussed in this symposium. But what role can anglers themselves play in the fight for fundamental policy changes to slow the advance of climate catastrophe? Is appreciating and embracing the quiet of the natural world enough? Is increasing educational awareness enough? Or must fly fishers themselves get more "political?"

For a decade I have been pondering such questions while teaching a First Year Seminar (FYS) on the literature and craft of fly fishing at Saint Michael's College in Vermont (Grover 2011; Crawford 2012). This paper will briefly explore my experiences as a teacher of fly fishing's history and traditions and suggest that the rich literature and hallowed practices of fly fishing offer a framework for understanding the responsibilities we face in an environmentally catastrophic world. Through this seminar I have made a modest contribution to nurturing the reassurance and hope envisioned by Stegner. Titled "A River Runs Through It: The Literature and Craft of Fly Fishing," the seminar is intended to expose students to the storied literature and passionate practice of fly fishing. The topic carries a deep literary tradition and is inherently interdisciplinary, spanning the fields of biology, entomology, ichthyology, and ecology to explorations of history, philosophy, ethics, religion, politics, class, gender, poetry, and the craft of fly tying. I envisioned a natural synergy of the formal seminar classroom and the greater "classroom" of nature. To that end I hoped the literature would come to life if matched by real, hands-on engagement, and reciprocally, the field work and fishing would be more meaningful and enduring when reinforced through knowledge of the history and literature of fishing. Thinking about such rich and varied connections—disciplining the mind to see entwined perspectives and new ways of knowing—is invaluable. Little about our world is more readily understood through the narrow lens of just a single, isolated perspective. Although I have varied the seminar each fall semester, some major categories and themes have remained constant.

## Entomology, Ecology, and Field Work

We begin with readings focused on entomology and the lifecycle of insects, paying particular attention to mayflies, caddis flies and stoneflies. Among many articles I've used, Dave Whitlock's short essays on aquatic insects for *Trout* magazine are especially clear and informative for the non-specialist. Gierach (1990) brings a less technical but still useful and enjoyable perspective to bear on the life cycle of insects—it is, after all, just sex, death and fly fishing. David Quammen (1988) adds his personal appreciation for trout as an indicator species, a barometer of the ecological health of the environment where trout live. I have supplemented these readings with brief films, notably "The Hatch" and "Why Fly Fishing." I also have a member of the College Biology Department give a full-class talk on stream ecology and insect life, and he guides the entomology portion of our field work. Field work encompasses the next several weekends—these are required extra sessions. For the first trip we go to the Browns River, a small stream with a healthy naturally reproducing population of many types of fish, including Brown Trout *Salmo trutta* and Brook Trout *Salvelinus fontinalis*. The biologist leads one-half the class in the exploration of stream samples, primarily having some students kick up the substrate while downstream other students collect and identify the loosened aquatic life captured in D-frame nets. His colleague in the Biology Department, an ichthyologist, leads the other one-half of the class in stream shocking, taking time to examine and identify the diversity of fish species. Halfway through, we switch tasks. These hands-on experiences help illuminate some of the articles we have read, and they serve the additional practical goal of getting students accustomed to wearing waders.

Next we begin casting lessons and learning about the basic equipment involved in fly fishing casting—rods, reels, lines, leaders and tippets. Virtually all students are complete beginners with a fly rod. For these activities I draw on the expertise of fellow members of the Central Vermont Chapter of Trout Unlimited. Vermont weather is notoriously fickle, but September typically is a reliably beautiful month, so all of our field work is front-loaded into the first four weeks of the semester. Two full class sessions are devoted to casting lessons on the lawns overlooking the Green Mountains. I assist the casting instructor with the inevitable questions and frustrations that

arise. The second Saturday of this field work sequence is then spent in a large group fishing session on the Winooski River, where the students fish for the first time. Subsequent weekends are spent with me leading small groups of students to various sections of the Winooski River—Saturday and Sunday, two groups per day. Each student gets at least three trips to the water, and the thrill of watching them catch and release a fish never gets old.

## History

A section on the history of fly fishing is a must for situating the craft within a context that accounts for shifting political, economic and cultural values. The dilemma is where to begin and what to exclude. There are many options and the choices can be brutal. I have found Hughes's *A Jerk on One End* (1999) to be both brief and fairly comprehensive. He's a clear writer who moves through the long sweep of history with just enough detail for it all to make sense. I supplement his book with Berners's essay "A Treatise of Fysshynge with an Angle" and selections from Walton's classic *The Compleat Angler*—two iconic works that Hughes discusses as well. In addition to the often elusive combination of brevity and solid coverage, Hughes writes in an autobiographical style that fits in well with the next section of the seminar, and in tandem with Berners and Walton he offers our first foray into the ethics of fishing and the concept of environmental stewardship.

## The Search for Self

Not only is the seminar the namesake of Norman Maclean's *A River Runs Through It*, the novella also serves as the spiritual center of our endeavors. Students are powerfully drawn to the story of young Norman's search for a sense of who he is as he struggles to connect with his family and, especially, as he grapples with his inability to help his troubled and beautiful brother Paul. The themes of self, family, religion and fly fishing are interwoven with the awe and wonder of the landscape of southwestern Montana. The novella resonates with students on many levels, and it is a treat to watch them find new meanings and insights over the years. Maclean is so effective and affective for them because of their own lifecycle; college students are at a point in their lives when developing a sense of who they are is a full time job. That Maclean leaves them with no easy out makes

his work more profound, if unsettling. He remains famously “haunted by waters,” while students are haunted by the questions he leaves behind. To this masterpiece I add a story by Jan Zita Grover titled “Why Fish?” Her reflections about learning how to cast a fly while she is simultaneously haunted by the reproachful voice of her late father suggest that we all bring baggage to the water. Ernest Hemingway’s classic “Big-Two-Hearted River” also plays on the theme of self and memory and the struggle to construct a future while haunted by the past. And it is a delight to compare and contrast his clipped prose to the soaring flourishes of Maclean. Finally, David James Duncan’s *The River Why* is a class favorite, in part because Gus Orviston’s coming-of-age speaks to where the students are in their own lives, and does so against the backdrop of fishing in the Pacific Northwest. As a paean to the need for love and inner balance, it is important for the students to see Gus, the master fisherman, being “unmade” as he becomes “an undone fisherman”—his search for self leading him to make true progress as a person. He offers his readers the prospect that in the quest to find our *self* we may need to *unfind* some aspects of who we are. This need to rethink the fundamentals resonates with our current situation as people on a planet facing dire environmental troubles. For surely “nature” is no mere external force, neatly separable from us. We are part of it. We cannot “save” it without contemplating how our practices, our way of life, our *selves* threaten it.

### The Craft of Fly Fishing

I continue to have the students learn the basics of fly tying, near the end of the semester, when the weather outside has turned toward winter and we’ve been entrenched in literature for a long stretch. It’s a nice break and it shows them how one can stay connected to the practice of fly fishing even when actual fishing is not possible. Maclean (1976) invites us to think about craft both by directly talking about fly tying in his novella and through passages like this:

One of life’s quiet excitements is to stand somewhat apart from yourself and watch yourself softly becoming the author of something beautiful, even if it is only a floating ash (p. 43).

Here he is referring to a well-delivered cast, but the floating ash imagery is poignant, and it is

evocative of fly tying as the creation of floating ashes through the assemblage of feathers, hair and thread. I want my class to see that the connection between a short story, a mayfly dun floating on some riffles in a Vermont river, and a collection of feathers, dubbed hair, wire, and chenille is something beautiful, close to magical. I have a master fly tier from TU lead these two class sessions, where we tie two basic flies per meeting (eg. woolly buggers, Mickey Finn, hare’s ear Adams, Vermont caddis), and with my intermediate skills I serve as his assistant.

### Contemporary Dilemmas of the “New West”

It’s always a challenge to choose a final book for any course. By the end of the semester students (and faculty) are tired, and the best of intentions—to expose the students to some gem as the farewell text with all the answers—often are dwarfed by our collective fatigue. My response is to assign an “easy one,” easy in the sense that it is fairly brief and written in an accessible style. I’ve made several attempts to get this right, but I’ve had my best results with Robert Lee’s epistolary novel *Guiding Elliott*. Lee’s bumbling protagonist, fly fishing guide Donnie Phillips, faces multiple challenges as contemporary life presses up against his more traditional “backward” looking approach to life. But underneath his politically incorrect attitudes and endearing malapropisms are some important core principles. And as he reluctantly adjusts his orientation to the role of women, his emerging role as a craftsman beyond the water, and the encroachment of development on his pristine Montana, we find real wisdom in his parting counsel to “listen to rivers.” Excellent class discussions have resulted from the students wondering what we might hear if we listen to rivers.

### LIMITATIONS AND OUTCOMES OF THE FYS MODEL

The single biggest constraint of my first year seminar experience will sound familiar to any teacher: mission overload. We all desire our courses to be, at least in some sense, comprehensive. The tendency, then, is to try to do too much in one semester, leaving me with the feeling that at times we’ve given short shift to pretty much everything. Lots of classic literature gets left unread. Anyone with a working

knowledge of fly fishing’s rich literary fare would be surprised to see this or that classic gem omitted from the syllabus. But choices have to be made given time constraints. This feeling of incompleteness is compounded by the fact that the FYS model is freighted with requirements. Students read a common text in the summer and come to our first class meeting with a paper they’ve written about it, and that becomes the focus of the first week of class. But the common text does not have direct, obvious connections to any seminar per se. Since all seminars also are writing intensive, students must write frequently, certainly every week and often for every class session. This magnifies the time pressure within the quest for completeness, since portions of almost every class are devoted to students reading their own work aloud and offering suggestions to each other. Sometimes this writing intensive requirement creates a disjuncture in their view of the class. The field work—entomology, casting, fishing—is fun; we have a great time. But I still must remain a task master since the class serves a gatekeeper role for determining which students will be deemed “writing proficient” and which will be recommended for further writing classes. Thus the fun is tempered by serious business. We also are required to address the issue of academic integrity and introduce students to the use of library resources. Add to this my own commitment to students making at least one oral presentation of our readings to enhance their public speaking skills, and the time pressures intensify. These limitations aside, the strengths of the FYS model are considerable. Moreover, FYS helps us forge tight bonds with these students because of the variety of shared experiences (Belec and Crawford), bonds that open up important opportunities to have a lasting impact. And alumni have taken notice too. Many responded to an article in the alumni magazine with offers of equipment for the club and books for what is now a growing collection of fishing volumes for our library.

Certainly none of my reflections are offered as a blueprint. Pedagogical experiments like this need to be refined to see what works and what doesn’t, and I’ve discussed these limitations and outcomes elsewhere (Grover 2011). Here I want to focus one particular result—an attitudinal outcome—that, while hard to quantify, has affected how many of these students think about fly fishing and the window it opens into environmental issues and the need for stewardship of

natural resources. Such changes in perspective emerge in the conversations we have after each class and after the semester ends. They continue to be manifested in the work students do when they take subsequent Political Science classes with me, including Environmental Politics. In most instances students simply cannot be on the water with a fly rod in your hand for any length of time and not want to preserve and protect rivers and fish (particularly threatened cold water species) as a treasure. But the challenges, quite obviously, are daunting—indeed, unprecedented for the human species. Can the quiet humility and civility celebrated in so much of the fly fishing literature meet the challenges we face? Noted nature writer and environmental ethicist Aldo Leopold offers some perspective on this question in his discussion of leisure time hobbies (Leopold 1953). Describing a hobby as “the defiance of the contemporary” and the hobbyist as a classic nonconformist, he views a hobby as “an assertion of those permanent values which monetary eddies of social evolution have contravened or overlooked.” If this is true, he observes, then “every hobbyist is inherently a radical” (p. 4). He cautions, though, that the bane of the hobbyist is becoming too serious in seeking a rational justification. And herein lies the dilemma: on the one hand, “a good hobby...is a rebellion;” on the other hand, if it becomes too self-serious it becomes an industry, losing its subversive quality. What to do, then, when engaging in the serious business of politics and activism may offer the only way to preserve the terrain on which you practice your fly fishing hobby—the clean, cold water of rivers?

## CLIMATE CHANGE AND THE “TRICK OF QUIET”

Climate change and the attendant pressure it puts on our political, economic, social institutions—as well as the environmental fabric of the planet—poses potentially catastrophic dangers to our ecosystem that will continue even if nations were to take immediate and drastic coordinated action to redress them (McKibben 2007 and 2010; Kolbert 2006). Kolbert’s assessment is stark: “It may seem impossible to imagine that a technologically advanced society could choose, in essence, to destroy itself, but that is what we are now in the process of doing” (p. 189). Renowned environmentalist and activist Bill McKibben makes an impassioned case for such a conceptual reformulation

with urgent emphasis in his book *Deep Economy* (2007). McKibben carefully builds his case that we now face three fundamental challenges to the orthodox idea of growth as “more is better.” The first challenge is *political*. Defining economic growth (think rising GDP) as the continued quest for more—“the endless More”—produces staggering levels of inequality and insecurity, with unacceptable negative political and economic consequences. The second challenge comes from *Physics and Chemistry*. We do not have the energy sources we need to keep the magic of economic growth going without doing irreparable harm to the environment due to rapid climate change. The continued burning of fossil fuels portends a global climate catastrophe, the scientific basis of which has gotten noticeably worse with recent projections (McKibben 2012), a point driven home even more dramatically in May as the concentration of carbon dioxide in the atmosphere passed 400 ppm for the first time, well above the 350 ppm level climate scientists view as the “safe limit” for Earth as we have known it. Finally, the third challenge he deems *spiritual*. Even when growth does make us wealthier, beyond a certain point research shows that greater wealth does not make us any happier. The confluence of these three challenges has turned our old planet Earth into Eaarth, an “uphill planet,” where basic life will get progressively more difficult. As he warns, “This is the biggest thing that’s ever happened.” In essence “we’re running Genesis backward, decreating” (McKibben 2010).

Is it enough now to appreciate being “haunted by waters” or advocate listening to rivers? Must fly fishers and fly fishing seminars become more explicitly political so we have pristine trout-filled waters to ponder and listen to in the future? McGuane suggests as much in the quote that frames this paper from his opening remarks in *The Longest Silence*, proclaiming that “sixty million disorganized fishermen are being hornswaggled by tightly organized and greedy elites.... We really ought to get together” (pp. xiv-xv). Stegner was hopeful about the transformative impact of nature and wilderness. His “geography of hope” would flow from a rethinking of our relationship to the land. He contends that we need to

stop viewing wilderness as crudely exploitable in order to celebrate wilderness as an idea, an ideal worthy of preservation and expansion in and of itself—a spiritual resource. Time is limited, though, as he acknowledged in 1980 when he revisited his “Wilderness Letter” and found that his opinions “have actually been sharpened by an increased urgency. We are 20 years closer to showdown.” In those updated reflections he pointedly identifies the titanic clash between the public interest and corporate interests as the crux of the problem, with government too often enabling corporate interests to exploit natural resources at the public’s expense. McKibben, too, has become more explicitly political through his grassroots organization 350.org and its many protests and his recent “Do the Math” tour aimed at increasing public awareness and putting pressure on lawmakers and the President. He urges us to move beyond environmental platitudes and directly challenge the fossil-fuel industry, which he terms “a rogue industry, reckless like no other force on Earth.” He continues, “[T]hese numbers make clear that with the fossil-fuel industry, wrecking the planet is their business model. It’s what they do” (McKibben 2012).

The environmental message necessarily is urgent. My seminar is but one small attempt to introduce students to the myriad complexities that arise from engagement with the literature and craft of fly fishing. Thus I offer these observations tentatively. Students (all of us) need to ask deep questions about ourselves and the established practices of our society and our world. But in so doing, we also need to be mindful of the call for perspective and humility that rings from the words of Berners and Walton right up through the recent work of Anders Halverson in his critique of the fish culture movement and its effusive embrace of the stocking of Rainbow Trout *Oncorhynchus mykiss* (Halverson 2010). Unintended consequences lurk at every river bend. May I modestly suggest, in closing, that we no longer can limit ourselves and our fly fishing students to learning how to read the water. We also need to know how to read ourselves and the world. In so doing we may come face to face with the irony of the 21st century fly fisher—that learning the trick of quiet now may require us to make a lot of noise.

## REFERENCES

- Allen, L. 2013. "Protecting 'The Salmon Forest.'" *Trout* 55(3): 22-25.
- Belec, H.M. 2010. TU's Next Generation. *Trout* 52(3):41-48.
- Berners, D.J. 1496. *A Treatyse of Fysshynge with an Angle*. University of Oregon. Available: <https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/680/fishing.pdf?sequence=1>. (June 2010).
- Crawford, C. 2010. Fly Fishing and First-Year Students. *Saint Michael's College Magazine* (Winter).
- Duncan, D.J. 1983. *The River Why*. Bantam, New York.
- Gierach, J. 1990. "Sex, Death, and Fly-Fishing." *Sex, Death, and Fly-Fishing*. Simon and Schuster, New York.
- Grover, J.Z. 1999. "Why Fish?" *Northern Waters*. Gray Wolf, St. Paul, Minnesota.
- Grover, W. 2011. "Piscatorial Pedagogy and the 'Geography of Hope': Reflections on Teaching the Literature and Craft of Fly Fishing." *Yale Anglers' Journal* 11(2): 85-97.
- Halverson, A. 2010. *An Entirely Synthetic Fish*. Yale University Press.
- Hughes, R. 1999. *A Jerk on One End*. Ballantine Publishing Group, New York.
- Kolbert, E. 2006. *Field Notes from a Catastrophe: Man, Nature and Climate Change*. Bloomsbury USA, New York.
- Lee, R. 1997. *Guiding Elliott*. The Lyons Press, New York.
- Leopold, A. 1953. *Round River*. Oxford University Press, New York.
- Maclean, N. 1976. *A River Runs Through It and Other Stories*. University of Chicago Press, Chicago.
- McGuane, T. 1999. *The Longest Silence: A Life in Fishing*. Alfred A. Knopf, New York.
- McKibben, B. 2007. *Deep Economy: The Wealth of Communities and the Durable Future*. Times Books, New York.
- McKibben, B. 2010. *Eaarth: Making a Life on a Tough New Planet*. Times Books, New York.
- McKibben, B. 2012. "Global Warming's Terrifying New Math." *Rolling Stone* (July 19).
- Quammen, D. 1988. Synecdoche and the Trout. Pages 3-9 in D. Seybold, editor. *Seasons of the Angler*. Weidenfeld and Nicolson, New York.
- Raines, H. 1993. *Fly Fishing Through the Midlife Crisis*. William Morrow and Co., New York.
- Stegner, W. 1960. *Wilderness Letter*. The Wilderness Society. Available: <http://wilderness.org/content/wilderness-letter>. (March 2010).
- Stegner, W. 1980. Introduction to *Wilderness Letter*. The Wilderness Society. Available: <http://wilderness.org/content/wilderness-letter-introduction>. (June 2010).

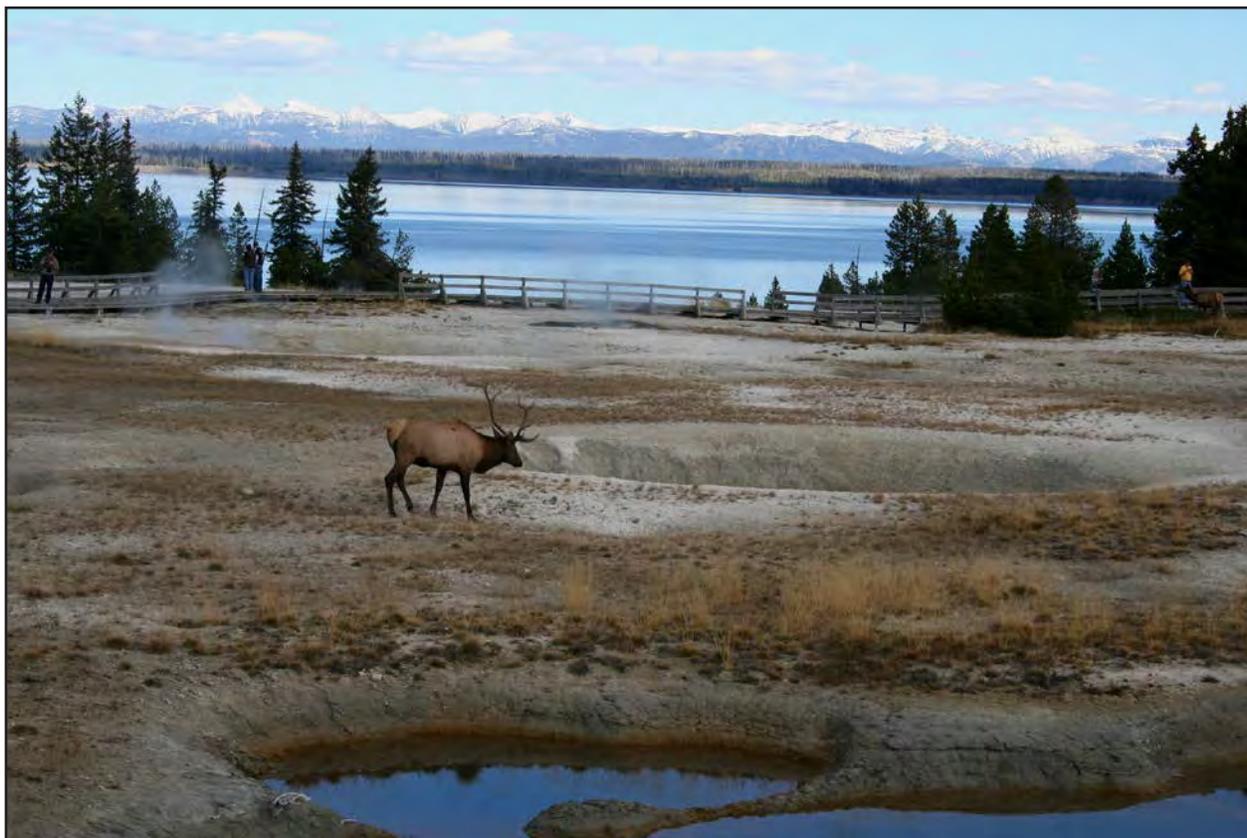


Photo courtesy of Eric Stark.

# Session 3

## Struggling with Invasive Species





## NOBLE VERSUS NATIVE—THE SOCIETAL CHALLENGES OF RESTORING NATIVE TROUT IN YELLOWSTONE NATIONAL PARK

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### INTRODUCTION

A large body of peer-reviewed science has demonstrated that nonnative salmonids can negatively affect native salmonids in a variety of aquatic systems, worldwide. Specifically, many studies have shown that the introduction of nonnative salmonids have contributed to the decline of native species, such as fluvial Arctic Grayling *Thymallus arcticus* and Cutthroat trout *Oncorhynchus clarkii* in the Greater Yellowstone Ecosystem. Results of scientific studies, coupled with National Park Service (NPS) policies aimed at maintaining and restoring natural systems with native species, led Yellowstone National Park to develop a Native Fish Conservation Plan to conserve and restore native fish species. The plan describes strategies to restore Yellowstone Cutthroat Trout *O. clarkii bouvieri* in Yellowstone Lake and riverine systems in the park's northeastern region and Westslope Cutthroat Trout *O. clarkii lewisi* and fluvial Arctic Grayling in streams along the park's western boundary. The purpose of the park's plan is to prevent the extirpation of native fish species within the park, maintain ecological processes, and maintain high quality fish watching and recreational angling experiences. Management activities focus on the removal and control of nonnative salmonids through fisheries management techniques such as the application of piscicides, selective fisheries regulations, and gillnetting. The plan focuses on restoring Yellowstone Cutthroat Trout in Yellowstone Lake, maintaining pure Yellowstone Cutthroat Trout in the park's Lamar River drainage, and restoring Westslope Cutthroat Trout and fluvial Arctic Grayling to rivers on the park's west side.

### PUBLIC OUTRAGE

Although the park's plan is anchored by a robust body of science and strongly supported by many conservation and fishing advocacy groups, some recreational anglers have had a difficult time accepting the removal of noble, yet nonnative trout, despite the

fact that their presence has contributed to significant declines in native fish species. In particular, several recreational anglers in the Jackson Hole, Wyoming area decided to launch a public campaign criticizing the park's native fish conservation activities. One member of the public started a nonprofit organization. Members of the public and the organization wrote dozens of letters to the National Park Service and numerous other politicians and media organizations. In short, the organization was critical of the killing of nonnative species, such as Lake Trout *Salvelinus namaycush*, to restore native species. The organization also criticized the use of piscicides and catch-and-kill requirements that were put into place in a small number of the park's creeks, rivers, and lakes to help remove nonnative species. The organization's communications sometimes included myths and inaccuracies regarding fisheries ecology, conservation, and management. Numerous newspaper and magazine articles, radio and television stories, and internet blogs highlighted the controversy. The workload associated with attempting to provide facts and correct misinformation associated with the controversy became a challenge for the park.

### THE PERFECT STORM

The primary outrage associated with the park's program was related to the killing of nonnative Lake Trout in Yellowstone Lake. The organization believed that Lake Trout were not a threat to native Yellowstone Cutthroat Trout and felt strongly that Lake Trout should be preserved as a fishery in Yellowstone Lake. Coincident with the park's Lake Trout control program, we also initiated stream restoration projects that included the use of rotenone, a new series of catch-and-kill regulations, and continued electroshocking removal projects on a small, select number of streams where Rainbow Trout *O. mykiss* hybridization with Cutthroat Trout is seriously threatening the long-term persistence of native Cutthroat Trout. The implementation of these activities

coincident with the Lake Trout control program appeared to be a tipping point for some anglers who perceived the park’s program as threatening to their long-standing use of park fisheries resources.

## MYTH-BUSTERS

Despite the science indicating that nonnative trout can and do negatively impact native trout, members of the public had their own opinions on these potential impacts and publically stated their hypotheses, many of which were not supported by current science. Examples included:

*Lake trout are not impacting Yellowstone cutthroat trout in Yellowstone Lake through predation.*

*Whirling disease, the 1988 fires, and drought are the primary factors affecting the decline of cutthroat trout.*

*Rotenone causes Parkinson’s disease, negatively impacts wildlife that drink from streams, and sterilizes the body of water where it is applied.*

## TO THE RESCUE

At the onset of launching the native fish conservation program, the park developed a strong partnership with conservation and recreational angling organizations, such as Trout Unlimited and its state organizations in Idaho, Montana, and Wyoming, The Federation of Fly Fishers, The Greater Yellowstone Coalition, the National Parks Conservation Association, Wyoming Game and Fish, Montana Fish, Wildlife, and Parks, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and others. As a result, prominent scientists and resource managers from these organizations were able to assist the park by publically, through opinion editorials, articles, and public education efforts, counteract the myths and inaccuracies that were sometimes promulgated by those unsupportive of the park’s native fish

conservation efforts. These partner communication efforts were essential to providing facts for the public conversations that were ongoing.

## LESSONS LEARNED

Many lessons were learned from our approach to implementing a progressive and large-scale native fish conservation program. First, society was not completely ready for native fish restoration at the expense of nonnative trout – to many, the bend of a rod and traditions involving catching nonnative fish appeared more important than native fish biodiversity. Second, it appears that the catch-and-release ethic is so strongly engrained in the recreational fly angling community that killing nonnative fish is difficult to embrace. It also appeared that the public does not understand the role of the NPS in maintaining native species and ecological processes and, similarly, the NPS is only beginning to understand the attitudes, understanding, and desires of the recreational angling community.

## RECOMMENDATIONS

It would be valuable to spend more time with the industry (fly shops, guides, etc.). These members of the public should be considered park partners and they may help to effectively provide facts as they are the opinion leaders in the recreational angling community. The park may have taken the science for granted, assuming that the public understand the science and how it influences management. Fisheries managers should socialize the science – synthesize and use balanced pieces of information to help educate the public on the “why”. Managers may also make a more concerted effort to implement education and outreach in myriad ways: website, social media, printed media, public meetings, and informal discussions. Finally, to help build trust, managers should concentrate on communicating successes; the stories of native fish restoration projects have resulted in unique, high quality angling opportunities for anglers.

## LAKE TROUT SPAWNING BEHAVIOR AND SITE SELECTION IN YELLOWSTONE LAKE: CARRINGTON ISLAND AND BEYOND

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**Abstract**—Lake trout *Salvelinus namaycush* suppression in Yellowstone Lake has primarily relied on removal with gill and trap nets; however, new strategies to maximize program effectiveness include destruction of Lake Trout embryos on spawning grounds. Because these methodologies require knowledge of spawning areas, an acoustic telemetry study was initiated in 2011. Two hundred seventy-nine adult Lake Trout (> 500 g) were implanted with acoustic transmitters. A subset of transmitters was equipped with depth/temperature sensors to gain further insight into Lake Trout spawning behavior. Fifty-two receivers were deployed in Yellowstone Lake, and an additional 11 receivers were arrayed near Carrington Island to provide two-dimensional positions of Lake Trout at the known spawning location. Data collected from this fine-scale array yielded important information about movement patterns and timing of spawning activities around the island. Comparisons with Lake Trout detections at other receivers in the lake suggested additional potential spawning locations. For example, Lake Trout were frequently detected near the surface at Carrington Island, and instrumented individuals were consistently located at shallow depths (< 3 meters) at only six other sites around the lake. Combined with temperature data, results suggest a potential spawning window from early September to early October for Lake Trout in Yellowstone Lake. Research is currently focused on verification of the recently identified putative spawning sites.

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## DIRYMO OR LESS? AN ASSESSMENT OF BIOLOGICAL IMPACT TO A VIRGINIA TAILWATER

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**Abstract**—*Didymosphenia geminata* (didymo) is a stalk-producing alga that can create carpeted layers of biomass on the substrate of oligotrophic streams, presenting problems to trout fisheries worldwide. Didymo is an invasive diatom to Virginia and has been located in four coldwater tailraces statewide. Didymo was first identified in the Jackson River Tailwater in Alleghany County, Virginia in 2006. The Jackson River Tailwater is a 29-km reach that supports naturalized populations of Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* from <150C water released from Gathright Dam. We developed a methodology to score didymo relative abundance and distribution at two locations from 2008 to 2010. Didymo scores peaked in May at a transect immediately below the dam and began to decline throughout the summer as water temperatures and turbidity increased. Didymo presence was consistently low at the Johnson Spring transect, located 5.8 km downstream of the dam. Benthic macroinvertebrate abundance remained high before and after didymo infestation at the dam transect; however, there was a sharp decline in Simuliidae larvae with a concurrent increase in Chironomidae larvae. Rainbow Trout relative abundance at the dam transect began to decline in 2002, but stabilized to a mean catch rate of > 150 fish/h in the post-didymo infestation years. From this study, didymo appears to have a short growing season and a limited range of infestation in the Jackson River Tailwater. Biological and recreational impacts to the fishery appear to be minimal, although more research is needed. The scoring protocol used in this study is an inexpensive, rapid method of quantifying algal abundance that can be used by citizen scientists to aid professionals in determining the spread and persistence of didymo in local watersheds.

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### INTRODUCTION

The Gathright Dam-Lake Moomaw Project was conceived in the 1940s by local businessmen to control flooding in the industrial town of Covington, Virginia, and to augment summer flows in the Jackson River to improve water quality. In addition, recreation was included in the cost-benefit analysis for the project. Angling was an important consideration in the development of the two-story reservoir known as Lake Moomaw, as well as in the Jackson River downstream of Gathright Dam. Conservation groups such as Trout Unlimited and government agencies sought to replace inundated fluvial habitat with a downstream coldwater fishery through sophisticated engineering.

Subadult Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta* were each stocked at a rate of 862 fish/km from 1989 to 1997. Stocking was discontinued in 1997 when signs of natural reproduction for both species was documented. Current regulations for Rainbow Trout are catch-and-release between 305 mm and 406 mm in total length

and catch-and-release for Brown Trout under 508 mm in total length. Anglers can creel four trout per day, but only one is allowed to be a Brown Trout.

In 1975, *Didymosphenia geminata* (didymo) was reported as being geographically distributed in Virginia, but no specific location or details were documented (Patrick et al 1975.) In 2006, didymo was discovered in the tailwater below Lake Moomaw by trout anglers and reported to the Virginia Department of Game and Inland Fisheries (DGIF.) The 2006 sample was confirmed by Sarah Spaulding of the U.S. Geological Survey as didymo. Because of the Jackson River Tailwater's importance as a recreational resource for trout anglers, aquatic biologists with the U. S. Forest Service (USFS) and DGIF determined that a rapid, user-friendly methodology to monitor the spread of didymo was needed. Altered macroinvertebrate composition has been reported in South Dakota (Larson 2007), and negative impacts to recreational angling have been documented in New Zealand (Beville et al. 2012) as a result of strong didymo

presence. Thick didymo mats cover oligotrophic river bottoms worldwide, where productivity is low, water clarity is high, sunlight exposure is high, and ambient water temperatures remain cold year-round. Ironically, these conditions often match well with healthy trout fisheries, especially in southeastern United States tailwaters.

The purpose of this study was to design a simple method to measure didymo abundance, seasonally quantify didymo abundance related to turbidity and temperature, and examine didymo infestation relative to the aquatic biology of the river.

## STUDY AREA

The Jackson River Tailwater is a 29-km wild trout fishery that flows out of Lake Moomaw in Allegheny County, Virginia. It is a major tributary to the James River and flows through the Ridge and Valley Physiographic Province of western Virginia. Two study sites were selected, one directly below Gathright Dam, where didymo was first discovered in this river, and another at Johnson Spring, 5.8 km downstream of Gathright Dam. Both transect locations are federally owned access points frequently used by the angling public. Transect widths were 32 m at Gathright Dam and 26 m at Johnson Spring.

## METHODS

A 1-m<sup>2</sup> rebar frame was fabricated to set on the river bottom at 2-m intervals across the width of the river at transect locations. The frame was painted bright yellow for easy delineation and divided into four quadrants with nylon string for better didymo estimation. Using a view-scope, a biologist would estimate percent cover of didymo over the substrate within each quadrant. Scores were assigned as follows: none observed = 0, 1% - 35% = 1, 36% - 70% = 2, and > 70% = 3. The four quadrant scores were summed at each 2-m interval, and then averaged. To calculate an overall score for that transect, individual

1-m<sup>2</sup> values were summed and divided by the number of observations to derive a score between 0 and 3. Observations were made monthly from February 2008 to August 2010 (with some exceptions) to give us a seasonal estimation of didymo abundance. Water temperature was recorded on each sample date with a thermometer, and turbidity was measured in Nephelometric Turbidity Units (NTU) using a Hach 2100P Turbidimeter.

Benthic macroinvertebrates were sampled at the dam transect using a 0.26-m<sup>2</sup> modified Surber sampler. Samples were preserved in the field and identified in the laboratory down to genus, except chironomids, which were identified to family level. Trout were sampled using an electrofishing barge at the dam transect.

## RESULTS

Twenty-four didymo measurements were recorded at the Gathright Dam transect between February 2008 and August 2010. Scores ranged from 0.0 in October 2009 to 2.78 in May, 2008. Didymo scores peaked in the May-June period in 2008, 2009, and 2010, and rapidly declined until fall of each year. Except for June, 2008, didymo abundance was inversely related to NTU measurements (Figure 1.) As winter began and the dam-released water clarified from fall turnover, didymo abundance increased rapidly until spring.

Didymo coverage at the Gathright Dam transect increased until water temperatures reached their monthly maximum and stabilized at around 14° C through the summer and early fall (Figure 2.) As the tailwater maintained ~14°C from May to August, didymo presence rapidly declined.

Flows in this tailwater typically range from 4.5 to 8 m<sup>3</sup>/s throughout the year, but sometimes are significantly increased to maintain desired levels in the reservoir. During the study period, river flows increased as high as 102 m<sup>3</sup>/sec during the spring months, but these releases did not deter didymo growth.

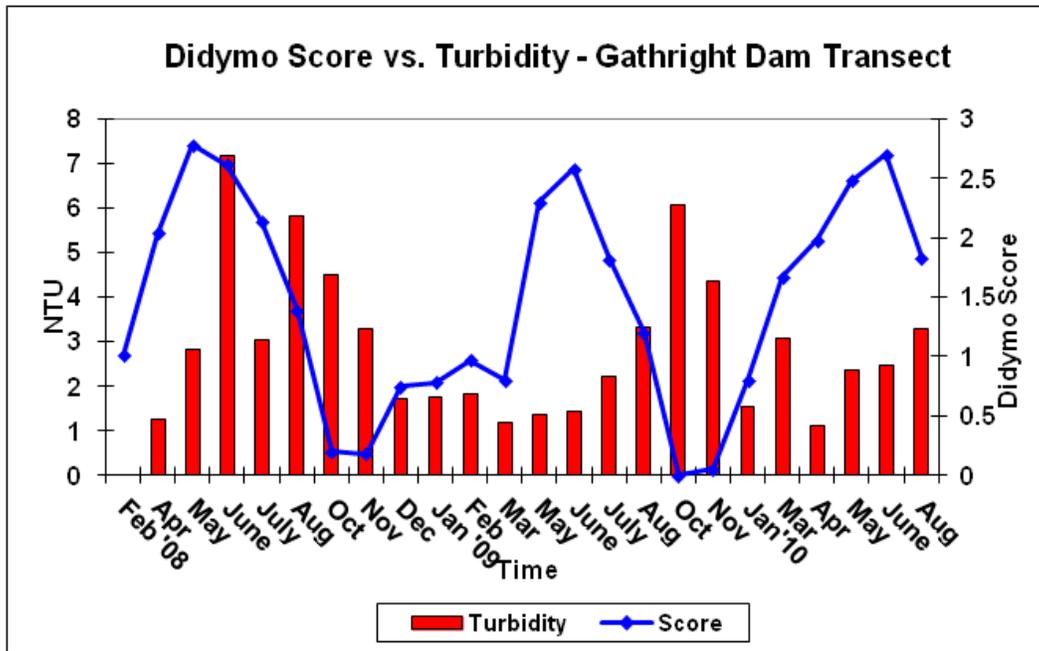


Figure 1. Turbidity levels and didymo scores by month at Gathright Dam transect.

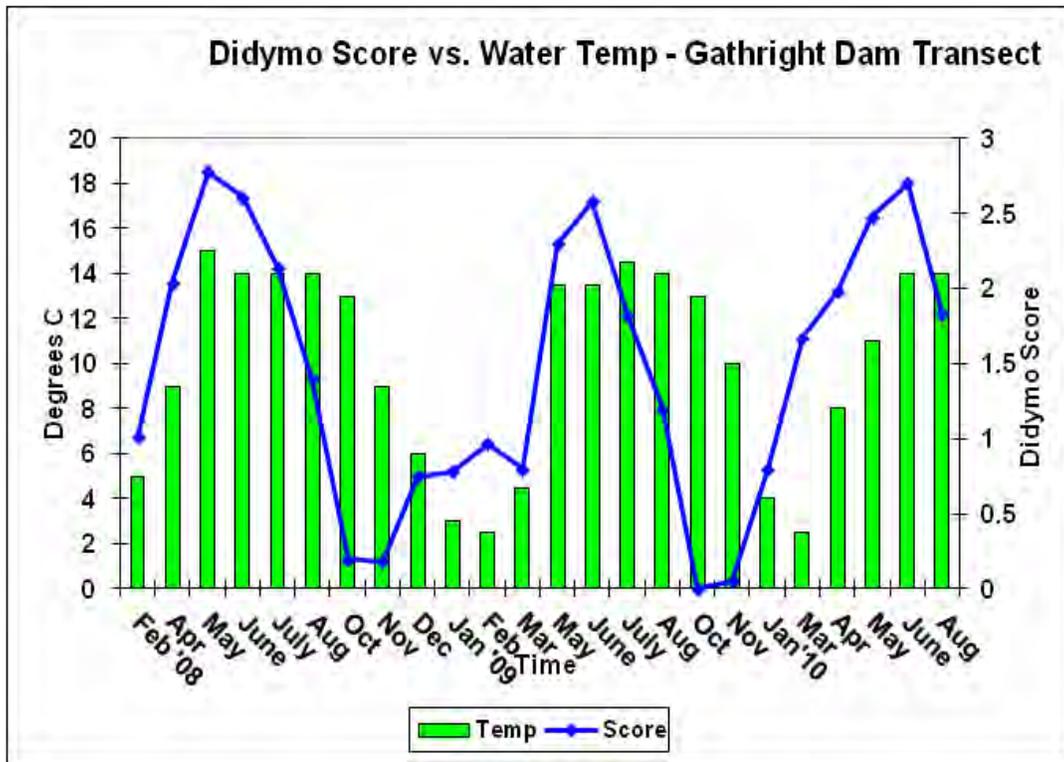


Figure 2. Water temperatures and associated didymo scores at below the Gathright Dam Transect, Jackson River, Virginia.

Didymo scores at our downstream transect, Johnson Spring, were very low (Table 1) in all cases. Paired downstream transect water temperatures were slightly higher than the upstream transect, but not significantly ( $t = -4.58$ ,  $df = 7$ ,  $\alpha = 0.05$ .)

Benthic macroinvertebrate abundance remained high before and after didymo infestation at the

dam transect; however, there was a sharp decline in Simuliidae larvae with a concurrent increase in Chironomidae larvae (Table 2.)

Mean relative abundance of Rainbow Trout before and after didymo infestation at the dam transect (Table 3) did not vary significantly before and after didymo infestation ( $t = 0.6658$ ,  $df = 4$ ,  $\alpha = 0.05$ .)

**Table 1. Didymo scores, water temperatures, and turbidity for the Johnson Spring transect, Jackson River, Virginia.**

Month/Year	Didymo Score	Water Temp (C)	Turbidity (NTU)
Feb 2009	0.83	3	1.06
Mar 2009	0.29	6	1.97
May 2009	0.021	16	3.07
July 2009	0.020	16.5	2.26
Aug 2009	0.0	16.5	2.29
Nov 2009	0.0	10	2.97
May 2010	0.37	12	1.90
June 2010	0.75	16	1.49

**Table 2. Benthic macroinvertebrate abundance and composition pre- and post-infestation of didymo at the Gaithright Dam Transect, Jackson River, Virginia.**

Didymo	Year	Insects/m <sup>2</sup>	Simuliidae %	Chironomidae %
Pre	1992	7,383	75	22
Pre	1993	2,608	79	2
Post	2007	28,060	26	68
Post	2008	7,660	22	72

**Table 3. Rainbow Trout relative abundance pre- and post-infestation of didymo at the Gaithright Dam Transect, Jackson River, Virginia.**

Didymo	Year	Rainbow Trout/hour
Pre	1999	108
Pre	2001	177
Pre	2002	362
Post	2006	238
Post	2007	123
Post	2008	115

## DISCUSSION

Using our developed methodology, didymo concentrations at our most impacted transect, Gathright Dam, rise precipitously in the February to April period and peak in May. Once summer water temperatures stabilize near 14°C, the algae mats begin to decline rapidly until fall. This trend follows similar observations of didymo thriving in low water temperatures. Didymo thrived in the gin-clear waters of late winter, but as turbidity increased in late summer, didymo scores declined precipitously. Again, this agrees with international observations that this diatom grows best in pristine conditions. Approximately 1 km downstream of Gathright Dam, a coolwater tributary (Cedar Creek) joins the Jackson River Tailwater and didymo mats begin to decline until they are virtually nonexistent at Johnson Spring. Because turbidity and sunlight exposure are not measurably different between the sites, perhaps the slight difference in water temperatures between the two transects has an influence on the lack of didymo downstream. Since more accurate temperature data are required to support this claim, we have since deployed a continuous temperature recorder at Johnson Spring to more closely examine differences in water temperature between the two transects.

Our macroinvertebrate data sets before and after didymo infestation showed a community shift from Simuliidae to Chironomidae. This is similar to data from other researchers (Gillis and Chalifour 2009; James et al. 2010) who also found a change in insect community distribution with an increase in Chironomidae following didymo infestation.

The reach of river below Gathright Dam has been dominated by adult wild Rainbow Trout for over 10 years; young-of-year Rainbow Trout are not found in appreciable numbers at this location, nor are Brown Trout. Prior to didymo infestation, up to 382 Rainbow Trout per hour were collected, but the average electrofishing catch was 216 fish/h. This number has since stabilized to an average of 159 fish/h post-infestation.

The Commonwealth of Virginia has eschewed regulating felt soles on anglers' waders. We have taken the path of education to control the spread of this invasive diatom within our borders. To date, didymo has invaded four coldwater tailwaters: the Jackson

River (Alleghany County), Smith River (Henry County), Pound River (Wise County), and Dan River (Patrick County.) Infestation of Virginia's warmwater tailtraces and coldwater mountain streams has not taken place to date, and this seems to fit the general pattern of didymo distribution found in North America. However, in June 2013, Pennsylvania scientists found didymo present in Pine Creek, a warmwater stream managed as a stocked trout stream. This discovery supports observations that didymo's ecological preference to oligotrophic streams may be broadening to warmer environments (Spaulding 2007.)

## CONCLUSIONS

Through some unknown vector (possibly anglers), *Didymosphenia geminata* has found its way into Virginia's four coldwater tailwaters. Heavy growth of didymo occurs in the spring months in Jackson River, when angling pressure increases (thus generating significant complaints to managers), but it declines as summer wanes. We suggest that, in this situation, slight increases in water temperature throughout the growing season may affect didymo presence in a negative manner. This is supported by the contribution of a coolwater tributary into the Jackson River tailwater, where didymo abundance rapidly declines downstream of its confluence. Further, didymo abundance is inversely proportional to turbidity in the summer and fall after the reservoir has stratified. So, if water clarity can be manipulated in tailwaters, didymo may be controlled. Structure of the macroinvertebrate community directly below Gathright Dam has shifted following the introduction of didymo and consequent seasonal changes in substrate, but overall abundance remains high. Rainbow Trout relative abundance somewhat declined, but stabilized at a healthy level (> 150 fish/h) during the post didymo period. We conclude that didymo is a seasonal recreational nuisance to Jackson River Tailwater trout anglers, restricted to a short reach of the river. Its presence has not affected macroinvertebrate and trout populations in a deleterious manner to date. This observation is anecdotally supported by district fisheries biologists who have witnessed similar patterns in the other three coldwater tailwaters in the state. Further investigation of the short periodicity of this alga in the Jackson River Tailwater may provide clues on its limiting factors.

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## LITERATURE CITED

- Beville, S.T, G.N. Kerr, and K.F.D. Hughley. 2012. Valuing impacts of the invasive alga *Didymosphenia geminata* on recreational angling. *Ecological Economics* 82: 1-10.
- Gillis, C.A., and M. Chalifour. 2009. Changes in the macrobenthic community structure following the introduction of the invasive algae *Didymosphenia geminata* in the Matapedia River (Que'bec, Canada.) *Hydrobiologia* 647: 63-70.
- James, D.A., S.H. Ranney, S.R. Chipps, and B.D. Spindler. 2010. Invertebrate Composition and Abundance Associated with *Didymosphenia geminata* in a Montane Stream. *Journal of Freshwater Ecology*, 25 (2): 235-241.
- Larson, A.M. 2007. Relationships between nuisance blooms of *Didymosphenia geminata* and measures of aquatic community composition in Rapid Creek, South Dakota. Biological Assessment Report, Water Resources Assistance Program, Division of Financial and Technical Assistance, South Dakota Department of Environment and Natural Resources, Pierre, South Dakota.
- Patrick R., and C.W. Reimer. 1975. Diatoms of the United States. Vol 2, Part 1: 146-147. Monographs of the Academy of Natural Sciences, Philadelphia, Pennsylvania.
- Spaulding, S. 2007. Increase in nuisance blooms and geographic expansion of the freshwater diatom *Didymosphenia geminata*: Recommendations for response. White paper, EPA Region 8, Denver, Colorado.

## COLDWATER AS A CLIMATE SHIELD TO PRESERVE NATIVE TROUT THROUGH THE 21<sup>ST</sup> CENTURY

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**Abstract**—Native trout are culturally and ecologically important, but also likely to undergo widespread declines as the coldwater environments they require continue to shrink in association with global warming. Much can be done to preserve these fish but efficient planning and targeting of conservation resources has been hindered by a lack of broad-scale datasets and precise information about which streams are most likely to support native trout populations later this century. Using accurate stream temperature climate scenarios developed in the NorWeST project, we identify stream habitats for native Cutthroat Trout *Oncorhynchus clarkii* and Bull Trout *Salvelinus confluentus* across northern Idaho and northwestern Montana that are cold enough to serve as climate refugia and resist invasions by nonnative trout. Climate-safe coldwater habitats for Cutthroat Trout in the historical scenario encompassed 7,547 – 16,821 stream kilometers (depending on the local co-occurrence of Brook Trout *Salvelinus fontinalis*) and 12,189 kilometers for Bull Trout. The majority of coldwater habitats (77%-88%) currently occur on federal lands, a pattern that will become even more pronounced late in the century if the projected 63%-82% declines in coldwater habitats occur. The information developed for this project, and accompanying geospatial databases, are also available for a much larger area across the northwest U.S. to assist managers in strategic decision making about where to allocate conservation resources to best preserve native trout.

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### INTRODUCTION

From a societal perspective, the marquis freshwater fish in cold waters across the globe are salmonines—trout, salmon, and char in the subfamily Salmoninae. Not only do these fish have commercial, recreational, and cultural importance, they serve an array of ecological roles as predators, prey, hosts of freshwater mussels, and conduits of nutrients from oceans, lakes, and rivers to headwater tributaries and their associated riparian habitats. These fish evolved in and colonized waters throughout the Northern Hemisphere, but have also been widely introduced outside their native ranges in suitable waters of the Southern Hemisphere. Nevertheless, within their native ranges, every taxon of these fish has undergone declines over the last two centuries, coincident with our exploitation of them for food, their habitats for water extraction or development, and their watersheds for resources (e.g., Montgomery 2003; Williams et al. 2011). In North America, many taxa or conservation units within them have been designated as in need of conservation action e.g., listing under the U.S. Endangered Species Act, Canada's Species At Risk

Act, or state or provincial programs identifying species of concern. For some taxa, these declines have been arrested, but restoration to their former habitats has been difficult and costly, in many cases because invasive species, including salmonids introduced outside their historical ranges, now occupy those habitats (Fausch et al. 2009).

The relatively rapid and pervasive changes in global climate and stream temperatures (Webb and Nobilis 2007; Kaushal et al. 2010; Isaak et al. 2012) in recent decades constitute a further threat to the persistence of many salmonid populations. Growing evidence documents shifts in populations of these fishes (Comte et al. 2013; Eby et al. 2014) as they attempt to track the distribution of the cold waters on which they depend. In many cases, these changes are likely to constrain populations to smaller and more fragmented headwater habitats (Rieman et al. 2007; Wenger et al. 2011b). Given limited resources to conserve fishes that have already undergone broad-scale range reductions, further work that addresses the threat of climate change demands strategic planning. To that end, managers have begun to ask

which locations are likely to retain thermally suitable habitats of adequate size and connectivity for native salmonids despite anticipated changes in climate. If such climate refugia could be identified, it would allay fears of species losses this century and the refugia could serve as cornerstones in the development of strategic conservation networks. Moreover, because growth and survival of nonnative fishes are precluded in exceptionally cold streams where native salmonids often thrive, refugia with temperatures below certain thresholds would be resistant to invasions and require limited management intervention. In effect, cold water could be used as a “climate shield” to protect native salmonids against climate change and invasive species this century.

Accurately modeling the distribution of coldwater stream habitats is now possible because of the availability of nationally consistent stream geospatial data (Cooter et al. 2010; Wang et al. 2011), high-resolution climate scenarios for stream temperature and flow (Isaak et al. 2010; Wenger et al. 2010; Isaak et al. 2011), and new statistical models for stream data that enable development of unbiased information from large databases and accurate predictions of patterns throughout stream networks (Ver Hoef et al. 2006; Isaak et al. 2014; Ver Hoef et al. 2014). Our goal is to demonstrate how these data and tools may be used to identify current and future distributions of coldwater habitats for two species of native salmonid fishes—Bull Trout *Salvelinus confluentus* and Cutthroat Trout *Oncorhynchus clarkii*—across selected river basins in the upper Columbia River basin in Idaho and Montana. The work described herein is the initial phase of

delineating specific climate refugia for these species across a much broader area of the northwestern U.S.

## METHODS

The study area included northern Idaho (north of the Salmon River basin) and northwestern Montana within the Columbia River basin (Figure 1). Stream elevations ranged from 200 to 2,500 m between the Continental Divide to the east and the mouths of major rivers to the west.

To delineate the fish-bearing stream network, geospatial data for the NHDPlus 1:100,000-scale stream hydrography layer (Cooter et al. 2010) were downloaded from the Horizons Systems website (<http://www.horizon-systems.com/NHDPlus/index.php>) and filtered by minimum flow and stream slope. Each reach in the NHDPlus hydrography layer already has many descriptive attributes calculated, among them stream slope (Wang et al. 2011). Stream reaches with slopes exceeding 10% were trimmed from the network because fish densities are low in these reaches, steep reaches are prone to post-fire debris torrents that can extirpate salmonid populations (Brown et al. 2001), and because they occur at the top of the network where slopes become progressively steeper. Summer streamflow values were downloaded from the Western US Flow Metrics website ([http://www.fs.fed.us/rm/boise/AWAE/projects/modeled\\_stream\\_flow\\_metrics.shtml](http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml); Wenger et al. 2010) and linked to each reach in the hydrography layer through the COMID field. Summer flow values for three climate periods were available from that website: a

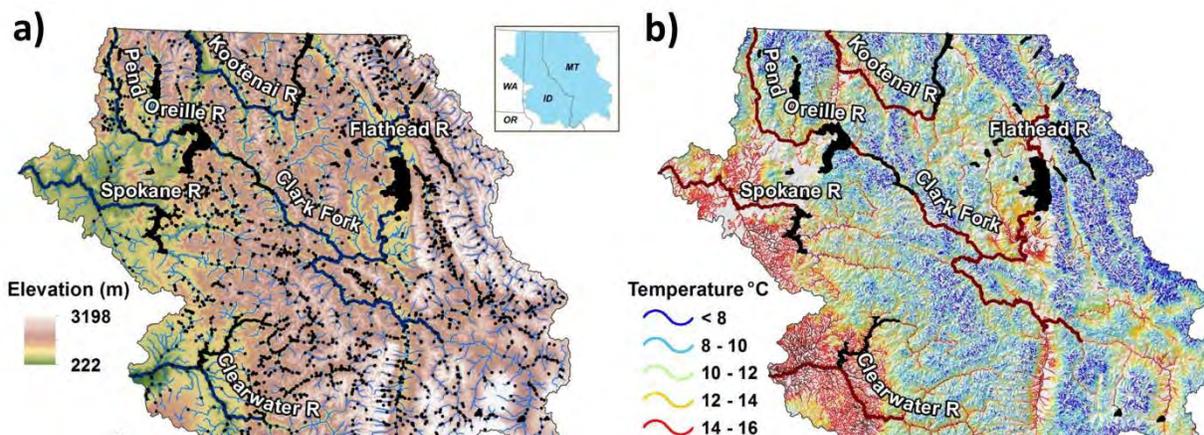


Figure 1. Stream temperature observations ( $n = 9,969$ ) used to fit the NorWeST model in the study area (panel a) and an interpolated map of August mean temperatures representing the 1980s historical period (panel b).

historical period (1970–1999, hereafter referred to as 1980s) and two future periods (2030–2059, hereafter 2040s; 2070–2099, hereafter 2080s) associated with the A1B climate trajectory. Peterson et al. (2013b) described the relationship between summer flows and stream width and found that summer flows of 0.034 m<sup>3</sup>s (1.2 ft<sup>3</sup>s) approximated stream widths of 1.5 m. Trout presence in streams narrower than 1.5 m becomes sporadic due to small habitat sizes (Peterson et al. 2013a), so the network was also trimmed to exclude reaches with summer flows < 0.034 m<sup>3</sup>s. Application of the slope and flow criteria reduced the original set of blue-lines in the NHDPlus hydrography layer from 84,191 stream km to 35,850 km, the latter of which was used to represent fish habitat in the baseline 1980s period.

Summer stream temperature scenarios represented by August means were downloaded from the NorWeST website ([www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html](http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html); Isaak et al. 2011) and used to attribute the baseline hydrography layer. The number of stream temperature observations used to fit the NorWeST model in the study area was 9,969 (Figure 1a) and the model had good predictive accuracy across these observed sites over a wide range of historical climate variation ( $r^2 = 0.92$ ; RMSE = 0.78°C). NorWeST scenarios were available for the same A1B climate trajectory and future climate periods described above at a 1-km resolution for all streams in the study area.

Thermal niches for Bull Trout and Cutthroat Trout encompass colder temperatures than do those of nonnative salmonids such as Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and Rainbow Trout *O. mykiss* (Wenger et al. 2011a,b). Thus, important spawning and juvenile rearing habitats for allopatric populations of the native trout species are often upstream of the distribution of nonnative trout. Temperatures in Bull Trout natal habitats are so cold that overlap with nonnative trout is limited (Rieman et al. 2006; Isaak et al. 2010). However, Cutthroat Trout spawn over a wider temperature range and displacement by nonnative salmonids is common where species overlap in warmer streams. To estimate temperatures that delineated suitable natal Bull Trout habitats and buffered Cutthroat Trout populations against invasions, we referenced stream locations where juvenile trout of either species (<150 mm) had been sampled against mean August water temperature calculated using the NorWeST S1 historical scenario

(which represented the climate composite from 1993–2011) at the same location. For Bull Trout, the juvenile survey data came from longitudinal surveys of 74 streams across the interior Columbia River basin (Rieman et al. 2007). The mean stream temperature at the farthest downstream locations of juvenile Bull Trout in those streams was 10.9°C (99% CI, 10.7–11.1°C), so we used  $\leq 11^\circ\text{C}$  to delineate natal Bull Trout habitats.

Locations of juvenile Cutthroat Trout in the study area were obtained from 863 reach surveys (Young et al. 2013; M. K. Young, unpublished data). Those data indicated juvenile Cutthroat Trout occurred most frequently in stream reaches with temperatures less than 10°C, but juveniles were not uncommon where August mean temperatures approached 14°C. Brown Trout and Rainbow Trout become more common in warmer streams (Wenger et al. 2011a), but those surveys did not include enough sites to reliably estimate temperatures at the upstream limits of these species. For that, we relied on information from a regional fish survey database that included approximately 20,000 site surveys (S. Wenger, unpublished data). Cross-referencing those surveys with the NorWeST S1 historical scenario indicated that Rainbow Trout and Brown Trout rarely occurred where temperatures were < 12°C so this value was used as one criterion for delineating Cutthroat Trout natal habitats. Another nonnative species, Brook Trout, has a colder thermal niche than Rainbow Trout or Brown Trout. The regional fish survey database and earlier research (Al-Chokhachy et al. 2013) indicate that Brook Trout are most common in reaches with mean August temperatures near 12°C and become relatively rare where temperatures are < 10°C. Hence, we used  $\leq 10^\circ\text{C}$  to delineate Cutthroat Trout habitats that would resist Brook Trout invasions in streams where this nonnative also occurred.

To determine the amount of stream habitat that met the above criteria, we queried the trimmed hydrography layer to identify those reaches  $\leq 10$ , 11, and 12°C that also had summer flows > 0.034 m<sup>3</sup>s. The query was done for the historical and two future periods and the total length of coldwater streams summarized. Results from that query were cross-referenced with land ownership compiled for the ICBEMP project (Quigley and Arbelbide 1997) to determine the administrative status of coldwater refuge streams.

## RESULTS

Considerable thermal heterogeneity existed across the study area due to the complex topography (Figure 1). Portions of the stream network with significant amounts of cold water occurred along the Continental Divide to the east and at high elevations scattered throughout various mountain ranges. August stream temperatures in the historical period ranged from 5.1°C to 24°C and averaged 12.5°C. Average temperatures were projected to increase by 1.4°C in the 2040s and 2.5°C in the 2080s. Application of the 12°C thermal criteria to the historical temperature scenario suggested that Cutthroat Trout had 16,821 km of streams cold enough to impede invasions by Brown Trout and Rainbow Trout (Table 1; Figure 2), but only 7,547 km if the more restrictive thermal criteria of 10°C was applied to limit Brook Trout invasions. Coldwater Bull Trout habitats were intermediate between these two extremes at 12,189 km.

Relative to the historical baseline, the amount of habitat in the 2080s that was  $\leq 10^\circ\text{C}$  was predicted to decline by 82% to 1,355 km, whereas habitat  $\leq 12^\circ\text{C}$  was predicted to decline by 63% to 6,169 km. Future habitat reductions reflected both summer flow declines that truncated headwater streams and summer temperature increases that shifted isotherms upstream. Of these two effects, temperature increases

accounted for most of the projected reductions (94–98%) in coldwater habitat length. The large majority of coldwater refugia streams in the historical period (77–88%) were on federal lands, and this will increase in the future because most non-federal lands are at lower elevations where streams are relatively warm. Approximately 23% of the historical coldwater habitats are considered protected based on special land designations (18.7% in Forest Service Wilderness Areas, 2.6% in Glacier National Park).

## DISCUSSION

Consistent with many previous assessments (e.g., Rieman et al. 2007; Wenger et al. 2011b), our results indicate that coldwater habitats for salmonids will markedly decline as a consequence of climate change this century. Unlike many previous studies, however, our approach uses accurate stream temperature model scenarios and species-specific thermal criteria developed from large biological and temperature databases to greatly increase the precision of our projections. The approach is conservative in that it assumes nonnative species will invade all thermally suitable habitats and restrict the distribution of both native species. That is clearly not the case at present; Brook Trout, for example, are absent from large numbers of basins they could seemingly occupy

**Table 1. Kilometers (% in parentheses) of stream habitat by land administrative status for Bull Trout and Cutthroat Trout that are cold enough to resist invasion by other trout species during historical and future periods.**

Land status <sup>1</sup>	1980s			2080s		
	$\leq 10^\circ\text{C}$	$\leq 11^\circ\text{C}$	$\leq 12^\circ\text{C}$	$\leq 10^\circ\text{C}$	$\leq 11^\circ\text{C}$	$\leq 12^\circ\text{C}$
Private	691 (9.2)	1,655 (13.6)	3,200 (19.0)	82 (6.1)	217 (6.7)	556 (9.0)
Tribal	115 (1.5)	202 (1.7)	290 (1.7)	33 (2.4)	60 (1.9)	100 (1.6)
State/City	133 (1.8)	243 (2.0)	375 (2.2)	13 (1.0)	49 (1.5)	127 (2.1)
COE	2 (0.1)	2 (0.1)	2 (0.1)	0 (0.0)	2 (0.1)	2 (0.1)
BLM	59 (0.8)	111 (0.9)	149 (0.9)	0 (0.0)	7 (0.2)	34 (0.6)
FWS	0 (0.0)	0 (0.0)	4 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)
NPS	149 (2.0)	321 (2.6)	456 (2.7)	21 (1.6)	65 (2.0)	136 (2.2)
FS-wilderness	1,674 (22.2)	2,274 (18.7)	2,688 (16.0)	452 (33.3)	871 (27.0)	1,329 (21.5)
FS-nonwilderness	<u>4,725</u> (62.6)	<u>7,380</u> (60.5)	<u>9,657</u> (57.4)	<u>754</u> (55.6)	<u>1,948</u> (60.5)	<u>3,885</u> (63.0)
Total	7,547	12,189	16,821	1,355	3,219	6,169

<sup>1</sup>Abbreviations: COE, Corps of Engineers; BLM, Bureau of Land Management; FWS, Fish and Wildlife Service; NPS, National Park Service; FS, Forest Service.

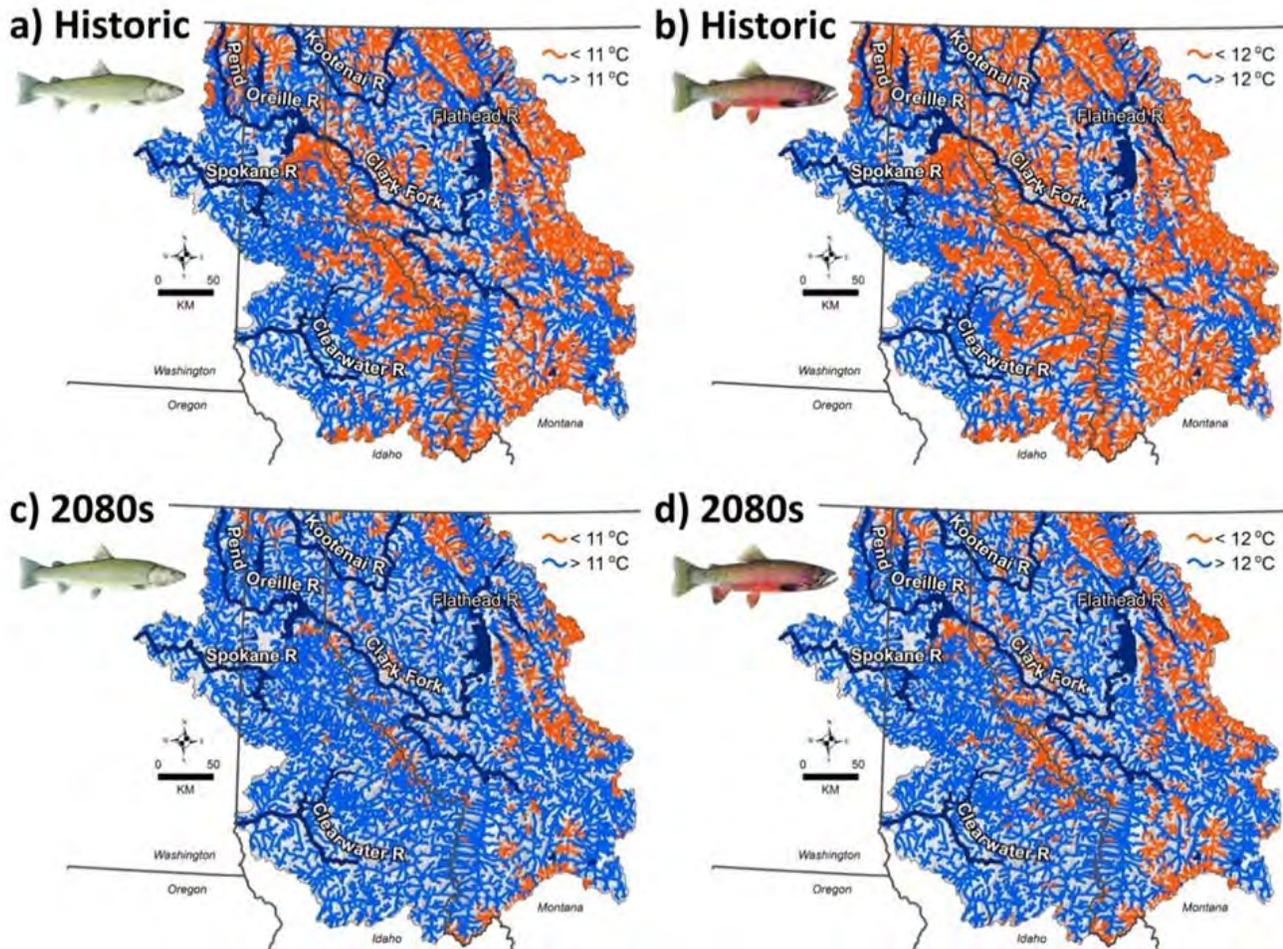


Figure 2. Streams for Bull Trout (panels a and c) and Cutthroat Trout (panels b and d) that are cold enough to resist invasion by other trout species during historical and future periods.

(Al-Chokhachy et al. 2013; M. K. Young, unpublished data; Wenger et al. 2011a). Nevertheless, the future spread of Brook Trout, Brown Trout, and Rainbow Trout—either by natural colonization or human-assisted (and generally illegal) transport—seems likely (Rahel 2004), and the coldwater streams highlighted here can serve as climate-safe and invasion-resistant refuge habitats.

Despite seemingly inevitable future declines, the long-term persistence of Bull Trout and Cutthroat Trout in the study area does not appear to be in jeopardy. There are thousands of stream kilometers that are cold enough to provide suitable habitats even with substantial future climate change and warming this century. Most of these coldwater habitats occur on federal lands at higher elevations, particularly the National Forests. Future climate change will only

enhance this pattern, emphasizing the role that federal land management can play in maintaining a climate shield to conserve native coldwater species. Many coldwater refuge streams already occur in designated wilderness areas and support disproportionate numbers of strong Cutthroat Trout and Bull Trout populations of (e.g., Rieman and Apperson 1989; Kershner et al. 1997), but wilderness designation may be insufficient insurance against climate change. For example, many portions of the Selway-Bitterroot Wilderness Area in Montana and Idaho are expected to warm beyond the thresholds acceptable to Bull Trout, and to favor more thermally tolerant trout species at the expense of Cutthroat Trout. Such areas will constitute a dilemma for biologists wishing to actively manage watersheds to retain coldwater species. However, coldwater habitats in adjacent non-wilderness public and private

lands have fewer restrictions and might be strategically targeted for conservation actions that bolstered native trout populations.

Identification of coldwater streams is only the beginning of climate-smart native trout conservation. The next steps in this process include developing demographically based estimates of habitat sizes needed for population persistence, implementing the approach across entire species ranges and large river basins, and providing climate refugia information in geospatial digital map formats for easy use with numerous native trout conservation initiatives, such as those sponsored by the multi-agency Western Native Trout Initiative. The approach taken is also generalizable in that it could be extended to other native headwater species that are dependent on cold water (e.g., Rocky Mountain Tailed Frog *Ascaphus montanus* or Coastal Giant Salamander *Dicamptodon tenebrosus*). In the northwestern U.S., doing so simply requires developing an estimate of habitat size needed for population persistence and species-specific thermal criteria, both of which can be derived using broadly available geospatial stream data and biological survey information. Coldwater climate refugia could also be delineated in other parts of the U.S. or globally where native organisms persist and thrive in cold environments that constrain nonnative species invasions. The primary limitation for identifying such areas currently is the limited availability of stream temperature data (and perhaps ecological data for poorly surveyed species), but monitoring networks and databases have begun to grow rapidly in recent years with the advent of inexpensive sensors and reliable protocols for data collection (Isaak et al. 2011; Isaak et al. 2013). In all cases, better information about the locations and likely persistence of coldwater climate refugia will contribute to more strategic allocation of limited conservation resources, help rally support among multiple stakeholders concerned about the future of coldwater fauna, and increase the odds of long-term species preservation.

## REFERENCES

- Al-Chokhachy, R., S. J. Wenger, D. J. Isaak, and J. L. Kershner. 2013. Characterizing the thermal suitability of instream habitat for salmonids: a cautionary example from the Rocky Mountains. *Transactions of the American Fisheries Society* 142:793–801.
- Brown, D. K., A. A. Echelle, D. L. Propst, J. E. Brooks, and W. L. Fisher. 2001. Catastrophic wildfire and number of populations as factors influencing risk of extinction for Gila Trout (*Oncorhynchus gilae*). *Western North American Naturalist* 61:139–148.
- Comte, L., L. Buisson, M. Daufresne, and G. Grenouillet. 2013. Climate-induced changes in the distribution of freshwater fish: observed and predicted trends. *Freshwater Biology* 58:625–639.
- Cooter, W., J. Rineer, and B. Bergenroth. 2010. A nationally consistent NHDPlus framework for identifying interstate waters: Implications for integrated assessments and interjurisdictional TMDLs. *Environmental Management* 46:510–524.
- Eby, L. A., O. Helmy, L. M. Holsinger, and M. K. Young. 2014. Evidence of climate-induced range contractions for Bull Trout in a Rocky Mountain watershed, U.S.A. *PLoS ONE* doi:xxxxxxx
- Fausch, K. D., B. E. Rieman, J. B. Dunham, M. K. Young, and D. P. Peterson. 2009. Invasion versus isolation: trade-offs in managing native salmonids with barriers to upstream movement. *Conservation Biology* 23:859–870.
- Isaak, D. J., C. Luce, B. Rieman, D. Nagel, E. Peterson, D. Horan, S. Parkes, and G. Chandler. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. *Ecological Applications* 20:1350–1371.
- Isaak, D. J., D. L. Horan, and S. P. Wollrab. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. U.S. Forest Service General Technical Report RMRS-GTR-314.
- Isaak, D. J., E. Peterson, J. V. Hoef, S. Wenger, J. Falke, C. Torgersen, C. Sowder, A. Steel, M. J. Fortin, C. Jordan, A. Reusch, N. Som, and P. Monestiez. 2014. Applications of spatial statistical network models to stream data. *Wiley Interdisciplinary Reviews - Water* 1 doi: 10.1002/wat2.1023.
- Isaak, D.J., S. Wenger, E. Peterson, J. M. Ver Hoef, S. Hostetler, C. Luce, J. Dunham, J. Kershner, B. Roper, D. Nagel, D. Horan, G. Chandler, S. Parkes, and S. Wollrab. 2011. NorWeST: An interagency stream temperature database and model for the Northwest United States. Website: <http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>
- Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest US from 1980–2009 and implications for salmonid fishes. *Climatic Change* 113: 499–524.

- Kaushal, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, K. T. Belt, D. H. Secor, and R. L. Wingate. 2010. Rising stream and river temperatures in the US. *Frontiers in Ecology and the Environment* 8:461–466.
- Kershner, J. L., C. M. Bischoff, and D. L. Horan. 1997. Population, habitat, and genetic characteristics of Colorado River Cutthroat Trout in wilderness and non-wilderness stream sections in the Uinta Mountains of Utah and Wyoming. *North American Journal of Fisheries Management* 17:1134–1143.
- Montgomery, D. R. 2003. *King of fish: the thousand-year run of salmon*. Westview Press, Boulder, Colorado.
- Peterson, D. P., B. E. Rieman, D. L. Horan, and M. K. Young. 2013a. Patch size but not short-term isolation influences occurrence of Westslope Cutthroat Trout above human-made barriers. *Ecology of Freshwater Fish*. DOI: 10.1111/eff.12108.
- Peterson, D. P., S. J. Wenger, B. E. Rieman, and D. J. Isaak. 2013b. Linking climate change and fish conservation efforts using spatially explicit decision support models. *Fisheries* 38:111–125.
- Quigley, T., and S. Arbelbide (editors). 1997. *An assessment of the ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins*. U.S. Forest Service General Technical Report PNW-GTR-405.
- Rahel, F. J. 2004. Unauthorized fish introductions: fisheries management of the people, for the people, or by the people? *American Fisheries Society Symposium* 44:431–443.
- Rieman, B. E., and K. A. Apperson. 1989. *Status and analysis of salmonid fisheries: Westslope Cutthroat Trout synopsis and analysis of fishery information*. Idaho Department of Fish and Game, Boise. Job Performance Report. Project F-73-R-11, Subproject II, Job 1.
- Rieman, B. E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on Bull Trout habitats and populations across the interior Columbia River basin. *Transactions of the American Fisheries Society* 136:1552–1565.
- Rieman, B. E., J. T. Peterson, and D. L. Myers. 2006. Have Brook Trout displaced Bull Trout along longitudinal gradients in central Idaho streams? *Canadian Journal of Fisheries and Aquatic Sciences* 63:63–78.
- Ver Hoef, J. M., E. E. Peterson, and D. Theobald. 2006. Spatial statistical models that use flow and stream distance. *Environmental and Ecological Statistics* 13:449–464.
- Ver Hoef, J. M., E. E. Peterson, D. Clifford, and R. Shah. 2014. SSN: An R package for spatial statistical modeling on stream networks. *Journal of Statistical Software* 56:1–47.
- Wang, L., D. Infante, P. Esselman, A. Cooper, D. Wu, W. Taylor, D. Beard, G. Whelan, and A. Ostroff. 2011. A hierarchical spatial framework and database for the national river fish habitat condition assessment. *Fisheries* 36:436–449.
- Webb, B. W., and F. Nobilis. 2007. Long-term changes in river temperature and the influence of climatic and hydrological factors. *Hydrological Sciences Journal* 52:74–85.
- Wenger, S. J., D. J. Isaak, J. B. Dunham, K. D. Fausch, C. H. Luce, H. M. Neville, B. E. Rieman, M. K. Young, D. E. Nagel, D. L. Horan, and G. L. Chandler. 2011a. Role of climate and invasive species in structuring trout distributions in the Interior Columbia Basin. *Canadian Journal of Fisheries and Aquatic Sciences* 68:988–1008.
- Wenger, S. J., D. J. Isaak, C. H. Luce, H. M. Neville, K. D. Fausch, J. B. Dunham, D. C. Dauwalter, M. K. Young, M. M. Elsner, B. E. Rieman, A. F. Hamlet, and J. E. Williams. 2011b. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences* 108:14175–14180.
- Wenger, S. J., C. H. Luce, A. F. Hamlet, D. J. Isaak, and H. M. Neville. 2010. Macroscale hydrologic modeling of ecologically relevant flow metrics. *Water Resources Research* 46, W09513, doi:10.1029/2009WR008839.
- Williams, J. E., R. N. Williams, R. F. Thurow, L. Elwell, C. P. Philipp, F. A. Harris, J. L. Kershner, P. J. Martinez, D. Miller, G. H. Reeves, C. A. Frissell, and J. R. Sedell. 2011. Native fish conservation areas: a vision for large-scale conservation of native fish communities. *Fisheries* 36:267–277.
- Young, M. K., K. S. McKelvey, K. L. Pilgrim and M. K. Schwartz. 2013. DNA barcoding at riverscape scales: assessing biodiversity among fishes of the genus *Cottus* (Teleostei) in northern Rocky Mountain streams. *Molecular Ecology Resources* 13:583–595.

# Session 4 Brook Trout





## WHAT ARE BROOK TROUT HIDING? ELEVATED MERCURY CONCENTRATIONS IN BROOK TROUT RELATIVE TO CO-HABITATING BROWN TROUT

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**Abstract**—Mercury (Hg) is a persistent element in the environment, and one that has the ability to bioaccumulate and biomagnify up food webs with potentially harmful effects on fish, wildlife, and humans. Little Hg research has focused on wild trout, and virtually no studies exist to determine Hg concentrations between Brook Trout (BKT, *Salvelinus fontinalis*) and Brown Trout (BRT, *Salmo trutta*) in cohabitation. This study set out to determine if differences in bioaccumulation of Hg exist between BKT and BRT in cohabitation, and explore factors driving bioaccumulation of Hg. Brook Trout (n=57) and BRT (n=45) were captured across 11 stream and filets were analyzed for total mercury (THg) concentration. Length normalized (LN) Hg concentrations in BKT were found to be significantly higher than in BRT (p=0.037). Modelling efforts revealed that region, stream site, year sampled, percent aquatic invertebrates, and instantaneous growth rate (IGR) are significant at explaining the variance (p<0.01) and combined account for 76% of the variation (R<sup>2</sup> adjusted). Our results suggest a combination of watershed characteristics, growth rates, and food source are driving Hg bioaccumulation differences between species and regions where fish were sampled. The results of this study are the first to document significantly higher mercury concentrations in BKT relative to cohabitating BRT.

### INTRODUCTION

Mercury (Hg) is a potent neurotoxin that biomagnifies up the food web in aquatic ecosystems, posing potential threats to high trophic level organisms such as fish and even humans (Evers 2005). Sources of Hg to aquatic ecosystems are both natural and anthropogenic in nature, and atmospheric sources have the ability to be ubiquitously deposited across landscapes and watersheds. Mercury can be converted into methylmercury (MeHg), which has the ability to bioaccumulate and biomagnify through food webs (Driscoll et al. 2013). Human exposure to Hg occurs mostly through fish consumption, and currently all 50 states in the USA have issued at least one fish eating advisory due to mercury. Twenty six states have issued statewide mercury advisories, and in Pennsylvania, fish eating advisories have been posted for over 1,411 stream kilometers and 28 lakes (USEPA 1995; USEPA 2009).

Brook Trout (BKT, *Salvelinus fontinalis*) are the only native trout species in Pennsylvania streams and are a good indicator species of stream quality due to their need for clean water, intact habitat, and strong food webs (Lyons et al. 1996; Marschall and Crowder 1996). Brown Trout (BRT, *Salmo trutta*), an introduced species from Europe, represent a

potential threat to BKT by introducing interspecific competition due to similarly occupied niches. Other research suggests that BRT are better competitors, and BKT populations are compromised in the presence of BRT (Hoxmeier and Dieterman 2011).

One largely overlooked implication of co-habiting BKT and BRT is that differences in diet might lead to differences in Hg accumulation between species. Competition between these species may affect the availability food sources, which has implications towards Hg concentrations (Ward et al. 2010), because aquatic organisms available for BKT and BRT consumption are believed to have higher Hg levels than terrestrially derived food sources (Ward et al. 2010; Ward et al. 2012). Additionally, competition over food source could lead to elevated growth rates in BRT (Carlson et al. 2007; Hoxmeier and Dieterman 2011), and research has linked growth rates and Hg concentration (Simoneau et al. 2005). More specifically, fish with higher growth rates tend to have lower Hg concentrations compared to slower growing species (Simoneau et al. 2005). This phenomenon has been explained through somatic growth dilution (SGD), where faster growing fish have lower Hg concentrations, because they are more efficient at converting food into biomass (Ward et al. 2010).

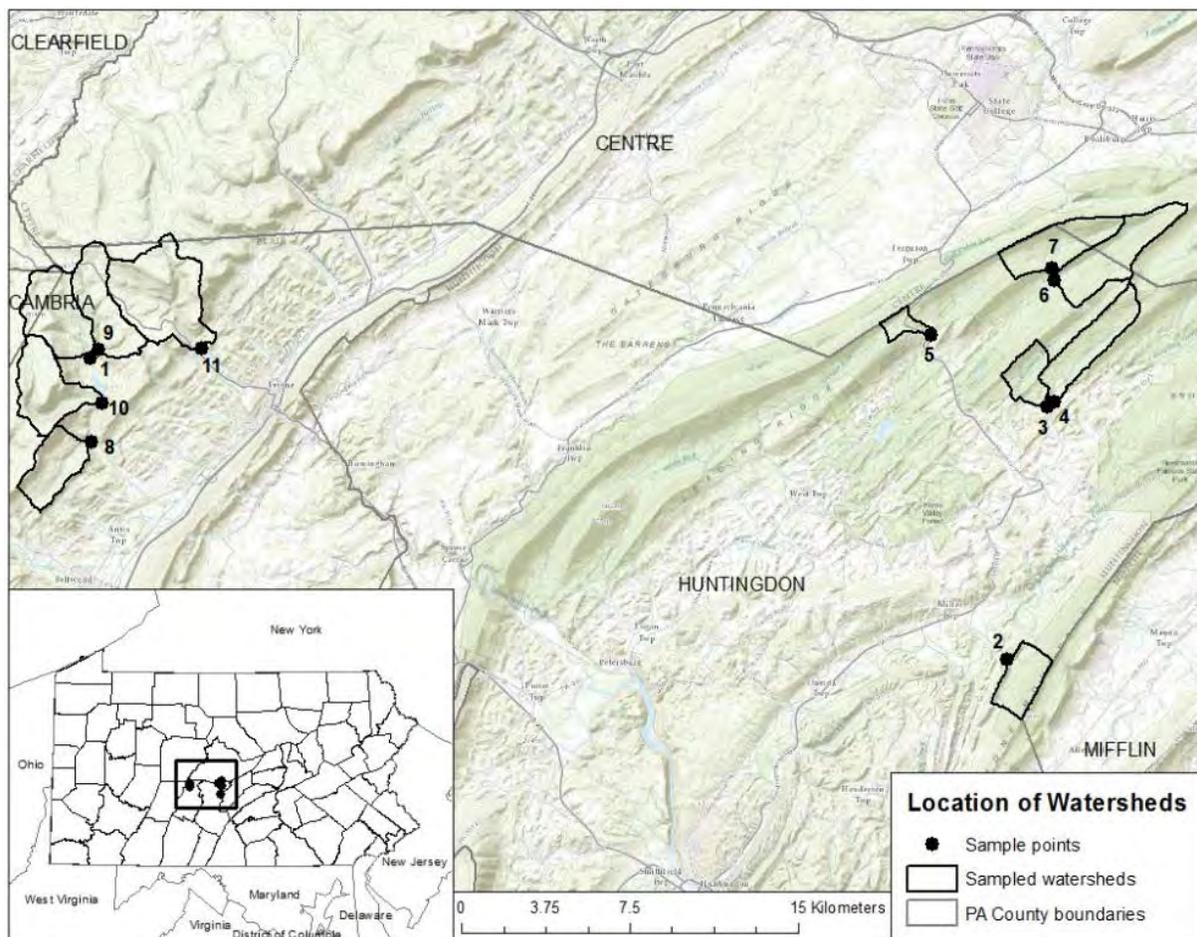
Our research aimed to discover if there exists a difference in Hg concentration between co-habiting BKT and BRT across eleven streams in Pennsylvania. Further, we explored the driving forces of Hg bioaccumulation in trout, and watershed characteristics, food source, and growth rates to help explain variation in Hg concentration in both BKT and BRT.

## METHODS

### Study Sites and Field Collection

Eleven streams containing naturally reproducing BKT and BRT populations were sampled in the summer of 2011 and fall of 2013 (Figure 1). Fish were collected on representative 100-m unblocked segments using a

Smith and Root LR 24 backpack electrofisher. At each site, three BKT and three BRT (on average) were kept in 2011 and 2013 for Hg analysis (total BKT n=57, BRT n=45), and total lengths (mm) were recorded in the field. Less than three trout were taken from a site if only small populations were observed. We used the watershed tool in ArcGIS 10.0 to calculate watersheds with a 10-m resolution National Elevation Dataset (NED), digital elevation model (DEM), and GPS coordinates for each sampling point. All elevation and slope metrics were calculated using NED DEM, and land cover metrics (i.e. percent forest) were determined using the PAMAP Land Cover for Pennsylvania. Because streams were clustered, they were grouped into two regions for analysis (east and west).



**Figure 1. Map showing sampling locations and watersheds for 11 sites used for this study. Numbers correspond to study sites: 1-Tipton Run Above, 2-Unnamed tributary of S. Stone, 3-Greenlee Run, 4-Croyle Run, 5-Roaring Run, 6-Laurel Run, 7-Shingletown Branch, 8-Mulligan Run, 9-Three Springs Run, 10-Loop Run, 11-Sink Run.**

## Lab Analysis

Filet samples taken from the left dorsal section posterior to the depressed dorsal fin were stored at  $-80^{\circ}\text{C}$  until analyzed for Hg. All samples were analyzed for Hg content by combustion atomic absorption spectrophotometry (CAAS) (Milestone DMA 80 direct mercury analyzer, Milestone, Monroe, CT) according to US EPA method 7473 (USEPA 1998). Total mercury concentration was corrected for sample weight and length normalized (LN) for each fish.

Fish stomach contents were removed and identified to the order or genus level (Merritt and Cummins 2008) and categorized as terrestrial or aquatic. Percent aquatic invertebrates were calculated for each fish.

For lab validation of growth rates, 65 BKT and 60 BRT were housed in the living streams following the guidelines set in McMahan et al. (2007) and supplemented by Selong et al. (2001). Scales were collected from all lab validation and wild caught fish and viewed under fluorescent or brightfield microscopy. After back-calculated lengths (BCLs) were calculated for each experimental fish (Fraser 1916; Lee 1920), actual and measured total absolute growth rates (AGR) (Selong et al. 2001) and total instantaneous growth rates (IGR) (Jensen 1990) were calculated for all fish (using length measures). For the wild caught BKT and BRT, the AGR and IGR were calculated from hatch to death for each fish.

## Statistical Analysis

Two-sample t-tests were used to analyze differences in Hg concentration and growth rates existed between BKT and BRT overall, by species, year, and region. Mercury concentrations were  $\text{Log}_{10}$  transformed to normalize the data. We used analysis of variance (ANOVA) general linear model (GLM) to help us determine the factors driving Hg bioaccumulation in fish. Pearson's correlation was used to assess relationships between average Hg concentration per stream and watershed characteristics. A Kruskal-Wallis test was used to compare percent aquatic prey species consumed by BKT vs. BRT overall, by species, region, and year. All tests were considered significant at an  $\alpha$  level of 0.05, unless otherwise stated.

## RESULTS AND DISCUSSION

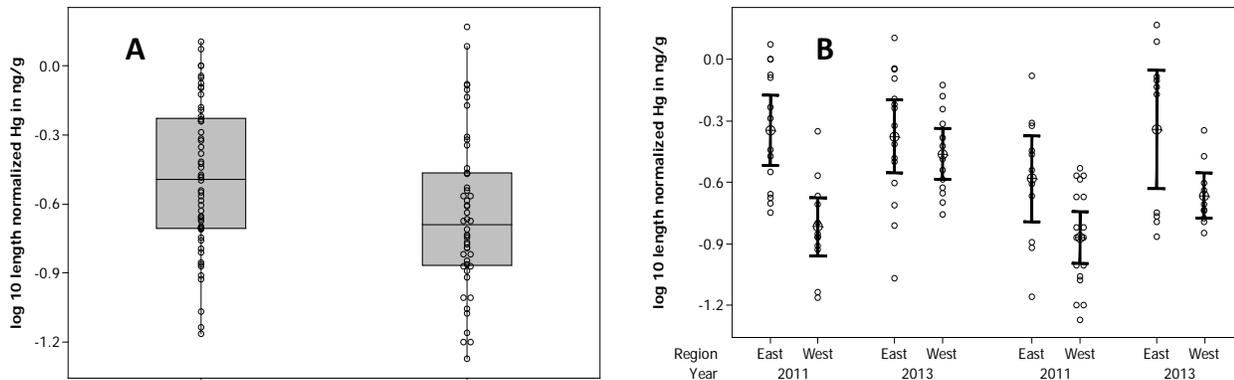
### Watershed Characteristics

All streams were similar in catchment characteristics and were remotely located, forested, headwater streams that had no significant anthropogenic impacts. All streams were found in small (mean=600 ha), relatively steep (mean=11.5 degree slope) watersheds, with the majority of their area in forested land cover (>93%), and very little wetlands present (mean <0.01%). Overall, these streams and corresponding watersheds met the typical criteria for classification as undisturbed basins, allowing for accurate comparison across sites (Gillion 1995). Streams located in the eastern region to had a greater amount of watershed in forest cover ( $p=0.001$ ) than those in the western region and, and eastern streams had marginally more hydric soils ( $p=0.090$ ).

### Species Differences in Hg Bioaccumulation in Trout

Across all trout sampled for this study, mercury concentrations were lower than the majority of studies assessing Hg concentration in trout across streams, large rivers, and lakes (Kamman et al. 2005; Peterson et al. 2007) but more similar to studies focused on smaller streams in the northeastern United States (Castro et al. 2007; Driscoll et al. 2007). Among all trout ( $n=102$ ) in this study, approximately 17 fish were above the U.S. Fish and Wildlife Service piscivorous bird and wildlife advisory (0.1 ppm; Brightbill et al. 2004), and one BRT was above the U.S. EPA Hg fish-eating advisory for human consumption (0.3 ppm; USEPA 2001b).

Overall, we found that BKT had significantly higher mercury concentrations than co-habiting BRT (Figure 2A). Other research has shown BKT to have higher Hg concentrations than BRT (Kamman et al. 2005; Riva-Murray et al. 2013) and BRT to have higher Hg concentrations than BKT (Depew et al. 2012; Kenšová et al. 2012). However, none of these studies were conducted on streams where fish co-habited, and our results indicate BKT differed in some way to cause higher Hg concentration when compared to BRT.



**Figure 2. (A) Boxplot depicting log transformed LN Hg concentrations of BKT (n=57) and BRT (n=45) across all study sites. Significantly higher Hg concentrations were observed in BKT (0.42 ng/g/mm) than BRT (0.31ng/g/mm) ( $p=0.037$ ). (B) 95% confidence interval plot showing Hg concentration of fish sampled in this study when grouped by region, year, and species. Significantly higher Hg accumulation in BKT ( $p=0.0001$ ) and BRT ( $p=0.002$ ) sampled in streams located in the eastern region. Combining regions, Hg concentrations significantly increased from 2011 to 2013 (BKT:  $p=0.044$ , brown:  $p=0.038$ ).**

### Driving Factors for Hg Bioaccumulation

Modelling efforts suggested several key variables may explain some of these interspecific differences in Hg bioaccumulation. In addition to species, ANOVA GLM showed that region, stream site, year sampled and percent aquatic invertebrates (in stomach contents) helped explain observed variance ( $p<0.05$ ). Additionally, instantaneous growth rate (IGR) was included in the model at  $p=0.087$ , because it increased  $R^2$  adjusted from 0.70 to 0.76. Exponential representation of growth (IGR) and linear representation of growth (AGR) were correlated. Instantaneous growth rate was used in the model because the majority (~90%) of the fish in this study were  $\leq 2$  years old, and displayed some exponential growth.

### Region, Stream-Site, and Year Effects

Stream site, region, and year when fish were captured seem to be important variables in impacting Hg bioaccumulation across species. More specifically, watershed characteristics are probably one of the driving factors causing these observed differences in Hg bioaccumulation across BKT and BRT (Figure 2B). While all watersheds were primarily forested (>88%), variation among sites existed, and streams located in the eastern region had significantly greater percent forest than western streams ( $p=0.001$ ). Additionally, there was a positive correlation between stream mean Hg concentration in fish and percent forest ( $r=0.648$ ,  $p=0.033$ ). Other studies have suggested

that direct deposition of mercury onto vegetation can increase the amount of mercury available to the ecosystem (Drenner et al. 2013), and increased woody vegetation in watersheds increases leaf litter and its degradation reaching the stream (Benoit et al. 2013). While others have also shown positive correlations between Hg concentration in trout and percent wetland (Castro et al. 2007), we did not observe any significant relationship for these factors (many of our watersheds having no measured wetlands). However, eastern streams were had higher amounts of hydric soils ( $p=0.09$ ) in their watershed, which could act as a better surrogate for small riparian wetlands or rich methylation conditions (anoxic conditions with sulfur reducing bacteria) that may go undocumented in larger scaled land-cover datasets for GIS.

Year was an important variable in modelling Hg bioaccumulation in trout, because Hg concentration significantly increased from 2011 to 2013 across all fish ( $p=0.003$ ). Additionally, when grouped by species Hg concentrations significantly increased from 2011 to 2013 (Figure 2B), suggesting something changed to cause increases in Hg concentrations. Changes in feeding and food web structure are one possible cause, and research has shown that changes in diet and food web structure affects Hg levels (Cabana et al. 1994). Increased atmospheric deposition is another potential factor, because research has suggested that even over short time spans (Prestbo et al. 2006) and distances (Evers et al. 2007) atmospheric deposition can change drastically.

## Growth Rate Effects

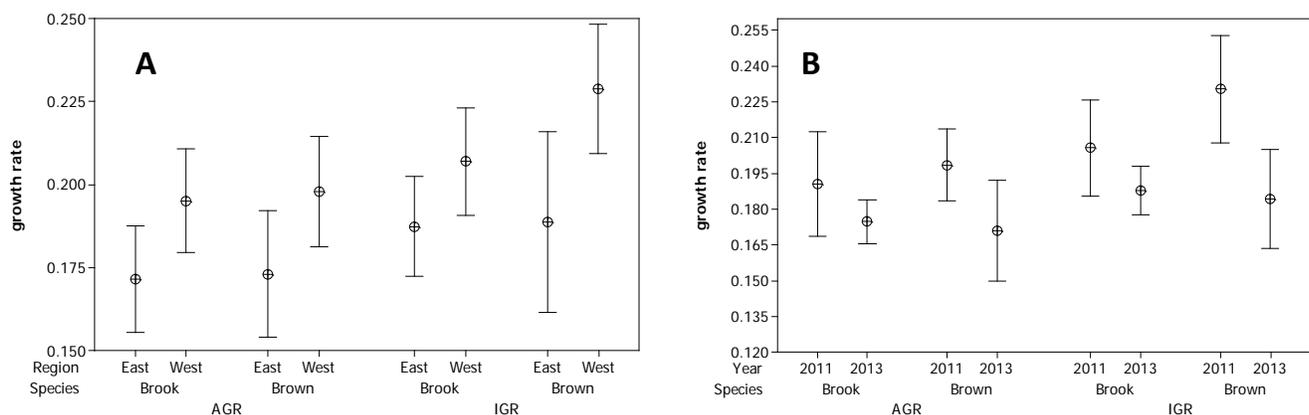
Growth rates appear to be an important contributing factor to Hg accumulation in trout across regions and year. Among all trout, both AGR and IGR were significantly higher in the western region and when broken into species, both BKT and BRT had higher growth rates in the western streams (Figure 3A). Growth rates also appear to help explain the observed difference in Hg concentration between years in the western streams. In both species, AGR and IGR significantly decreased from 2011 to 2013 (Figure 3B). Trout sampled in the western streams and those collected in 2011 grew faster than those in the eastern streams and those collected in 2013, signifying that somatic growth dilution (SGD) is affecting Hg bioaccumulation between the two regions and between years. Our results agree with the literature that shows lower growth rates are associated with higher Hg concentrations in fish (Castro et al. 2007; Ward et al. 2010; Simoneau et al. 2005), resulting from somatic growth dilution (Ward et al. 2010). We believe these increases in growth rates in western fish and those collected in 2011 in part, explain the corresponding increase in Hg bioaccumulation in BKT and BRT.

No difference was found between BKT and BRT growth rates ( $p>0.10$ ), which is contrary to our expectations. Others have shown that when BKT and

BRT are living in sympatry, BRT have higher growth rates than BKT (Carelson et al. 2007) and that BKT growth rates decreased with increasing BRT densities (Hoxmeier and Dieterman 2011). This competition has been directly linked to increased growth rates in BRT, because they will exclude BKT from the best feeding territories (Fausch and White 1981).

## Diet Effects

While no significant differences were observed in percent aquatic invertebrates in stomach contents between species (overall or within years;  $p>0.10$ ), trout stomach contents contained significantly more aquatic macroinvertebrates in 2013 than in 2011 ( $p=0.019$ ). When grouped by species, increases in consumption of aquatic invertebrates were observed for both BKT and BRT between 2011 and 2013 (BKT  $p=0.098$ , BRT  $p=0.050$ ). Since mercury bioaccumulates through aquatic ecosystems (Ward et al. 2012), aquatic prey species are expected to have higher concentrations of Hg than terrestrial prey species (Ward et al. 2010; Ward et al. 2012). Therefore, consumption of more aquatic invertebrates, would accumulate more Hg in trout. We believe this increased consumption in aquatic invertebrates in 2013 may help explain the corresponding increase in Hg bioaccumulation in BKT and BRT in 2013.



**Figure 3. (A) 95% confidence interval plot showing AGR and IGR grouped by species and region. Significantly higher growth rates observed for trout in western regions (AGR:  $p=0.003$ ; IGR:  $p=0.01$ ). When grouped by species, similar increased growth rates were observed in fish in the western region (BKT AGR:  $p=0.021$ , BKT IGR:  $p=0.071$ ; BRT AGR:  $p=0.079$ , BRT IGR:  $p=0.086$ ). (B) Significantly higher growth rates were observed for trout in 2011 (AGR:  $p=0.008$ ; IGR:  $p=0.001$ ). When grouped by species, similar increased growth rates were observed in fish in 2011, except for BKT AGR. (BKT AGR:  $p=0.142$ , BKT IGR:  $p=0.086$ ; BRT AGR:  $p=0.033$ , BRT IGR:  $p=0.003$ ).**

## CONCLUSION

This is the first study to document significantly higher Hg concentrations in BKT living in sympatry with BRT. A combination of watershed characteristics, growth rates, and food source appeared to be driving Hg bioaccumulation differences between species and regions where fish were sampled. Observed increases in Hg concentrations in BKT have serious implications for conservation efforts. Elevated Hg burden can decrease fish fitness (Friedman 1996), which could affect the ultimate success of BKT in streams where they are co-habitating with BRT. Future research will be dedicated to examining food web structure, other aquatic indicators of mercury, and atmospheric deposition rates of mercury at each stream site.

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## REFERENCES

- Ackerman, P. A., J. D. Morgan, and G. K. Iwama. 2005. Anesthetics. CCAC (Canadian Council on Animal Care) Guidelines on the care and use of fish in research, teaching and testing, Canada.
- Benoit, J. M., D. A. Cato, K. C. Denison, and A. E. Moreira. 2013. Seasonal mercury dynamics in a New England vernal pool. *Wetlands* 33: 887-894.
- Brightbill, R. A., K. R. Murray, M. D. Bilger, and J. D. Byrnes. 2004. Total mercury and methylmercury in fish fillets, water, and bed sediments from selected streams in the Delaware River Basin, New Jersey, New York, and Pennsylvania, 1998-2001. U. S. Geological Survey. Water Resources Investigation Report 03-4183.
- Cabana, G., A. Tremblay, J. Kalff, and J. B. Rasmussen. (1994). Pelagic food chain structure in Ontario lakes: a determinant of mercury levels in lake trout (*Salvelinus namaycush*). *Canadian Journal of Fisheries and Aquatic Sciences* 51: 381-389.
- Carlson S.M., Hendry A.P., Letcher B.H. 2007. Growth rate differences between resident native brook trout and non-native brown trout. *Journal of Fish Biology* 71: 1430-1447.
- Castro, M. S., R. H. Hilderbrand, J. Thompson, A. Heft, and S. E. Rivers. 2007. Relationship between wetlands and mercury in brook trout. *Archives of Environmental Contamination and Toxicology* 52: 97-103.
- Depew, D. C., N. M. Burgess, M. R. Anderson, R. Baker, S. P. Bhavsar, R. A. Bodaly, C. S. Eckley, M. S. Evans, N. Gantner, J. A. Graydon, K. Jacobs, J. E. LeBlanc, St. Louis VI, and L. M. Campbell. 2013. Overview of mercury concentration in freshwater fish species: a national fish mercury dataset for Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 70: 1-16.
- Drenner, R. W., M. M. Chumchal, C. M. Jones, C. M. B. Lehmann, D. A. Gay, and D. I. Donato. 2013. *Environmental Science and Technology* 47: 1274-1279.
- Driscoll, C. T., Y. Han, C. Y. Chen, D. C., Evers, L. K. Fallon, T. M. Holsen, N. C. Kamman, and R. K. Munson. 2007. Mercury contamination in forest and freshwater ecosystems in the northeastern United States. *Bioscience* 57: 17-28.
- Driscoll, C. T., R. P. Mason, H. M. Chan, D. J. Jacob, and N. Pirrone, 2013. Mercury as a global pollutant: sources, pathways, and effects. *Environmental Science and Technology* 47: 4967-4983.
- Evers, D. C. 2005. Mercury connections: The extent and effects of mercury pollution in northeastern North America. Biodiversity and Research Institute. Gorham, Maine.
- Evers, D. C., Y. Han, C. T. Driscoll, N. C. Kamman, M. W. Goodale, K. F. Lambert, T. M. Holsen, C. Y. Chen, T. A. Clair, and T. Butler. 2007. Biological mercury hotspots in the northeastern United States and southeastern Canada. *Bioscience Magazine* 57: 29-43.
- Fielder, D. G. 2002. Methodology for immersion marking walleye fry and fingerlings in oxytetracycline hydrochloride and its detection with fluorescence microscopy. *Michigan Department of Natural Resources Fisheries Division* 2002(1): 1-16.
- Fraser, C. M. 1916. Growth of the spring salmon. *Transactions of Pacific Fisheries Society* 1915: 29-39.
- Friedman, A.S., Watzin C., Brinck-Johnsen T., Leiter J.C. 1996. Low levels of dietary methylmercury inhibit growth and gonadal development in juvenile walleye (*Stizostedion vitreum*). *Aquat. Toxicol.* 35:265-278.
- Gillion, R. J. 1995. Design of the national water quality assessment program occurrence and distribution of water-quality conditions. U. S. Geological Survey, U. S. Geological Survey Numbered Series 1112. United States.
- Hoxmeier, R. J. H., and D. J. Dieterman. 2011. Seasonal movement, growth and mortality of brook trout in sympatry with brown trout in headwater streams in southeast Minnesota.

- Jackson, T. A. 1998. Mercury in aquatic ecosystems. Pages 77-158 in W. J. Langston and M. J. Bebianno, editors. *Metal metabolism in aquatic environments*. Springer, New York.
- Jensen, A. J. 1990. Growth of young migratory brown trout (*Salmo trutta*) correlated with water temperature in Norwegian rivers. *The Journal of Animal Ecology* 60:3-614.
- Kamman, N. C., N. M. Burgess, C. T. Driscoll, H. A. Simonin, W. Goodale, J. Linehan, R. Estabrook, M. Hutcheson, A. Major, A. M. Scheuhammer, and D. A. Scruton. 2005. Mercury in freshwater fish of northeast North America – a geographic perspective based on fish tissue monitoring databases. *Ecotoxicology* 14: 163-180.
- Kenšová, R., K. Kruzikova, and Z. Svobodova. 2012. Mercury speciation and safety of fish from important fishing locations in the Czech Republic. *Czech Journal of Food Science* 30: 276-284.
- Klumb, R. A., M. A. Bozek, and R. V. Frie. 2001. Validation of three back-calculation models by using multiple oxytetracycline marks formed in the otoliths and scales of bluegill x green sunfish hybrids. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 352-364.
- Lee, R. M. 1920. A review of the methods of age and growth determination in fishes by means of scales. *Fish. Invest. Ser. II Mar. Fish. G.B. Minist. Agric. Fish. Food*, 4(2): 1-35.
- Lyons, J., L. Wang, and T. D. Simonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. *North American Journal of Fisheries Management* 16: 241-256.
- Marschall, E. A., and L. B. Crowder. 1996. Assessing population responses to multiple anthropogenic effects: a case study with brook trout. *Ecological Applications* 6: 152-167.
- McMahon, T. E., A. V. Zale, F. T. Barrows, J. H. Selong, and R. J. Danehy. 2007. Temperature and competition between bull trout and brook trout: a test of the elevation refuge hypothesis. *Transactions of the American Fisheries Society* 136: 1313-1326.
- Merritt, R. W., and K. W. Cummins. 2008. *An introduction to the aquatic insects of North America*, 4th edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.
- Pennsylvania Fish and Boat Commission (PAFBC). 2014. Commonwealth of Pennsylvania Public Health Advisory. Fish Consumption. Available: <http://fishandboat.com/fishpub/summary/sumconsumption.pdf> (July 2014).
- Peterson, S. A., J. Van Sickle, R. M. Hughes, J. A. Schacher, and S. F. Echols. 2005. A biopsy procedure for determining filet and predicting whole-fish mercury concentration. *Archives of Environmental Contamination and Toxicology* 48: 99-107.
- Peterson, S. A., J. V. Sickle, A. T. Herlihy, and R. M. Hughes. 2007. Mercury concentrations in fish from streams and rivers throughout the western United States. *Environmental Science and Technology*. 41: 58-65.
- Prestbo, E. M., J. M. Leutner and C. D. Pollman. 2006. Abrupt Decrease in Mercury Wet-Deposition Concentration and Annual Flux in Seattle, Washington Due to Emission Point-Source Changes. *Mercury. AMBIO: A Journal of the Human Environment* 36(1):19-33.
- Riva-Murray, K., P. M. Bradley, B. C. Scudder Eikenberry, C. D. Knightes, C. A. Journey, M. E. Brigham, and D. T. Button. 2013. Optimizing stream water mercury sampling for calculation of fish bioaccumulation factors. *Environmental Science and Technology* 47: 5904-5912.
- Selong, J. H., T. E. McMahon, A. V. Zale, and F. T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. *Transactions of the American Fisheries Society* 130:1026-1037.
- Simoneau, M., M. Lucotte, S. Garceau, and D. Laliberté. 2005. Fish growth rates modulate mercury concentrations in walleye (*Sander vitreus*) from eastern Canadian lakes. *Environmental Research* 98(1): 73-82.
- Taylor, J. K. 1987. *Quality assurance of chemical measurements*. Lewis Publishers, Chelsea, Michigan.
- USEPA (U. S. Environmental Protection Agency). 1995. Great Lakes water quality initiative technical support document for wildlife criteria, EPA 820-B95-009 U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- USEPA (U.S. Environmental Protection Agency). 1998. Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrometry. U.S. Environmental Protection Agency, draft method 7473, Washington, DC.
- USEPA (U. S. Environmental Protection Agency). 2001a. Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses. U.S. Environmental Protection Agency, Office of Water. Technical Manual EPA 823-B-01-002, Washington, DC.
- USEPA (U. S. Environmental Protection Agency). 2001b. National Listing of Fish and Wildlife Advisories (NLFWA). Environmental Protection Agency, Office of Water, Washington, DC.
- USEPA (U. S. Environmental Protection Agency). 2007a. Chapter Three: Inorganic Analytes. U.S. Environmental Protection Agency, Method Chapter 3 Revision 4, 1-28, United States.
- USEPA (U. S. Environmental Protection Agency). 2007b. Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry. U. S. Environmental Protection

- Agency, Method 7473 Revision 0, 1-17, United States. Washington, DC.
- USEPA (U.S. Environmental Protection Agency). 2009. National listing of fish advisories: technical fact sheet; 2008 biennial national listing. U.S. Environmental Protection Agency, EPA-823-F-09-007. Available: <http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/tech2008.cfm> (December 2013).
- Ward, D. M., K. H. Nislow, and C. L. Folt. 2010. Bioaccumulation syndrome: identifying factors that make some stream food webs prone to elevated mercury bioaccumulation. *Annals of the New York Academy of Sciences* 1195: 62-83.
- Ward, D. M., K. H. Nislow, and C. L. Folt. 2012. Do low-mercury terrestrial resources subsidize low mercury growth of stream fish? Differences between species along a productivity gradient. *PLoS ONE* 7(11): 1-7.

# RAINBOW TROUT VERSUS BROOK TROUT BIOMASS AND PRODUCTION UNDER VARIED CLIMATE REGIMES IN SMALL SOUTHERN APPALACHIAN STREAMS

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**Abstract**—Many Appalachian streams historically dominated by Brook Trout *Salvelinus fontinalis* have experienced shifts towards fish communities dominated by Rainbow Trout *Oncorhynchus mykiss*. We used empirical estimates of biomass and secondary production of trout conspecifics to evaluate species success under varied thermal regimes. Trout populations were sampled in 13 Appalachian streams from Maryland to North Carolina during summer 2012, and biomass and production of trout species were examined in relation to habitat and water temperature data. Rainbow Trout and Brook Trout were found co-occurring at three sites, Rainbow Trout populations were encountered at an additional five sites, and Brook Trout populations were also encountered at an additional five sites. Brook Trout co-occurred at one site with Brown Trout *Salmo trutta*. Biomass estimates for Brook Trout and Rainbow Trout ranged from 0.01 to 1.15 g·m<sup>-2</sup> and 0.35 to 1.60 g·m<sup>-2</sup>, respectively. Secondary production estimates for Brook Trout and Rainbow Trout ranged from 0.12 to 1.09 g·m<sup>-2</sup>·yr<sup>-1</sup> and from 0.06 to 7.48 g·m<sup>-2</sup>·yr<sup>-1</sup>, respectively; thus, Rainbow Trout tended to dominate production in study streams where both species co-occurred. Brown Trout biomass where it co-occurred with Brook Trout was 1.14 g·m<sup>-2</sup> and production was 1.20 g·m<sup>-2</sup>·yr<sup>-1</sup>; thus, it also dominated biomass and production compared to Brook Trout. Logistic regressions revealed percent production of Rainbow Trout had a positive relationship with mean minimum winter air temperature ( $P < 0.05$ ) and, conversely, percent production of Brook Trout had a negative relationship with mean minimum winter temperature ( $P < 0.05$ ). Thus, temperature coupled with interspecific competition could be influencing Brook Trout production in these mixed trout streams. Our results suggest that with increasing winter temperatures Brook Trout production could decrease, further highlighting the need to mitigate the effects of climate change on Brook Trout in their native range.

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## INTRODUCTION

Brook Trout *Salvelinus fontinalis* are increasingly threatened across their native range by a myriad factors, including increasing temperatures, habitat fragmentation, nonnative species, and other natural and anthropogenic disturbances (Larson and Moore 1985; Meisner 1990; Thieling 2006; Poplar-Jeffers et al. 2009). As a result, Brook Trout biomass, secondary production, and habitat preferences in the southern Appalachians and elsewhere in the eastern United States have been intensely studied and often compared to similar estimates and preferences of nonnative trout species, Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta* (Neves and Pardue 1983; Whitworth and Strange 1983; Ensign et al. 1990; Flebbe and Dolloff 1995; Kwak and Waters 1997). Rainbow Trout and Brown Trout tend to dominate in areas where Brook Trout co-existed and that once Rainbow Trout establish, they typically usurp Brook

Trout in dominance (Waters 1983; Whitworth and Strange 1983). Yet, continued studies on dynamics and thresholds for species dominance are still needed to understand these patterns in the context of multiple or additive anthropogenic effects, e.g., synergistic effects of species invasions and climate change (Clark et al. 2002; Fausch 2008).

Biomass and secondary production can be used as indicators of biological success to gage the relative success of co-existing species (Waters 1983; Hayes et al. 2007). Secondary production is defined as the formation of living mass of a heterotrophic population or group of populations over some period of time (Waters and Crawford 1973). Secondary production is especially attractive as a response variable due to its integration of other important biological variables (abundance, growth and biomass) into a single dynamic metric. Indeed, rates of secondary production have already served as a strong tool for better

understanding fish populations and for improving conservation management initiatives in the face of environmental change (Waters 1977; Valentine-Rose et al. 2011). Furthermore, the concept of production is strongly aligned with the goals of fisheries science and management more generally (Waters 1977; Waters 1983). The principle reason for the lack of utilization of production as a response variable appears to be mostly related to the time and cost involved in its calculation (Dolbeth et al. 2012). Understanding the production dynamics of co-occurring and competing species may be critical to the future conservation management of coldwater fish populations. Whereas, species possess unique thermal ecologies as a result of different evolutionary trajectories (Magnuson et al. 1979), their biological response to thermal change might be highly divergent (Lyons et al. 2010; Rypel 2013). With increasing temperatures, there could be concomitant shift in fish communities towards species more tolerant of higher temperatures in Appalachian streams (Dunham et al. 2002; Chu et al. 2005). The goal of this study was to use trout biomass and secondary production coupled with continuous air and water temperature and general habitat and water quality data to determine which trout species (i.e., Brook Trout or Rainbow Trout) exhibited increased dominance across a macro-ecological gradient in small southern Appalachian streams.

## METHODS

**Study sites**—Thirteen streams were randomly selected from approximately 100 streams previously identified as potential southern Appalachian Brook Trout habitat by the United States Forest Service, Eastern Brook Trout Joint Venture (EBTJV 2006), and Virginia Tech. The study sites were located in West Virginia, Virginia, Maryland, and North Carolina with one site in Tennessee. Streams covered a variety of localities and physiographic provinces including the Alleghany Mountains, Great Smoky Mountains, Blue Ridge Mountains, and in the Piedmont region of the Appalachian Mountains (Figure 1). Study streams were mostly second and third order streams ranging from elevations of 360 to 1,050 meters and average annual air temperatures of 9.8 to 13.80 °C. Habitat attributes were relatively homogenous across study locations as we selected streams with similar physical

habitat characteristics (e.g., watershed area, stream length, percent forested area, etc.) to decrease the influence of these potential covariates in the analysis.

**Data collection**—A onetime sampling event at each study stream was conducted from June 2012 to August 2012. We randomly selected a starting point upstream of the HOBO air and water temperature loggers at each study site. Using an Appalachian Aquatics Backpack Electrofishing Unit (Morristown, TN), we sampled fish from two 50-m reaches spaced 50 m apart until depletion. Small mesh block nets were placed upstream and downstream of the reach to prevent fish immigration and emigration during the sampling period. We measured total lengths (mm) and weights (g) of all trout captured, euthanized 15-30 individuals in tricaine methanesulfonate (MS-222) of varying lengths, and immediately placed specimens on ice for transport and otolith removal in the lab.

We used the Basinwide Visual Estimation Technique, BVET, to estimate various independent habitat parameters at each reach (e.g., dominant/subdominant substrate, percent riffle/pool/run habitat, amount of large wood, etc.) (Dolloff et al. 1993). We also collected replicate water samples, which were analyzed at the Coweeta Hydrologic Laboratory for ammonium, nitrite, nitrate, phosphorous, sulfate, potassium, calcium, and magnesium using standard methods (USEPA 1983a; USEPA 1983b). We calculated several temperature variables using the continuous temperature data recorded by the HOBO temperature loggers. We determined the mean annual temperatures, the average daily maximum and minimum summer temperatures, and the average daily maximum and minimum winter temperatures from the year preceding the sampling event.

In the lab, we removed otolith sagittae from all trout collected and weighed the stomach contents of each individual. Ages of each fish were blindly estimated by an experienced reader by viewing each otolith under a stereomicroscope interfaced with image analysis software. Site- and species-specific logarithmic and von Bertalanffy growth functions ( $L=L_{\infty}(1-e^{-K(t-t_0)})$ ) created using EXCEL solver were then used to predict the age of all measured fish (for which no otoliths were taken) using the total length as the predictor (Allen 1966). Biomass was determined by summing the weights of all trout encountered and dividing by the total area sampled. To calculate

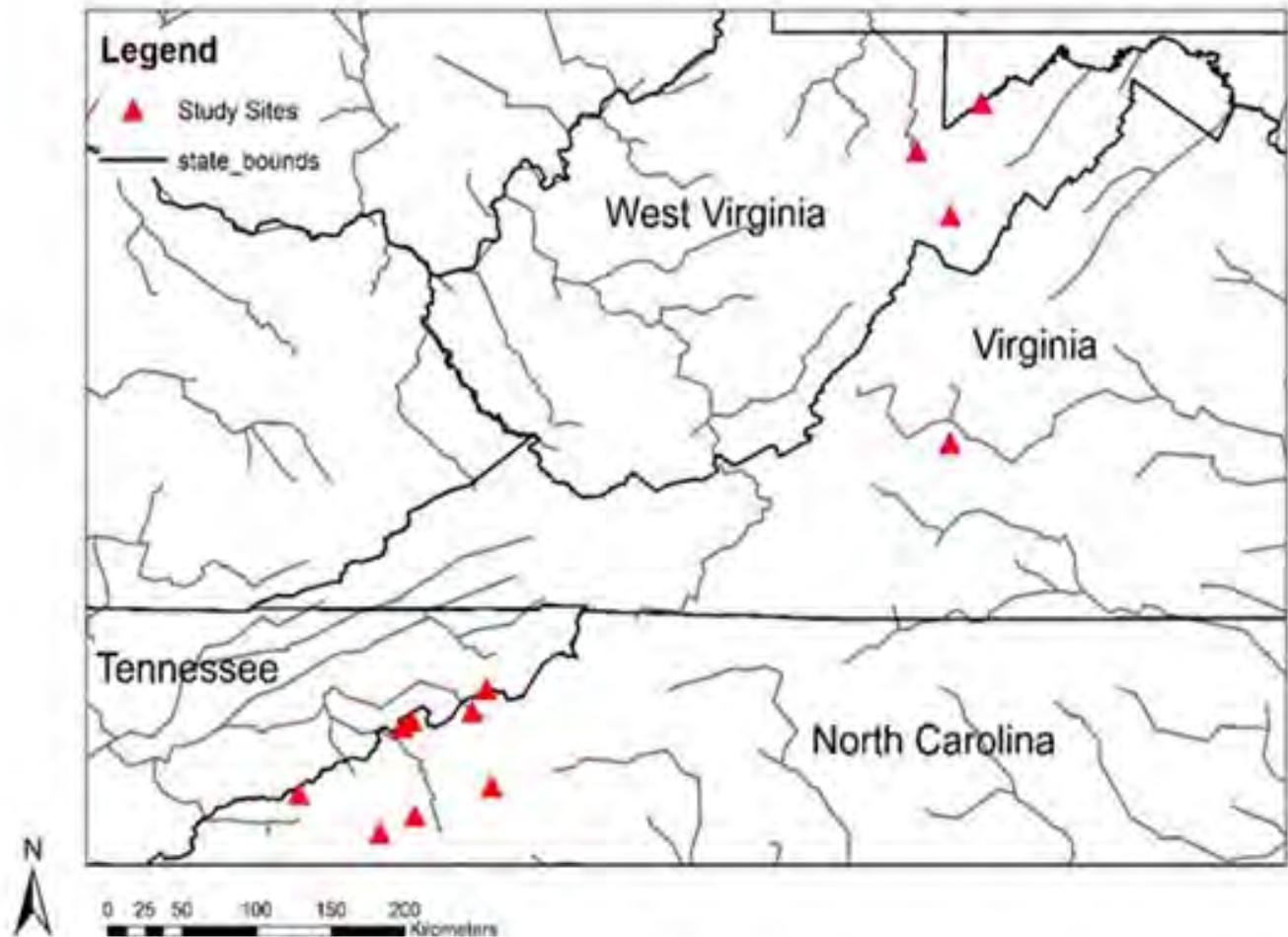


Figure 1. Study stream locations in the southern Appalachian Mountains in Maryland, West Virginia, Virginia, North Carolina and Tennessee sampled during summer 2012.

secondary production we used a modified version of the instantaneous growth rate method (P=GB) (Waters 1977; Hayes et al. 2007), which sums the accumulation of biomass between age classes (B) and is multiplied with the instantaneous growth rate (G) (Valentine-Rose et al. 2007; Valentine Rose et al. 2011). Negative production values were considered to be 0.

**Data analysis**—Statistical mean comparisons of Brook Trout and Rainbow Trout biological estimates were not conducted due to our limited sample size of streams where both species co-occurred. We calculated total trout biomass and production at each site by taking the sum of the biomass or production estimates for both Brook and Rainbow Trout. With these data, we conducted a multiple linear regression using XLSTAT software on the log-transformed total

production estimate using potential habitat covariates (i.e.,  $[\text{NO}_3]$ ,  $[\text{Ca}]$ , and mean minimum winter temperatures). Non-parametric Spearman  $r$  correlations were conducted among the covariates and total trout production, Brook Trout production, and Rainbow Trout production. We then determined the percent biomass and percent production of Brook Trout and Rainbow Trout relative to the total trout values at each site. We conducted a set of multiple multinomial logistic regressions with percent biomass and percent production of the species as the dependent variables, and various temperature and water chemistry variables as potential predictors. We then selected the lowest Akaike Information Criteria (AIC) model to identify the independent variables that accounted for the most variation in percent biomass and percent production for Brook Trout and Rainbow Trout logistic models.

## RESULTS

**Biomass, production, estimates**—Rainbow Trout were encountered at eight streams with number of individuals ranging from 5 to 78, and Brook Trout were encountered at eight streams with number of individuals ranging from 3 to 72. Both Rainbow Trout and Brook Trout occurred together at three sites. One individual Brown Trout occurred at one site with both Rainbow Trout and Brook Trout (Beech Flats Prong), and 16 Brown Trout were encountered at one site where Brook Trout were present (Scapecat Branch). Biomass estimates ranged from 0.01 to 1.15  $\text{g}\cdot\text{m}^{-2}$  and 0.35 to 1.60  $\text{g}\cdot\text{m}^{-2}$  for Brook Trout and Rainbow Trout, respectively. Production estimates ranged from 0.00 to 1.09  $\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$  and from 0.00 to 7.48  $\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$  for Brook Trout and Rainbow Trout, respectively. Brown

Trout production at Scapecat Branch was 1.20  $\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ . Brook Trout production to biomass (P/B) ratios ranged from 0 to 2.12, and Rainbow Trout production to biomass ratios ranged from 0 to 7.16. Rainbow Trout tended to dominate production, biomass, and P/B across all 13 sites; however, Brook Trout had higher abundances (Figure 2).

**Temperature-Production regressions**—Log transformed total trout production had a significant, positive relationship with mean minimum winter temperature while controlling for [Ca] and [NO<sub>3</sub>] ( $P=0.009$ ) (Figure 3). Holding [Ca] and [NO<sub>3</sub>] constant for every one degree increase in the mean minimum winter temperature, log transformed total trout production is expected to increase by 0.1 units. Furthermore, when species-specific production

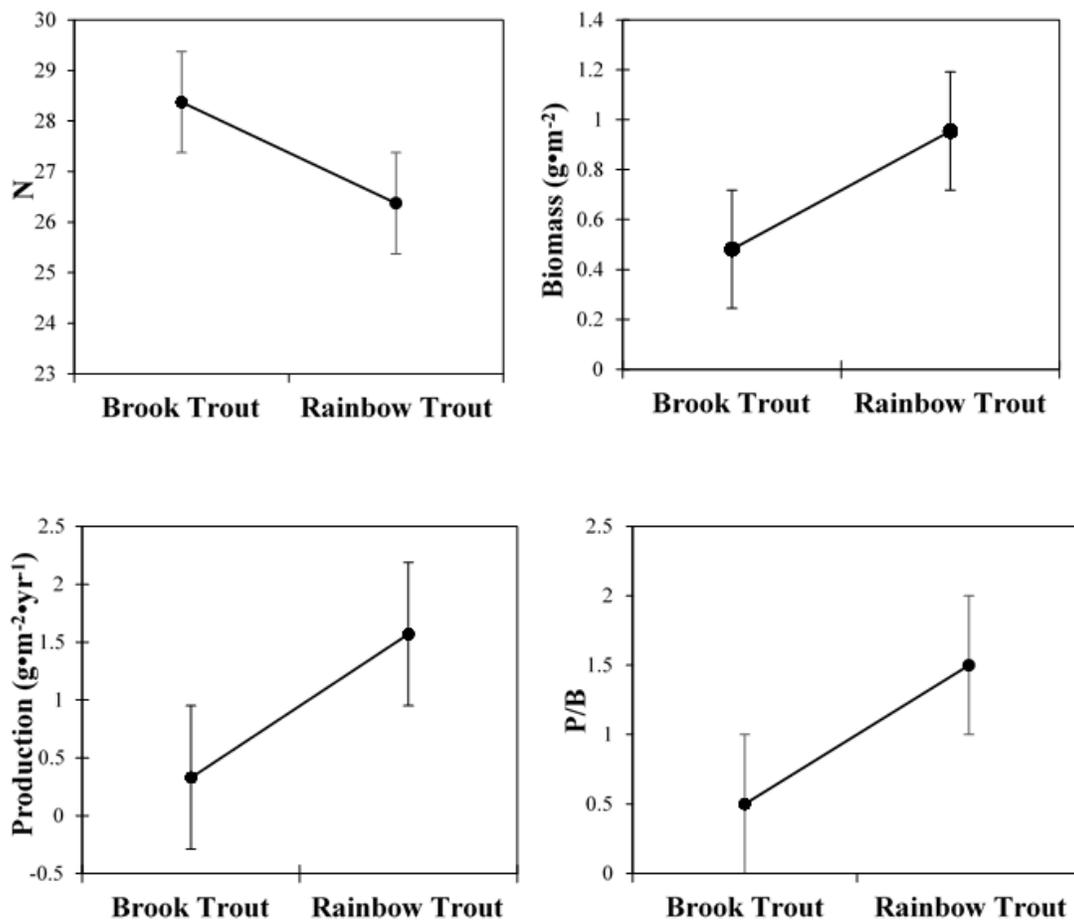


Figure 2. Interspecific comparison of Mean N (number of individuals), biomass ( $\text{g}\cdot\text{m}^{-2}$ ), production ( $\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ), and P/B (production/biomass ratio) with standard error bars for Brook Trout versus Rainbow Trout from 13 southern Appalachian streams sampled during summer 2012.

estimates were isolated, Rainbow Trout and Brook Trout production demonstrated opposite responses to mean minimum winter temperature (Figure 3).

A similar relationship between mean minimum winter temperature while controlling for  $[NO_3]$  and  $[Ca]$  was evident in the logistic regression models of percent biomass and percent production as the dependent variable. Brook Trout and Rainbow Trout had opposite relationships with mean minimum winter temperature. Holding  $[NO_3]$  and  $[Ca]$  constant, the odds of Brook Trout comprising 100% of the production or biomass of a trout population decreases by 0.002 and 14.8, respectively, for every 1 degree

increase in the mean minimum winter temperature. In contrast, the odds of Rainbow Trout comprising 100% of the production or biomass of a trout population increases by 0.002 and 22.5, respectively, for every one degree increase in mean winter minimum temperature holding  $[NO_3]$  and  $[Ca]$  constant.

## DISCUSSION

**Biomass and production**—Our results are consistent with previous studies that estimated trout biomass, production, and P/B ratios in similar habitats in Minnesota, USA and other southern Appalachian

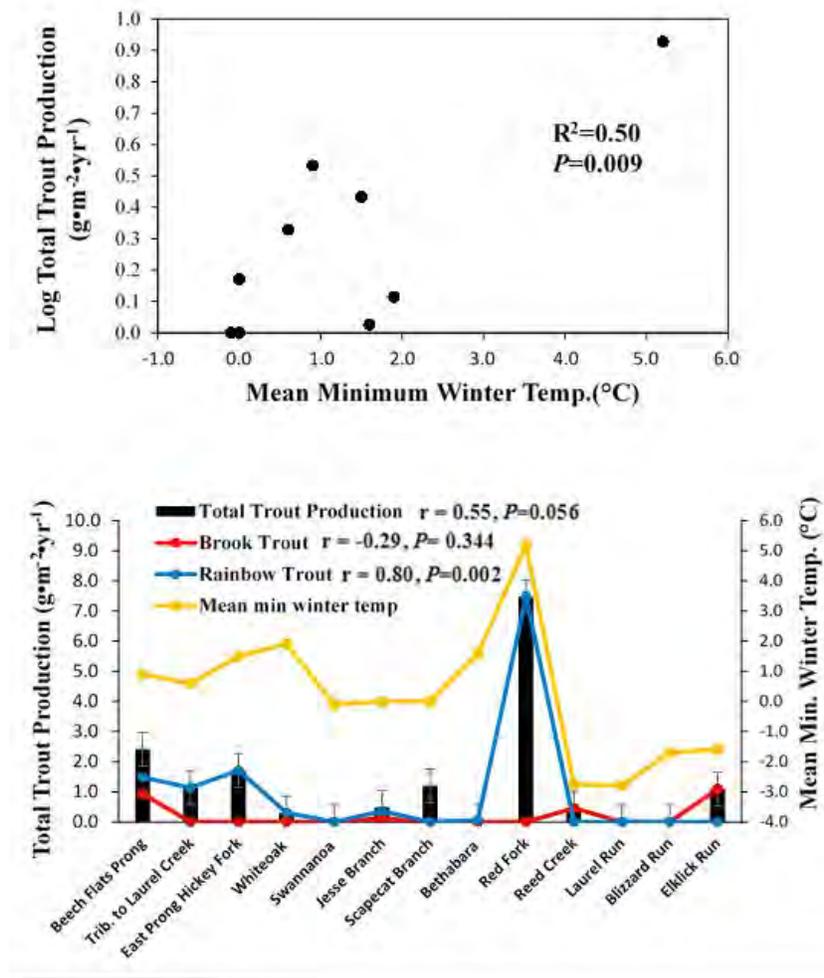


Figure 3. Graph 1-Log total Trout production ( $g \cdot m^{-2} \cdot yr^{-1}$ ) as a function of mean minimum winter air temperature (°C). Adjusted  $R^2$  and P-value shown on graph. Graph 2-Total Trout production (sum of Trout species production,  $g \cdot m^{-2} \cdot yr^{-1}$ ) (black bars) and the amount of Brook Trout (red line) and Rainbow Trout (blue line) production with the associated mean minimum winter air temperature (°C) (yellow line) at each stream location. Spearman's  $r$  values with associated P-values in the legend correspond to correlations between trout production rates and mean minimum winter temperature.

streams (Whitworth and Strange 1983; Kwak and Waters 1997) (Table 1). From this study, Rainbow Trout production and the P/B ratio at one site were both above 7.0, which is slightly higher than other published estimates. This particular site had a large amount of age 0 fish; thus, the production rate increased dramatically compared to streams with older age classes, which is a typical trend, and is still within the range of published data (Waters 1977; Neves and Pardue 1983; Neves et al. 1985). Brook Trout production estimates were similar to those of Brook Trout co-occurring in areas with Rainbow Trout in another Appalachian stream (Whitworth and Strange 1983). Neves et al. (1985) also found Brook Trout production to be lower in areas with Rainbow Trout present, and Rose (1986) concluded that Brook Trout abundance was lower when competitors (e.g., Rainbow Trout) were present. In general, southern Appalachian streams have low densities of Brook Trout due to soft water and reduced stream fertility (Neves and Pardue 1983). Using these empirical estimates, we concluded that Rainbow Trout likely dominate streams compared to Brook Trout when both species co-occur; however, a larger sample size of mixed trout streams require sampling to strengthen these results. With a larger sample size, statistical significance between mean biomass and production of co-occurring Brook Trout and Rainbow Trout could be reached, but we were unable to conclude statistical significance with only 3 streams where Rainbow Trout and Brook Trout coexisted.

**Production and temperature**—As a group, trout have been classified as coldwater fishes regardless

of species (Magnuson et al. 1979; Lyons et al. 2010). However, Magnuson et al. (1979) highlighted that even species within the same family can exhibit wide variation in thermal niche dimensions. As a result, small differences in thermal niche size may create disproportionate levels of interspecific competition for preferred thermal habitats where biological fitness parameters (e.g., growth) are optimized. Rainbow Trout are considered more tolerant of temperature variations than Brook Trout and have a higher maximum temperature tolerance of 24.0°C compared to 22.4°C for Brook Trout (Neves et al. 1985; Eaton and Scheller 1996). Jenkins and Burkhead (1993) noted that Brook Trout prefer temperatures between 14-16°C and Rainbow Trout prefer temperatures between 12-19°C. Competition between Brook Trout and Rainbow Trout could be influencing the effects of increased temperatures on Brook Trout's temperature threshold in the southern Appalachians. Lohr and West (1992) found Rainbow Trout occupied the middle, deeper sections of the stream while Brook Trout were forced to stay on the margins; however, when Rainbow Trout were removed Brook Trout migrated into deeper water. Brook Trout could be competitively excluded from these areas by Rainbow Trout. With increasing temperatures, margins would likely be unsuitable habitat for Brook Trout. Furthermore, behavioral differences of introduced species could be contributing to disproportionate production rates of Brook Trout in favor of Rainbow Trout. Introduced species are suggested to be more aggressive and adaptable under stress than native species (e.g., Brook Trout) (Waters 1983). This highlights the often convoluted effects temperature has on biological success of fish and

**Table 1. Production rates (P) ( $\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ) for Trout species in similar streams in the southern Appalachians and elsewhere in the United States.**

Stream	Rainbow Trout	Brook Trout	Brown Trout	Source
	P	P	P	
southern Appalachian streams	0.06-7.48	0.84-2.12	1.20	this study
South Fork Holston River, Virginia	3.60	*	*	Neves et al 1985
Rocky Fork Creek, Tennessee	0.98-1.2	0.77-1.14	*	Whitworth and Strange 1983
Guy's Run, Virginia	*	0.54-1.93	*	Neves and Pardue 1983
Valley Creek, Minnesota	3.30	2.50	13.20	Waters 1983

the need to rigorously manage at-risk Brook Trout populations (Dunham et al. 2002).

**Management implications**—Mean annual temperatures are projected to increase by approximately 4.5°C in the future in northeastern United States (i.e., where Brook Trout are native). These changes could dramatically shrink the availability of suitable Brook Trout habitat and encourage further population declines (Eaton and Scheller 1996). With 2012 being the hottest year on record in the United States (NCDC 2013), using a robust integrative metric like production to determine the biological responses of Brook Trout to warm temperatures may be essential to documenting the response of this species to climate change. Observed patterns can be contrasted with more temperature tolerant competitors (i.e., Rainbow Trout), in mixed trout streams to intuit appropriate management decisions.

Our study revealed that winter temperature minimums were significantly related to Brook Trout and Rainbow Trout percent biomass and percent production and that analyzing several biological estimates (i.e., abundance, biomass, and production) can produce divergent results at different scales (inter- versus intraspecific). Steps will continuously need to be taken to mitigate effects of Rainbow Trout on Brook Trout in the northeastern U.S. where temperatures (especially winter temperatures) are expected to rise (Eaton and Scheller 1996). For example, Rainbow Trout removal by electrofishing and stocking of Brook Trout could be used as management tools as these methods significantly increased the densities of Brook Trout in a mixed trout stream model (Clark et al. 2002). Ultimately, a multitude of management strategies need to be employed to protect Brook Trout populations in their native range and to diminish the effects of climate change coupled with the presence of nonnative trout species.

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## REFERENCES

- Allen, K.R. 1966. A method of fitting growth curves on the von Bertalanffy type to observed data. *Fisheries Research Board of Canada* 23: 163-179.
- Chu, C., N.E. Mandrak, and C.K. Minns. 2005. Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. *Diversity and Distributions* 11:299-310.
- Clark, M.E., K.A. Rose, D.A. Levine, and W.W. Hargrove. 2001. Predicting climate change effects on Appalachian trout: combining GIS and individuals-based modeling. *Ecological Applications* 11:161-178.
- Dolbeth, M., M. Cusson, R. Sousa, and M.A. Pardal. 2012. Secondary production as a tool for better understanding of aquatic ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1230-1253.
- Dolloff, C.A., D.G. Hankin, and G.H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service General Technical Report SE-83.
- Dunham, J.B., S.B. Adams, R.E. Schroeter, and D.C. Novinger. 2002. Alien invasions in aquatic ecosystems: toward an understanding of brook trout invasions and potential impacts on inland cutthroat trout in western North America. *Reviews in Fish Biology and Fisheries* 12: 373-391.
- Eaton, J.G. and R.M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography* 41:1109-1115.
- EBTJV (Eastern Brook Trout Joint Venture). 2006. About the Eastern Brook Trout Venture. Available: [www.easternbrooktrout.org](http://www.easternbrooktrout.org) (September 2012).
- Ensign, W.E., R.J. Strange, and S.E. Moore. 1990. Summer food limitation reduces brook and rainbow trout biomass in a southern Appalachian stream. *Transactions of the American Fisheries Society* 119: 894-901.
- Fausch, K.D. 2008. A paradox of trout invasions in North America. *Biological Invasions* 10:685-701.
- Flebbe, P.A., and C.A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. *North American Journal of Fisheries Management* 15: 579-590.
- Hayes, D. B., J. R., Bence, T. J. Kwak, and B. E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 in C. S. Guy and M. L. Brown, editors. *Analysis and interpretation of freshwater fisheries data*. American Fisheries Society, Bethesda, Maryland.
- Jenkins, R.E. and N.M. Burkhead. 1993. *Freshwater fishes of Virginia*. American Fisheries Society, Bethesda, Maryland.
- Kwak, T.J. and T.F. Waters. 1997. Trout production dynamics and water quality in Minnesota streams.

- Transactions of the American Fisheries Society 126: 35-48.
- Larson, G.L. and S.E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian Mountains. Transactions of the American Fisheries Society 114:195-203.
- Lohr, S.C. and J.L. West. 1992. Microhabitat selection by brook and rainbow trout in a southern Appalachian stream. Transactions of the American Fisheries Society 121(6):729-736.
- Lyons, J., J.S. Stewart, and M. Mitro. 2010. Predicted effects of climate warming on the distribution of 50 stream fishes in Wisconsin, U.S.A. Journal of Fish Biology 77:1867-1898.
- Magnuson, J.J., L.B. Crowder, and P.A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19:331-343.
- Meisner, J.D. 1990. Effect of climatic warming on the southern margins of the native range of brook trout, *Salvelinus fontinalis*. Canadian Journal of Fisheries and Aquatic Science 7:1065-1070.
- NCDC (National Climatic Data Center), NOAA. 2013. NCDC announces warmest year on record in the contiguous U.S.. <<http://www.ncdc.noaa.gov/news/ncdc-announces-warmest-year-record-contiguous-us>>Accessed July 2013.
- Neves, R.J. and G.B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Transactions of the American Fisheries Society 112:21-26.
- Neves, R.J., S.L. Brayton, and L.A. Helfrich. 1985. Abundance and production of a self-sustaining population of rainbow trout in the South Fork Holston River, Virginia. North American Journal of Fisheries Management 5:584-589.
- Poplar-Jeffers, I.O., J.T. Petty, J.T. Anderson, S.J. Kite, M.P. Strager, and R.H. Fortney. 2009. Culvert replacement and stream habitat restoration: implications from brook trout management in an Appalachian watershed, U.S.A. Restoration Ecology 17(3):404-413.
- Rose, G.A. 1986. Growth decline of subyearling brook trout (*Salvelinus fontinalis*) after emergence of rainbow trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquatic Science 43:187-193.
- Rypel, A.L. 2013. The coldwater connection: Bergmann's rule in North American freshwater fishes. The American Naturalist, In Press.
- Thieling, T.M. 2006. Assessment and predictive model for brook trout (*Salvelinus fontinalis*) population status in the eastern United States. Master's thesis. James Madison University. Harrisonburg, VA.
- USEPA (U.S. Environmental Protection Agency). 1983a. Methods for chemical analysis of water and waste. Determination of nitrogen as ammonia. In: Method 350.1, Environmental Monitoring and Support Lab., Office of Research and Development, USEPA, Cincinnati, OH.
- USEPA (U.S. Environmental Protection Agency). 1983b. Methods for chemical analysis of water and waste. Determination of nitrite/nitrate by automated cadmium reduction. In: Method 353.2, Environmental Monitoring and Support Lab., Office of Research and Development, USEPA, Cincinnati, OH.
- Valentine-Rose, L, A. L. Rypel, and C.A. Layman. 2011. Community secondary production as a measure of ecosystem function: a case study with aquatic ecosystem fragmentation. Bulletin of marine science 87:913-937.
- Valentine-Rose, L., C.A. Layman, D.A. Arrington, and A.L. Rypel. 2007. Habitat fragmentation decreases fish secondary production in Bahamian tidal creeks. Bulletin of Marine Science 80:863-877.
- Waters, T.F. 1977. Secondary production in inland waters. Advances in Ecological Research 10:91-164.
- Waters, T.F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: production and abundance. Transactions of the American Fisheries Society 112:137-146.
- Waters, T.F., and G.W. Crawford. 1973. Annual production of a stream mayfly population: a comparison of methods. Limnology and Oceanography 18:286-296.
- Whitworth, W.E. and R.J. Strange. 1983. Growth and production of sympatric brook and rainbow trout in an Appalachian stream. Transactions of the American Fisheries Society 112:469-475.

## HEALING IN THE HEADWATERS—A BROOK TROUT RESEARCH AND RESTORATION SUCCESS STORY

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**Abstract**—Shavers Fork is a high value native and stocked trout river in West Virginia. The historic fishery was widely regarded for producing great catches of large native Brook Trout *Salvelinus fontinalis*, even providing a food source for the lumber and railroad camps that would help to hasten the decline of the river's productivity. The large Brook Trout were greatly reduced in numbers by 1920; subsequent stockings of nonnative salmonids, coal mining, second-growth timber cutting, and acid precipitation created ongoing stressors to the remaining population of native trout preventing a rebound to previous levels. By the 1980's managers began investigating and prioritizing options to restore the river as a premier native and wild Brook Trout fishery. A large portion of the watershed came into Forest Service ownership in the 1980's allowing for some landscape recovery from timber and mining impacts. Research into acid precipitation treatment methods resulted in improved year-round water quality in larger tributaries and the main stem. Improvements in water quality treatments and investigations into the life history of the local Brook Trout community have been forged into the framework of current restoration activities. Telemetry research indicated seasonal association of trout to groundwater inputs. Habitat-use studies showed strong correlation of reproductive success to watershed size. Food availability and growth projects highlighted the importance of main-stem foods to increased scope for growth. Reconnection of isolated coldwater inputs, narrowing of widened channels, increasing large woody debris, and improving riparian cover are results of extensive research to improve the native and wild trout fishery. Managers have been provided the information and continue to implement the tools to reestablish the vigorous native Brook Trout of Shavers Fork. The future challenge is finding appropriate management strategies and fishing regulations to maximize the fishery value of this unique resource.

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### INTRODUCTION

An abundance of quality trout fisheries exist in West Virginia, but few have elicited such reverence and passion to the anglers of the Mountain State as the Shavers Fork, a major headwater tributary of the Cheat River in the Allegheny Mountains of the state. Its headwaters originate from the highest elevation spring sources in the state at over 1372 m providing habitat for the once abundant native Brook Trout. A few photographs exist (Figure 1) to validate the logbook of the Cheat Mountain Club (est. 1887), which documents angler's catches into the early 1900's as summarized by Zurbuch (2002):

*“1894, July, 115 trout (brook trout), one day trip; 1900, June, 129 trout, four days, water too cold for big trout up stream, only caught one 11 ¼”, all fair size but not as big fish as on former trips; 1901, June, largest trout of the season – 13 ¾”; 1901, July, 1 trout 12 ¼”, 4 trout 11 – 11 ¾”, 10 trout over 9*

*½”;* 1903, August, had a royal good time and caught bbls. of fish; 1904, June, 1 trout 10”, 1 trout 13 ¾”, 1 trout 14”, one hour catch – raining; 1905, June, 11 trout, trout jumping – caught 11 between hours of six and nine p.m., several rods were in use but no expert anglers were present; 1910, May, 26 trout, got trout in forenoon, one 11 ¼”, one 10 ½”; 1911, June 67 trout, 1 – 12”, 3 – 10”, several 9”.”

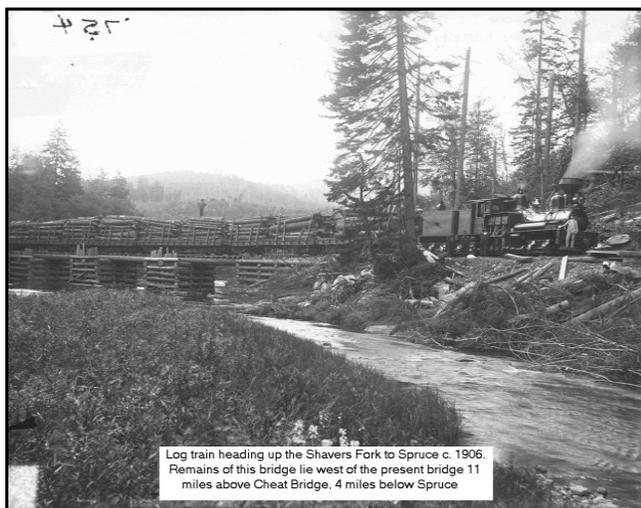
The peak of the railroad development and logging boom upstream (Figure 2) around the town of Spruce was occurring around 1912 (Clarkson 1964), and the impacts on the fishery were becoming evident to the anglers, and logbook entries detailing fishing excursions became less frequent:

*“1912, May, 50 trout and 2 chubs; 1914, July, chubs, only few trout – many (Oh thousands) of chubs (Ye little fish), it is this writers opinion that this date is too late for trout; 1917, June, chubs, 1 barrel of chubs; 1917, September, we want more fish in the stream”* (Zurbuch 2002 from Cheat Mountain Club logbook).

Rearing and stocking of hatchery fish had already become a common form of trout fishery management in West Virginia by the time the decline of the native fishery was noted by anglers, and the Shavers Fork has since received untold hundreds of thousands of supplemental fish (Kinney 1963) to support angler demands over the last century.



**Figure 1. Archival photo of stringer of Brook Trout caught from Shavers Fork.**  
*Courtesy Cheat Mountain Club.*



Log train heading up the Shavers Fork to Spruce c. 1906.  
 Remains of this bridge lie west of the present bridge 11 miles above Cheat Bridge, 4 miles below Spruce

**Figure 2. Example of logging and railroad impacts to upper Shavers Fork. Note that the knob in the left center background is completely devoid of trees.**  
*From Mountain State Railroad and Logging Historical Association.*

But logging and angler harvest were not the only impacts to the historic trout fisheries of the region. Deterioration of water chemistry in the Cheat River watershed due to coal mining has been recognized since 1929, and some negative effects on the Shavers Fork fishery have been attributed to acid mine drainage (Clayton et al. 1998). But by the 1960's and 1970's, more impacts to fisheries in Shavers Fork and other watersheds were recognized to be from acid precipitation than from the mining in the watershed (Zurbuch 1984). By the 1980's the acid deposition had gotten so bad that there were episodic fish kills from snowmelt runoff and a popular catch-and-release section was opened to angler harvest in the fall because of the lack of any carryover fishery (Kobuszewski 1992).

As treatment systems became more effective in other studied streams, i. e. Otter Creek to the north and Cranberry River to the southwest, attention was turned to studying ways to mitigate the landscape-scale acid precipitation impacting Shavers Fork to improve the year-round main-stem fisheries and quality native Brook Trout tributaries that flowed into it. Around the same time a large (~19425 ha) tract of private land within the Monongahela National Forest in the upper Shavers Fork came into ownership of the U.S. Forest Service. Plans for returning the watershed to its once-productive native trout fishery were now possible, but a century of impacts had to be overcome by a broad coalition of resource professionals to make it come to fruition.

### Initial Research—Addressing Water Quality Needs

Early research into improving the water quality was begun by the West Virginia Division of Natural Resources (DNR). That agency had already been studying the effects of acidification in streams and the methods to mitigate those effects for decades (Zurbuch 1963; Menendez 1974; Zurbuch 1981). And the necessity to improve early spring water quality for increasing angler opportunities through regular stockings was a priority of the agency. The success of the limestone drum stations on Cranberry River and Otter Creek (Zurbuch 1984; Menendez and Clayton 1992; Menendez et al. 1996) and the continued maintenance of water chemistry in times of extended shutdown periods (Zurbuch 1989) led the

DNR to pursue the feasibility of using point-source direct application of crushed limestone aggregate as a treatment method.

Ivahnenko et al. (1988) was the first pointed research to look at this dispersed method of crushed limestone aggregate for neutralizing effects of acidic deposition in the Shavers Fork watershed. The results of this study showed that it was possible to apply finely crushed limestone at a site adjacent to the streambed that is convenient to land managers and allow elevated flows to carry the particles downstream and store them in stream sediments to be used up over time, essentially as-needed based on the acidity, turbulence, and discharge of the flowing stream. The questions raised as a result of this project led to a more thorough investigation of the effects of these limestone “fines” on water chemistry, benthos, and fishes.

### The Next Step—Biota

As a result of the promising outcome of Ivahnenko’s (1988) study, major research funding was secured in a cooperative effort between the West Virginia DNR and two West Virginia University departments, the Cooperative Fish and Wildlife Research Unit and the Department of Geology and Geography. Benthological studies were conducted to determine the severity of the impact of acidification on Shavers Fork compared to adjacent drainages with circumneutral water quality (Kobuszewski 1992; Kobuszewski and Perry 1993). Their results corroborated other contemporary studies by describing a benthic community of low species richness of tolerant organisms even though abundance, density, and biomass remained comparable to adjacent unimpaired communities.

During the same period, Clayton et al. (1998) were studying refinements to the crushed limestone treatment method in order to maximize the benefit to local Brook Trout populations and downstream fish communities. Different sizes of aggregate at different dosing levels were applied to treatment streams to determine dissolution and retention rates in sediments and net improvement to water chemistry. Sand size aggregate applied at a single site annually to neutralize the annual acid load proved to yield the optimum biological, chemical, and economical results (Clayton et al. 1998). The results of this study still guide the West Virginia DNR limestone treatment program today.

### The Habitat—It’s All About the Habitat

Research professionals and resource managers were interested in initiating a collaborative research and restoration process. In 2000, representatives from 25 private, state, and federal organizations and nongovernmental organizations met at Snowshoe Mountain Resort at the head of the Shavers Fork culminating in eighteen participants drafting and signing a shared commitment document called “Healing the Headwaters” (<http://shaversforkcoalition.org/headwaters.htm>). This landmark partnership has led to the flush of research and restoration funding for addressing ongoing needs in the watershed for improving the Brook Trout fishery.

Impacts from industrial activities of the previous century had left the habitat of the main stem of the Shavers Fork in less than optimal condition. The construction of the railroads had straightened sections of the river, filled off-channel wetlands for rail beds, and put too-small culverts at inappropriate places cutting off important spawning tributaries. Logging activities had increased sediment loading, removed instream wood and boulder structure, and removed riparian shading from the main stem and tributaries (Figure 3). The combination of these activities reduced available habitats for spawning, growth, and cover, making a rebound of native stocks less likely once water quality issues were becoming addressed through management activities and limestone fines additions.



Figure 3. A typical reach, shallow and devoid of trout habitat in the main-stem Shavers Fork. The railroad bed is visible on the left in the picture.

A study of available habitat in the main-stem Shavers Fork was begun and culminated in Gaujot (2002). He recommended assessment of landscape-scale processes influencing local habitat and biological conditions prior to embarking on large, expensive main-stem habitat remediation measures. But much insight was gained into the ultimate stability of the river and potential of future efforts to improve the native Brook Trout fishery. Understanding the population dynamics of the Brook Trout and their relationship within the watershed was the next obvious direction for researchers.

### The Fish and Their Food

With improvements in treatment methods for acidic water chemistry, researchers turned attention to insight about the productivity of the watershed, and the ability of the landscape to support improving fish populations. Bopp (2002) studied the effects of canopy cover (light input), stream size, and alkalinity in determining the abundance, density, richness, and structure of the macroinvertebrate community of the upper Shavers Fork. His findings showed high species richness and abundance in the main stem, but also high density and richness (albeit a different community) in cold tributary systems with abundant light (low canopy cover). These results suggest the potential of a highly productive functional system with a high variability of feeding opportunities for fish depending on the fish's ability to access the appropriate habitat at the right time.

Lamothe (2002) and Petty et al. (2005) assessed the population dynamics of the Brook Trout in a large tributary network of the Shavers Fork watershed. This project described the spatial variability of reproductive effort and success (or lack thereof) within Second Fork, a major source of fish to the main stem and also a major temporal refuge for fish escaping inhospitable main-stem conditions (i. e. elevated temperatures and flows). The results reflected a dynamic population structure. Many adults in the smallest of tributaries moved little throughout their lives while other adults and juveniles were highly mobile, seeking out habitats to improve their potential for growth and reproduction. A critical piece of evidence from this study was the relationship of stream size (drainage area) to reproductive effort in Brook Trout. Observations described in Lamothe (2002) and Petty et al. (2005)

of spawning Brook Trout in Second Fork showed an intense usage, >70% of observed spawning effort, of stream segments draining 3 km<sup>2</sup> or less. Many of these small headwaters in the Shavers Fork watershed, however, arise in acidic bedrock, creating poor conditions for recruitment. This research emphasizes the importance of maintaining or improving water quality in headwater areas to eliminate reproductive “traps” where adults are attracted to spawn, but egg development fails due to episodes of excess acidity.

Petty and Thorne (2005) used the results of Lamothe (2002) and Petty et al. (2005) to predict the impact of a large-scale limestone fines treatment project across the upper Shavers Fork basin. Utilizing the stream-segment drainage area to estimate spawning intensity with field measurements of water quality (pH, alkalinity, and dissolved calcium) to estimate juvenile survivorship, the authors measured an 80% loss of historical juvenile recruitment potential. A variety of models yielded two optimal management scenarios: (1) relatively low-cost treatment of critical stream segments using existing access infrastructure for delivery of limestone sand, or (2) high-cost treatment of all impaired headwater stream segments using aerial (helicopter) application of limestone sand. This same procedure can be applied to other headwater restoration activities as well, such as culvert replacement impacts (Poplar-Jeffers et al. 2009). Managers can simply use their current and projected funding levels to prioritize restoration activities.

Hansbarger (2005), Hansbarger et al. (2008), and Petty et al. (2012) looked at the migratory capacity and habitat preferences of larger native Brook Trout and wild Brown Trout *Salmo trutta* residing in Shavers Fork and the tributary Rocky Run with radio telemetry. The findings showed a high degree of mobility, particularly in searching out coldwater inputs during times of elevated main-stem temperatures. Previously unrecognized coldwater sources were discovered by the researchers, increasing the scope for restoration processes to include these areas. There was also observed a high level of site fidelity at a given point in the annual cycle. Trout seem to return to the same areas routinely, whether for reproduction or refuge from temperature extremes.

Quantifying diet, consumption, and growth of Brook Trout was the objective of Thorne (2004) and Petty et al. (2014). Brook Trout diet in Shavers Fork is seasonally variable, leading to wide fluctuations in

growth and consumption. Smaller fish (juveniles and small adults) grow more rapidly than do larger adults despite consuming less food. Prey availability does not seem to be a limiting factor in tributaries, yet may limit growth in main-stem habitats. Larger adults that can take advantage of larger and more abundant prey items in the main stem (i. e. fish and crayfish) are at a competitive advantage for prime habitats, including reproductive sites. Mobility could also play a key role in a fish's ability to grow bigger more rapidly by affording access to prime habitats not available to non-mobile individuals. A key conclusion of this study is the importance of maintaining functionality of all habitat types for optimal population heterogeneity.

The role of connectivity of smaller direct main-stem tributaries was initially thought to be important due to the effects of the coldwater input and the thermal refuge provided at the main-stem interface. But the importance proved to be more complex. Liller (2006) described the relationship of these tributaries as patchy metapopulations acting as individual source habitats to the main-stem Shavers Fork sink habitat. He showed that local persistence was based on local recruitment and that main-stem populations were dependent on immigration from these source areas.

Population regulation at the watershed scale seems to be controlled through various processes, but the culmination of extensive research shows an overriding density-dependent process at work in both headwater areas and main-stem habitats (Huntsman and Petty 2014). Lack of overhead cover and thermal refugia limit quality usable habitat during seasons of decreased flows and elevated temperature, but all available usable habitats are occupied and utilized by Brook Trout. Improving cover area and increasing the area and access to thermal refugia in the main stem would likely increase the overall biomass of Brook Trout in the watershed if the population is indeed regulated by density in the main stem.

Assessing the differing populations of the many small tributaries has always been a topic of importance to the Shavers Fork researcher. Aunins et al. (2014) described the genetics of the complex populations of Shavers Fork and two comparable Appalachian river systems. Their work described the interconnectedness of all the tributaries in Shavers Fork due to the cooler nature of the main stem compared to adjacent warmwater main-stem Brook Trout systems, which exhibit more fragmentation. In this regard, Shavers

Fork exhibits characteristics more similar to northern Brook Trout systems (Kelson et al. 2014) than southern Appalachian systems (Richards et al. 2008; Hudy et al. 2010; Kanno et al. 2011; Whiteley et al. 2013) and the effective migratory nature of the tributary populations. These results highlight the importance of maintaining and improving habitat quality in the main stem and restoring connectivity of cutoff tributaries to facilitate the migratory nature of the tributary inhabitants.

### Temperature—The Limiting Factor

Each step of the research process has kept leading back to a common theme that limits Brook Trout size and abundance in the main-stem Shavers Fork: extreme summer temperatures. While studies showed that higher productivity was possible in the main stem because of the temperature regime (Thorne 2004; Petty et al. 2014), and coldwater inputs were prevalent longitudinally throughout the main stem (Hansbarger 2005; Liller 2006) to afford refugia in times of thermal stress (Hansbarger et al. 2008, Petty et al. 2012), temperature continued to be the pervasive limiting condition on restoring Brook Trout to desired levels. Ongoing research into temperature modeling (Tincher 2013) highlights the possible effects of climate change, further reducing habitat availability during seasons of elevated temperatures. But results from active channel restoration (restrictions and pool formation) may counter some effects by intercepting additional groundwater sources, providing cover, foraging habitats, and thermal refugia. Some initial findings (Tincher 2013) suggest a moderating effect may already be evident. With low flows and high air temperatures in 2012, site temperatures in some of the most problematic reaches of the Shavers Fork remained in the habitable range throughout the summer period.

## CONCLUSIONS

More work and watershed-scale modeling remains to be done detailing climate change scenarios and continuing impact of anthropogenic inputs on the Brook Trout of the Shavers Fork, but restoration is continuing and the trout are thriving with the effort put forth to date. With chemical restoration ongoing through limestone sand additions and initial phases of physical restoration completed, an evaluation of

past successes and failures will guide researchers and managers to attack future complex ecological questions with the same thoughtful, collaborative process that has helped bring the Shavers Fork back to a unique, large, high-quality native Brook Trout fishery.

## LITERATURE CITED

- Aunins, A. J., J. T. Petty, T. King, M. Schilz, and P. Mazik. 2014. River mainstem thermal regimes influence population structuring within an Appalachian brook trout population. *Conservation Genetics* 15:000-000 (<http://dx.doi.org/10.1007/s10592-014-0636-6>).
- Bopp, J. A. 2002. Combined effects of water chemistry, canopy cover, and stream size on benthic macroinvertebrates along a Central Appalachian stream continuum. Master's thesis, West Virginia University, Morgantown.
- Clarkson, R. B. 1964. Tumult on the mountains – lumbering in West Virginia 1770 – 1920. McClain Printing Company, Parsons, West Virginia.
- Clayton, J. L., E. S. Dannaway, R. Menendez, H. W. Rauch, J. J. Renton, S. M. Sherlock, and P. E. Zurbuch. 1998. Application of limestone to restore fish communities in acidified streams. *North American Journal of Fisheries Management* 18:347-360.
- Gaujot, R. C. 2002. Geology, surface hydrology, and fish habitat relationships in the upper Shavers Fork drainage basin, West Virginia. Master's thesis, West Virginia University, Morgantown.
- Hansbarger, J. L. 2005. Trout movement and habitat use in the upper Shavers Fork of the Cheat River, West Virginia. Master's thesis, West Virginia University, Morgantown.
- Hansbarger, J. L., J. T. Petty, and P. M. Mazik. 2008. Microhabitat use by brook trout in small tributaries and a large river main stem: implications for stream channel restoration in the upper Shavers Fork, WV. *Proceedings of the Annual Conference of Southeast Association of Fish and Wildlife Agencies* 62:142-148.
- Healing the Headwaters Summit. Website <http://shaversforkcoalition.org/headwaters.htm> accessed 31 July 2014.
- Hudy, M, J. A. Coombs, K. H. Nislow, and B. H. Letcher. 2010. Dispersal and within-stream spatial population structure of brook trout revealed by pedigree reconstruction analysis. *Transactions of the American Fisheries Society* 139:1276–1287.
- Huntsman, B. M., and J. T. Petty. 2014. Density-dependent regulation of brook trout population dynamics along a core-periphery distribution gradient in a central Appalachian watershed. *PLoS ONE* 9(3):e91673\_ (doi:10.1371/journal.pone.0091673).
- Ivahnenko, T. I. 1988. An evaluation of point-source limestone introduction as an ameliorative procedure to reduce acidity in two low buffer capacity streams. Master's thesis, West Virginia University, Morgantown.
- Ivahnenko, T. I., D. J. Renton, and H. W. Rauch. 1988. Effects of liming on water quality of two streams in West Virginia. *Water, Air, and Soil Pollution* 41:311-357.
- Kanno Y, J. C. Vokoun, and B. H. Letcher. 2011. Fine-scale population structure and riverscape genetics of brook trout (*Salvelinus fontinalis*) distributed continuously along headwater channel networks. *Molecular Ecology* 20:3711–3729.
- Kelson, S. J., A. R. Kapuscinski, D. Timmins, and W. R. Ardren. 2014. Fine-scale genetic structure of brook trout in a dendritic stream network. *Conservation Genetics* 15:000-000. (<http://dx.doi.org/10.1007/s10592-014-0637-5>).
- Kinney, E. C. 1963. Historical notes on fish management in West Virginia 1863 – 1963. West Virginia Conservation, West Virginia Conservation Commission, Charleston. 27(2, 3, 4).
- Kobuszewski, D. M. 1992. Aquatic insect community structure and secondary production in streams of low and circumneutral pH in the Appalachian Mountains of West Virginia. Master's thesis, West Virginia University, Morgantown.
- Kobuszewski, D. M., and S. A. Perry. 1993. Aquatic insect community structure in an acidic and circumneutral stream in the Appalachian Mountains of West Virginia. *Journal of Freshwater Ecology* 8(1):37-45.
- Lamothe, P. J. 2002. Spatial population dynamics of brook trout (*Salvelinus fontinalis*) in a central Appalachian watershed. Master's thesis, West Virginia University, Morgantown.
- Liller, Z. W. 2006. Spatial variation in brook trout (*Salvelinus fontinalis*) population dynamics and juvenile recruitment potential in an Appalachian watershed. Master's thesis, West Virginia University, Morgantown.
- Menendez, R. 1974. Limestone treatment of and acid stream: effects on chemistry, benthos, and trout. Master's thesis, West Virginia University, Morgantown.
- Menendez, R. and J. L. Clayton. 1992. Evaluation of limestone drum neutralization of selected acid impacted streams. Performance report, D-J project F-24-R-10, job I-4. West Virginia Division of Natural Resources, Elkins.
- Menendez, R., J. L. Clayton, and P. E. Zurbuch. 1996. Chemical and fishery response to mitigative liming

- of an acidic stream, Dogway Fork, West Virginia. *Restoration Ecology* 4:220-233.
- Petty, J. T., and D. Thorne. 2005. An ecologically based approach for identifying restoration priorities in acid impacted watersheds. *Restoration Ecology* 13:348-357.
- Petty, J. T., D. Thorne, B. M. Huntsman, and P. M. Mazik. 2014. The temperature – productivity squeeze: constraints on brook trout growth along an Appalachian river continuum. *Hydrobiologia* 727: 151–166.
- Petty, J. T., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook trout movement in response to temperature, flow, and thermal refugia within a complex Appalachian riverscape. *Transactions of the American Fisheries Society* 141:1060-1073.
- Petty, J. T., P. J. Lamothe, and P. M. Mazik. 2005. Spatial and seasonal dynamics of brook trout populations inhabiting a central Appalachian watershed. *Transactions of the American Fisheries Society* 134:572-587.
- Poplar-Jeffers, I. O., J. T. Petty, J. T. Anderson, S. J. Kite, M. P. Strager, and R. H. Fortney. 2009. Culvert replacement and stream habitat restoration: Implications from brook trout management in an Appalachian watershed, USA. *Restoration Ecology* 17:404-413.
- Richards A. L. , T. L. King, B. A. Lubinski, S. E. Moore, M. Kulp, and L. S. Webb. 2008. Characterization of the genetic structure among brook trout in LeConte Creek, Tennessee. *Proceedings of the Annual Conference of Southeast Association of Fish and Wildlife Agencies* 62:195–202.
- Tincher, M. 2013. Modeling water temperatures and brook trout (*Salvelinus fontinalis*) growth potential within a complex Appalachian riverscape. Master's thesis, West Virginia University, Morgantown.
- Thorne, D. W. 2004. Spatial and seasonal variation in brook trout diet, growth, and consumption in a complex Appalachian watershed. Master's thesis, West Virginia University, Morgantown.
- Whiteley A. R., J. A. Coombs, M. Hudy, Z. Robinson, A. R. Colton, K. H. Nislow, and B. J. Letcher. 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal of Fisheries and Aquatic Sciences* 70:678–688.
- Zurbuch, P. E. 1963. Dissolving limestone from revolving drums in flowing water. *Transactions of the American Fisheries Society* 92:173-178.
- Zurbuch, P. E. 1981. Acid neutralization of debilitated trout streams on the Monongahela National Forest in West Virginia. West Virginia Department of Natural Resources, Elkins.
- Zurbuch, P. E. 1984. Neutralization of acidified streams in West Virginia. *Fisheries* 9(1):42-47.
- Zurbuch, P. E. 1989. The self-feeding rotary drum stream neutralization system. West Virginia Department of Natural Resources, Federal Aid in Sport Fish Restoration, Project F-24-R, Job I-2, Final Report, Elkins.
- Zurbuch, P. E. 2002. Historic fishery of the Blackwater River. Special Report, Canaan Valley Institute, Thomas, West Virginia.

## FRAGMENTED POPULATION ISOLATES VERSUS WELL-MIXED BROOK TROUT METAPOPOPULATIONS: WHICH SHOULD WE SEEK TO RESTORE?

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**Abstract**—Central Appalachian Brook Trout *Salvelinus fontinalis* have undergone extensive declines resulting in fragmented populations dominated by small, sedentary, short-lived trout. Here we summarize results from 14 years of research on a unique, well-mixed Brook Trout metapopulation inhabiting the upper Shavers Fork watershed in eastern West Virginia, USA. Within this watershed, headwater streams serve as important spawning and source habitats that supply Brook Trout to larger downstream habitats. Results from mark-recapture, genetics, and isotope studies suggest that main-stem habitats are not simply sink habitats, but rather function as both supplemental foraging habitats and as dispersal corridors during cool years. Bioenergetics modeling indicates that these functions are highly vulnerable to projected climate change, and loss of main-stem function can be expected to fragment the watershed into a series of isolated tributary subpopulations. We hypothesize that warming in main-stem habitats and barriers to dispersal between tributaries and main stems are at least partially responsible for the loss of large, mobile, long-lived Brook Trout in this region and that this effect is exacerbated by harvest and competition with exotic trout. We propose a region-wide initiative that would seek to identify and restore well-mixed Brook Trout metapopulations in central Appalachian watersheds through protection and restoration of large river main stems capable of functioning as supplementary foraging habitat and as dispersal corridors.

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### INTRODUCTION

The Brook Trout *Salvelinus fontinalis* is an iconic salmonid valued throughout its native range for its recreational and aesthetic qualities, as well as its ecological importance as a keystone species. Especially within the Appalachian portion of its range in the eastern United States, Brook Trout have increasingly become a focus of conservation efforts due to population declines that have intensified over the last century (Hudy et al. 2008). The causes of these continuing declines include overharvest, acid precipitation, habitat degradation, competition with nonnative species, and climate change (Petty and Thorne 2005; Flebbe et al. 2006; McClurg et al. 2007; Hudy et al. 2008). An important consequence of habitat loss or degradation for Brook Trout is isolation, which may lead to reduced gene flow among populations making them more susceptible to stochastic environmental events and elevated genetic drift, potentially leading to the loss of unique adaptive variability (Whiteley et al. 2013). Consequently, there is considerable demand for implementation of restoration programs that will maximize population recovery and resilience of Brook Trout (Petty and Merriam 2012).

Because contemporary Brook Trout populations tend to be isolated in small, headwater streams, habitat conservation initiatives have tended to focus on headwater stream protection and restoration and Brook Trout reintroduction of into headwater catchments (Clayton et al. 1998, Hudy et al. 2000, Petty and Thorne 2005, McClurg et al. 2007). Petty and Merriam (2012) provide a comprehensive review of efforts to restore Brook Trout habitats and populations through a range of actions targeted at high elevation coldwater streams, including: riparian revegetation, acid remediation, large woody debris additions, exotic trout removal, and stream channel restoration. These authors concluded that although there are numerous examples of successful Brook Trout restoration, there is considerable variation in restoration effectiveness (Petty and Merriam 2012). This is especially true as it relates to full recovery of productive Brook Trout fisheries characterized by large individuals of recreational fishery value. One potential explanation for restoration failures is that the factors limiting population productivity operate at a larger, watershed scale that includes larger river main stems as well as small headwater tributaries (Petty et al. 2005, McClurg et al. 2007, Petty and Merriam 2012).

The long-range goal of our research is to maximize the effectiveness of Brook Trout restoration in Appalachian watersheds and to ensure that present-day restoration actions are effective within the context of a changing climate. In particular, we are interested in developing strategies to recover large, mobile phenotypes that were broadly characteristic of central Appalachian Brook Trout populations historically. To that end, we have been studying a Brook Trout population within the upper Shavers Fork watershed

located in eastern West Virginia, USA (Figure 1, Table 1), which exhibits behavioral and population level characteristics that are quite different from “typical” Appalachian populations (Petty et al. 2005, Petty et al. 2012, Aunins et al. 2014, Huntsman and Petty 2014, Petty et al. 2014). We believe that the unique characteristics of this system can serve as an effective model for restoring productive Brook Trout fisheries throughout this region.

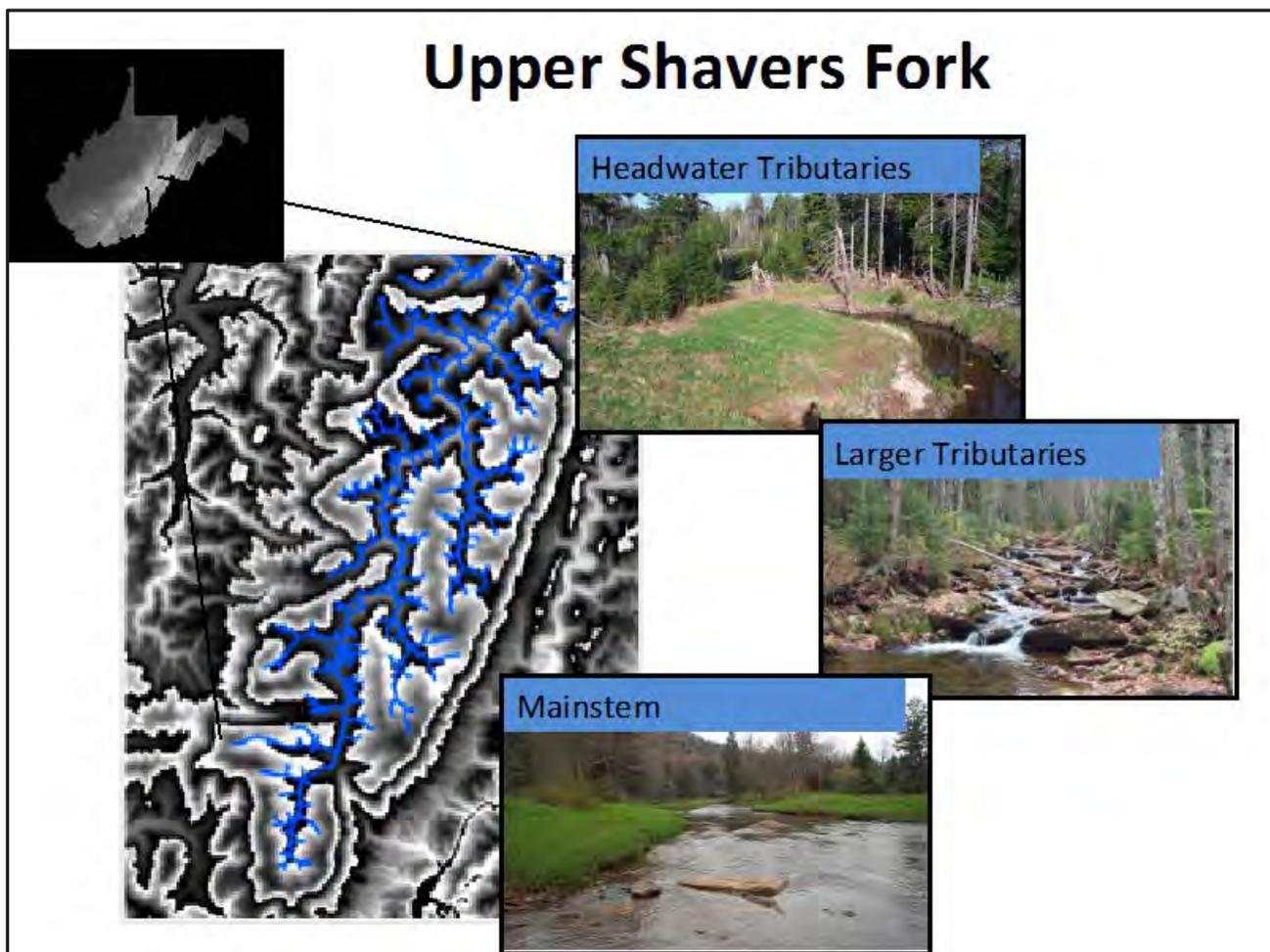


Figure 1. The upper Shavers Fork watershed located in eastern West Virginia, USA. Elevation ranges from 1,200-1,500 m and streams inhabited by Brook Trout range from < 1 km<sup>2</sup> up to > 100 km<sup>2</sup> drainage area. Our research has been focused on movements of Brook Trout among headwater source habitats, larger tributary habitats, and productive, but warm, main-stem habitats.

## OBJECTIVES

The overriding objective of this paper is to summarize research that demonstrates the importance of productive main-stem habitats to Brook Trout populations in the upper Shavers Fork watershed, which is unique when compared to other populations in this region. Specifically, we will

1. Quantify the importance of main-stem habitats as dispersal corridors and as supplemental foraging habitat for Brook Trout;
2. Identify constraints of main-stem habitat conditions on Brook Trout metapopulation dynamics; and
3. Propose guidelines for restoring Appalachian watersheds capable of supporting large, mobile Brook Trout.

**Table 1. Descriptive characteristics of headwater, large tributary, and main-stem habitats in the upper Shavers Fork watershed. DA = drainage area; Mean July Temperature; BT = Brook Trout; SL = Standard length. Exotic trout include Rainbow Trout and Brown Trout. Headwater streams tend to be small and cold, with relatively low invertebrate production and low fish diversity. Brook Trout populations in these streams are dominated by juveniles (YOY) and small adults. In contrast, main-stem habitats are large and warm, with high invertebrate production and diverse fish assemblages. Brook Trout populations in main stems are dominated by large, mobile individuals.**

	Headwater	Large Trib	Main stem
DA (km <sup>2</sup> )	0.1 – 3.0	10 – 15	25 – 60
July Temp (C)	14 – 15	16	20
Invert Density (#/m <sup>2</sup> )	1500	1000	3000
Fish Richness	1	5 – 13	17
BT Spawning (redds/100m)	20 – 22	2 – 3	0
BT YOY (#/m)	0.08	0.01	0.003
BT Sm Adult (#/m)	0.15	0.04	0.005
BT Lg Adult (#/m)	0.10	0.05	0.018
BT SL (mm)	97	115	140
Exotic Trout (#/m)	0	0.01	0.03

## Microsatellite Genetics

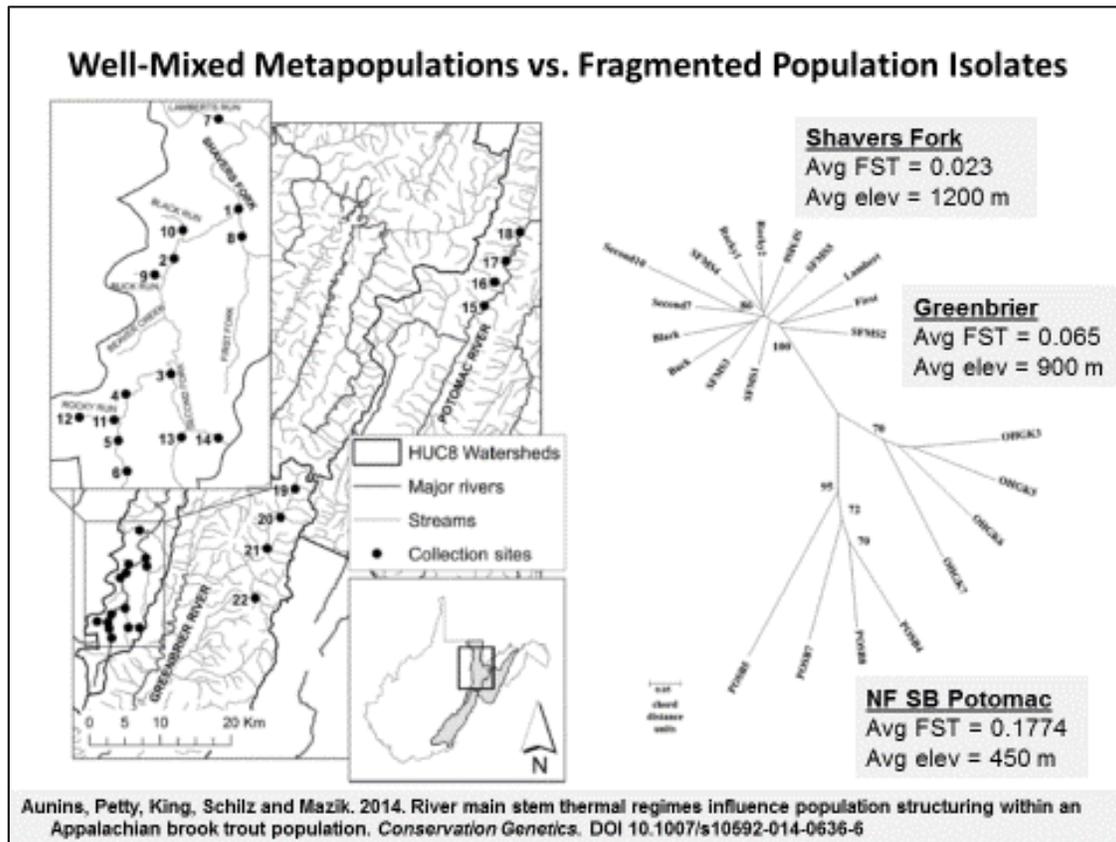


Figure 2. Map of Brook Trout subpopulations sampled within three Appalachian drainages and a summary of genetic differentiation among and within drainages. “FST - fixation index, a measure of population differentiation. Microsatellite analyses indicate that the upper Shavers Fork watershed is unique with regards to the high rate of gene flow among stream sub-populations. Aunins et al. (2014) concluded that the high rates of connectivity among subpopulations was dependent on the high quality Shavers Fork main stem as foraging habitat for Brook Trout.

### Stable Isotopes

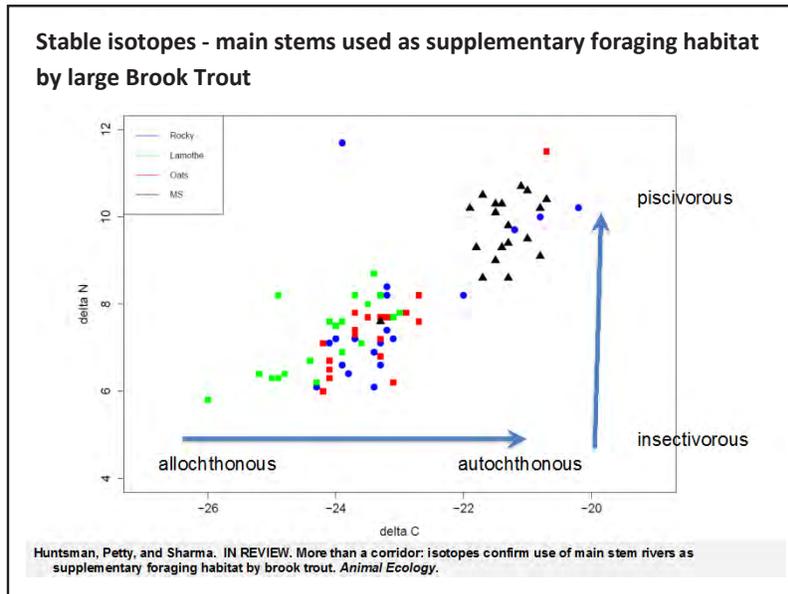


Figure 3. Variation in carbon (x-axis) and nitrogen (y-axis) isotopic signatures of Brook Trout residing in a network of tributaries (Rocky, Lamothe, and Oats) and main-stem (MS) habitats. Increasing values along the carbon axis indicate increasing importance of autochthonous based biomass in Brook Trout diets (i.e., algae based food webs vs. detritus based food webs). Increasing values along the nitrogen axis indicate increasing importance of piscivory in Brook Trout diets (i.e., fish based diet vs. insect based diet). Individuals within main-stem habitats tended to possess isotopic signatures characteristic of autochthonous based food webs and piscivory based diets. This information was used to identify individuals captured within tributaries that showed isotopic evidence of growth supplemented through main stem foraging.

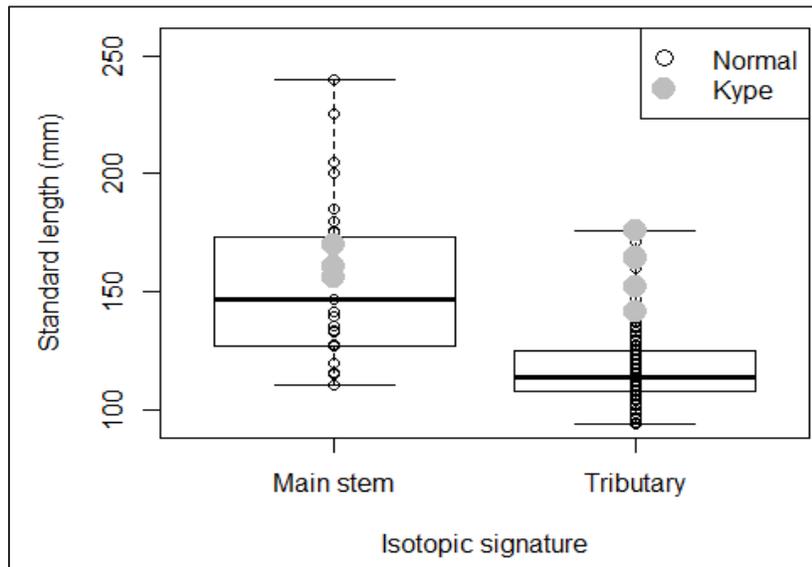


Figure 4. Relationship between main-stem vs. tributary foraging and Brook Trout standard length and presence of a kype. Huntsman et al. (IN REVIEW) observed no relationship between presence of a kype and foraging habitats. However, there was a clear relationship between size and main-stem use. All fish greater than 180 mm standard length showed evidence of main-stem foraging, suggesting that use of the main stem as supplementary foraging habitat is necessary to sustain large, mobile fish in this system.

## Brook Trout Growth

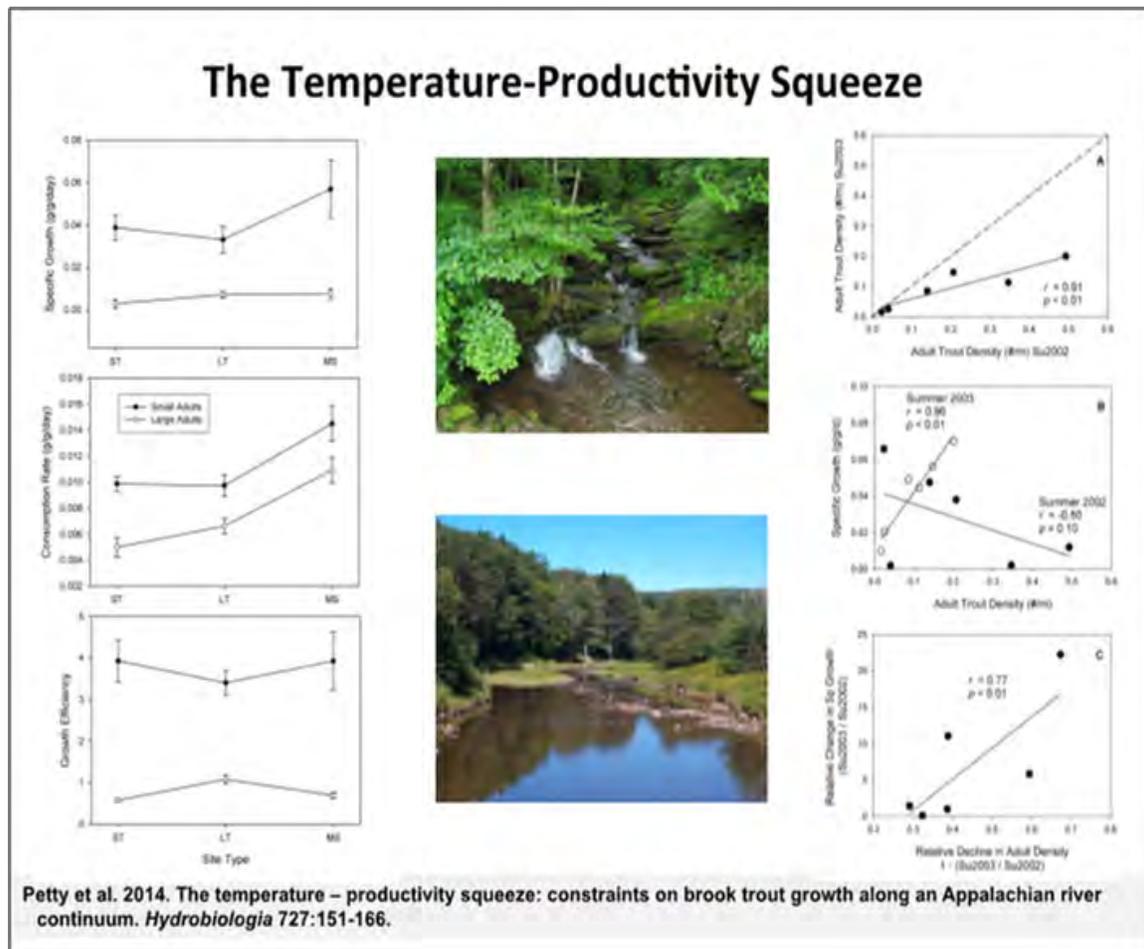


Figure 5. Site types: ST – small tributary; LT – large tributary; MS – main stem. Petty et al. (2014) found that growth rates of adult Brook Trout were maximized in the productive main stem due to high food availability, access to prey fish, and low competition. Access to thermal refugia in the main stem allowed fish to exhibit positive growth despite high summer temperatures. During cool years, Brook Trout populations expanded into the main stem and tributary populations exhibited higher growth rates due to reduced densities. During warm years, however, Brook Trout concentrated into the tributaries and realized reduced growth rate due to high densities. Ultimately, Brook Trout productivity at the watershed scale was controlled by access to habitats that provided both sufficient prey and acceptable temperatures. Petty et al. (2014) referred to this phenomenon as the “temperature-productivity” squeeze.

## CONCLUSIONS

Aunins et al. (2014) shows that the Shavers Fork main stem is functioning as an effective corridor linking headwater source populations of Brook Trout. This finding is in direct contrast to the patterns observed in other Appalachian watersheds where Brook Trout populations tend to exist as highly fragmented isolates. Overall, the genetics analysis coupled with previous telemetry studies (Petty et al.

2012) indicate that high rates of dispersal along the main-stem corridor results in a population structure that can be described as a well-mixed metapopulation. Headwater tributaries support self-sufficient source populations that supply dispersers to the broader metapopulation (Petty et al. 2005, Huntsman and Petty 2014). High rates of dispersal along the larger river main stems, however, result in high levels of mixing among the subpopulations. Presumably, if

the tributaries become isolated by dispersal barriers or through degradation of main-stem habitats, then the headwater subpopulations would be negatively affected over time (Letcher et al. 2007, Kanno et al. 2014).

In addition to its function as a dispersal corridor, isotope analysis (Huntsman et al., IN REVIEW) indicates that the main stem is functioning as supplementary foraging habitat. A variable but high percentage of individuals residing in tributaries is mobile and supplements growth through use of productive main-stem habitats. Furthermore, these results suggest that use of the main stem is necessary to support Brook Trout larger than 180 mm in this system. The results indicate all Brook Trout greater than 180 mm show isotopic signatures indicative of main-stem foraging. This suggests that fish of this size would be lost from the broader metapopulation if the main stem were no longer accessible as supplementary foraging habitat.

Finally, diet and growth studies of Petty et al. (2014) indicate that Brook Trout growth in the watershed is constrained by complex interactions of food, thermal regime, and competition. In cool years, Brook Trout distributions expand into the main stem. This results in higher growth rates of fish using the more productive main stem as well as for fish that remain in the tributaries due to lower competition. During warm years, however, a greater number of Brook Trout are confined to the tributaries where high levels of competition results in lower growth rates. Growth rates of Brook Trout in the main stem remain relatively high, likely as a result of access to thermal refugia. Petty et al. (2014) refer to this phenomenon as the “temperature-productivity squeeze” whereby Brook Trout productivity at the watershed scale is constrained by low food availability and competition for food in the cold tributaries and by limited access to thermal refugia in the productive, but warm main stem.

There has been an increased focus on Brook Trout conservation in recent years due to population declines and desire to recover functional recreational fisheries (Petty & Merriam 2012). Restoration actions have tended to be focused on reintroductions, acid remediation (McClurg et al. 2007), forest riparian management, and culvert replacement (Poplar-Jeffers et al. 2009). These actions have particularly focused on smaller streams, with the potential of restoring source habitats. Our research indicates that recovery,

especially of large Brook Trout, is dependent on a watershed scale approach that reconnects spawning habitats with supplementary foraging habitats downstream. The reasons larger Appalachian rivers fail to function as supplementary foraging habitats or as dispersal corridors for fragmented headwater Brook Trout populations are not clear. Dispersal barriers, main-stem warming, harvest and elevated mortality risk of mobile fish, and presence of exotic trout have all been suggested mechanisms responsible for this failure (Poplar-Jeffers et al. 2009; Petty et al. 2012; 2014; Wagner et al. 2013; Huntsman & Petty 2014). Regardless, we concur with Aunins et al. (2014) that a high priority should be placed on identifying and restoring well-mixed Brook Trout metapopulations in the Appalachian region.

## LITERATURE CITED

- Aunins, A. W., Petty, J.T., King, T.L., Schilz, M. and Mazik, P.M. 2014. Genetic differentiation and complex metapopulation structure of an Appalachian brook trout population. *Conservation Genetics*. DOI 10.1007/s10592-014-0636-6.
- Clayton, J. L., E. S. Dannaway, R. Menendez, H. W. Rauch, J. J. Renton, S. M. Sherlock, and P. E. Zurbuch. 1998. Application of limestone to restore fish communities in acidified streams. *North American Journal of Fisheries Management* 18: 347-360.
- Flebbe, P. A., L. D. Roghair, J. L. Bruggink. 2006. Spatial modeling to project southern Appalachian trout distribution in a warmer climate. *Transactions of the American Fisheries Society* 135: 1371-1382.
- Hudy, M., D. M. Downey, and D. W. Bowman. 2000. Successful restoration of an acidified native brook trout stream through mitigation with limestone sand. *North American Journal of Fisheries Management* 20: 453-466.
- Hudy, M., T. M. Thieling, N. Gillespie, and E. P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. *North American Journal of Fisheries Management* 28: 1069-1085.
- Huntsman, B. M., & Petty, J. T. 2014. Density-Dependent Regulation of Brook Trout Population Dynamics along a Core-Periphery Distribution Gradient in a Central Appalachian Watershed. *PLoS One*, 9, e91673.
- Letcher, B. H., Nislow, K. H., Coombs, J. A., O'Donnell, M. J., & Dubreuil, T. L. 2007. Population response to habitat fragmentation in a stream-dwelling brook trout population. *PLoS One*, 2, e1139.

- Kanno, Y., Vokoun, J. C., & Letcher, B. H. 2011. Sibship reconstruction for inferring mating systems, dispersal and effective population size in headwater brook trout (*Salvelinus fontinalis*) populations. *Conservation Genetics* 12: 619-628.
- McClurg, S. E., J. T. Petty, P. M. Mazik, and J. L. Clayton. 2007. Stream ecosystem response to limestone treatment in acid impacted watersheds of the Allegheny Plateau. *Ecological Applications* 17: 1087-1104.
- Petty, J. T., P. J. Lamothe, and P. M. Mazik. 2005. Spatial and seasonal dynamics of brook trout populations inhabiting a central Appalachian watershed. *Transactions of the American Fisheries Society* 134: 572-587.
- Petty, J.T. & Merriam, E.P. 2012. Brook trout restoration. *Nature Education*, 3, 17.
- Petty, J. T. & Thorne, D. 2005. An ecologically based approach for identifying restoration priorities in acid impacted watersheds. *Restoration Ecology* 13: 348-357.
- Petty, J. T., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook trout movement in response to water temperature, flow, and thermal refugia in a complex Appalachian riverscape. *Transactions of the American Fisheries Society* 141: 1060-1073.
- Petty, J. T., D. Thorne, B. M. Huntsman, and P. M. Mazik. 2014. The temperature-productivity squeeze: constraints on brook trout growth along an Appalachian river continuum. *Hydrobiologia* 727: 151-166.
- Poplar-Jeffers, I. O., J. T. Petty, J. A. Anderson, and J. S. Kite. 2009. Culvert replacement and stream habitat restoration: implications from brook trout management in an Appalachian watershed, U.S.A. *Restoration Ecology* 17: 404-413.
- Whiteley, A. R., Coombs, J. A., Hudy, M., Robinson, Z., Colton, A. R., Nislow, K. H., & Letcher, B. H. 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal of Fisheries and Aquatic Sciences*, 70: 678-688.

# BROOK TROUT METAPOPULATION RESTORATION IN AN APPALACHIAN WATERSHED

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**Abstract**—Brook Trout *Salvelinus fontinalis* have experienced major declines throughout their native range in the eastern U.S. Declines have been attributed to multiple limiting factors operating over large spatial and temporal scales. The objective of this study was to assess the effectiveness of an ongoing restoration approach that combines (1) acid remediation in headwater spawning habitats, (2) culvert replacement to facilitate dispersal between spawning areas and supplementary main-stem habitats, and (3) main-stem habitat enhancement to provide high quality foraging microhabitats and thermal refugia. We observed successful and strong recruitment within a depauperate acid-impacted headwater stream 4 years after the initiation of limestone treatment. Brook Trout densities increased relative to those of the circumneutral control stream. Prior to the replacement of an impassible culvert, 96% of individuals were genetically assigned back to the isolated population. Following culvert replacement, <50% of captured individuals were assigned to the previously isolated population. We quantified increased habitat suitability ( $\leq 86\%$ ) and decreased maximum daily and mean July temperatures following main-stem channel restoration. Our data suggest Brook Trout are responding to improved habitat at the reach and channel-unit scales. Restoration efforts that integrate multiple actions to achieve watershed-scale goals will likely result in the greatest benefits to declining salmonid populations across the U.S.

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## INTRODUCTION

Brook Trout *Salvelinus fontinalis* have experienced extensive declines throughout their native range over the past century. Consequently, considerable resources are being put toward restoring Brook Trout populations through amelioration of physical [e.g., habitat restoration, riparian management, and barrier removal (see Roni et al. 2002)], chemical [e.g., acid remediation (Clayton et al. 1998; Hudy et al. 2000; McClurg et al. 2007)], and biological factors (e.g., exotic trout removal) degrading local populations. However, the effectiveness of Brook Trout restoration efforts has been variable. A potential major limitation to restoration success is a limited understanding of multiple factors that simultaneously influence populations and operate at multiple and potentially large spatial scales [i.e., riverscape (*sensu* Fausch et al. 2002)] (Petty and Merriam 2012).

The upper Shavers Fork of the Cheat River, West Virginia represents a system where current Brook Trout populations are significantly reduced from historic levels as a result of numerous direct and indirect anthropogenic factors. Brook Trout within the upper Shavers Fork exist as a complex metapopulation wherein the majority of reproduction (i.e., >80%)

occurs within small headwaters, while the main stem offers important supplementary habitat for growth and dispersal at the watershed scale (Petty et al. 2005, Petty et al. 2012, Huntsman and Petty 2014, Petty et al. 2014). However, acidification of headwaters as a result of acid deposition has greatly reduced juvenile recruitment. Furthermore, historic land use and loss of riparian vegetation have degraded main-stem physical habitat and raised instream temperatures. The objective of this study was to assess the effectiveness of an ongoing watershed scale restoration program that combines (1) acid remediation in headwater spawning habitats, (2) culvert replacement to facilitate dispersal between headwater spawning areas and supplementary main-stem habitats, and (3) main-stem habitat enhancement to provide high quality foraging microhabitats and thermal refugia.

## STUDY AREA

The upper Shavers Fork is a 155-km<sup>2</sup>, high elevation (originating at approximately 1,350 m) watershed within the Monongahelia National Forest, West Virginia (Fig. 1). The current study area spanned from immediately downstream of the Snowshoe reservoir (local water supply for Snowshoe Mountain

resort) to the confluence of the Shavers and First Forks and included the Second Fork watershed. Land cover is predominantly mixed deciduous and conifer forest. Variations in bedrock geology result in a high degree of variability in local water chemistries that range from circumneutral to extensively acidified due to acid precipitation (Petty et al. 2005). The stream network is characterized by numerous high-gradient, well-shaded tributaries that drain into a wide, low-gradient main stem with an open canopy (Petty et al. 2001).

## METHODS

### Description of Restoration

We examined Brook Trout response to 3 separate restoration efforts. Regulatory agencies began treating the Second Fork watershed with limestone sand in 2007 in an effort to restore headwater spawning habitat (Figure 1). Limestone sand is placed directly in the stream channel, where it becomes incorporated into the bed load and continually acts to neutralize acid loads associated with acid precipitation. An impassable culvert was replaced on Beaver Creek in June 2012 (Figure 1). Beaver Creek is a second order tributary to Shavers Fork and represents important spawning habitat. The goal of this project was to improve habitat, restore access to spawning areas, and improve flood capacity of the Beaver Creek culverts. Lastly, in-stream habitat restoration occurred along a 4.5-mile section of the Shavers Fork main-stem in 2012 (Figure 1). The design included addition of rock vanes, riffles, pools, submerged woody habitat, and riparian vegetation. Restoration was designed to narrow and deepen the channel in an effort to decrease temperatures and improve Brook Trout habit.

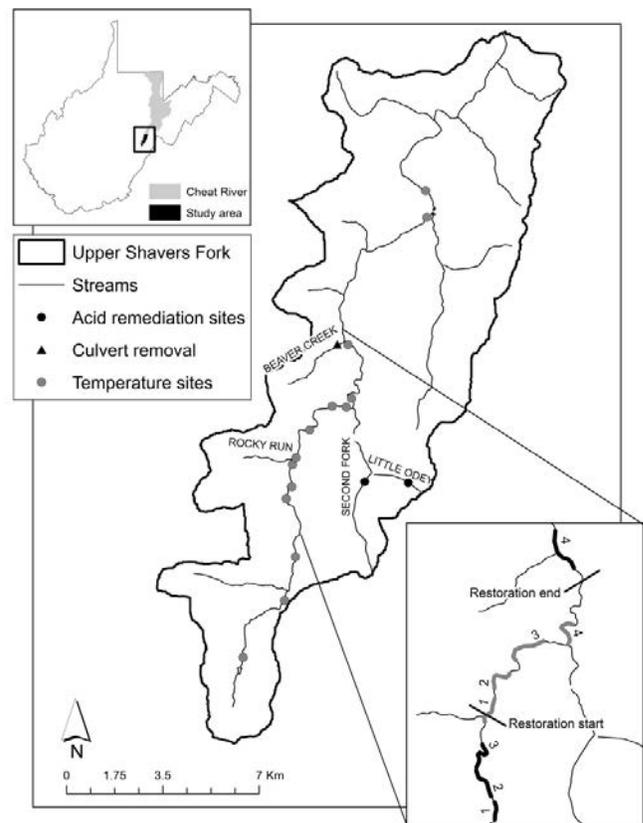
### Brook Trout Response to Limestone Treatment

Brook Trout have been sampled from 150-m sections of one naturally circumneutral (Little Odey) and one acidic (Upper 2<sup>nd</sup> Fork) stream during early June from 2002 to 2014 using a single-pass electrofishing technique (Figure 1; Hense et al. 2011). We categorized all individuals as juvenile (<60 mm standard length), small adult (60-110 mm), or large adult (>110mm) based on length frequency distributions established by Petty et al. (2005). We converted size class abundances to densities using total stream length. Instantaneous measures of pH

were obtained at the time of fish sampling with a YSI 650 equipped with a 600XL sonde (Yellow Springs Instruments, Yellow Springs, Ohio).

### Brook Trout Response to Barrier Removal

We used genetic assignment data provided by Wood (2014) to characterize Brook Trout response and dispersal patterns to the removal of an impassable culvert on Beaver Creek, a 2<sup>nd</sup> order tributary of the Shavers Fork (Figure 1). A full description of his methods can be found in Wood (2014). Briefly, he obtained a total of 482 tissue samples from Brook Trout occupying 17 potential source populations within 2<sup>nd</sup> and 3<sup>rd</sup> order tributaries of the Shavers Fork. Beaver Creek was sampled prior to culvert replacement in June 2011 and following culvert replacement in June 2012. He used a suite of 13



**Figure 1.** Location of the upper Shavers Fork study site within the Cheat River basin in West Virginia. Location of treatment (Upper 2<sup>nd</sup> Fork) and control (Little Odey) acid remediation, culvert replacement (Beaver Creek), and temperature sites are shown. Inset depicts location of main-stem habitat restoration treatment and control reaches.

microsatellite loci (Aunins et al. 2014) to assign individuals from Beaver Creek prior to and following culvert restoration to one of the potential source populations using the software GeneClass version 2.0 (Piry et al. 2004).

### Main-Stem Restoration Monitoring

We obtained hourly water temperature at 14 main-stem locations from May 1, 2010 to present using HOBO Water Temp Pro V2 data loggers (Figure 1). We calculated maximum daily temperature and weekly mean July temperature for each site. We measured physical habitat characteristics continuously between the upstream and downstream extent of fish sampling (Figure 1) during low flow conditions during the summers of 2011 (1 year prior to restoration) and 2013 (1 year post restoration). At evenly spaced points along the thalweg, we measured average current velocity ( $\pm 1$  cm/s), maximum current velocity within 60 cm of the thalweg, water depth ( $\pm 0.5$  cm), and distance to the nearest cover item (Petty et al. 2001). Cover items were defined as any object that is capable of concealing a 170-mm fish (Petty et al. 2001). We calculated Brook Trout habitat suitability index (HSI) scores with average current velocity and depth criteria provided by Hansbarger et al. (2008).

We sampled all trout species within eight main-stem sites during spring (early June) of 2011 to 2014 using a one-pass electrofishing procedure with backpack units (Smith-Root, DC, 60Hz, 400-600 V). We sampled four control (i.e., not contained in restoration reach) and 4 treatment (i.e., contained within the restoration reach) sites (Figure 1). Fish were measured for standard length and weight and characterized by the channel unit type from which they were captured (riffle, intermediate gradient riffle-run complex, low gradient riffle-glide complex, and natural and constructed pools). Abundances were converted to densities for each reach and channel unit.

## RESULTS

### Brook Trout Response to Limestone Treatment

Prior to the initiation of treatment with limestone sand (2002 to 2006), mean pH was 4.56 (SD = 0.68) in the acidic site and 6.99 (0.63) in the circumneutral control site. Following treatment with limestone sand (2007 to 2014), mean pH was 6.71 (0.26) and 7.22

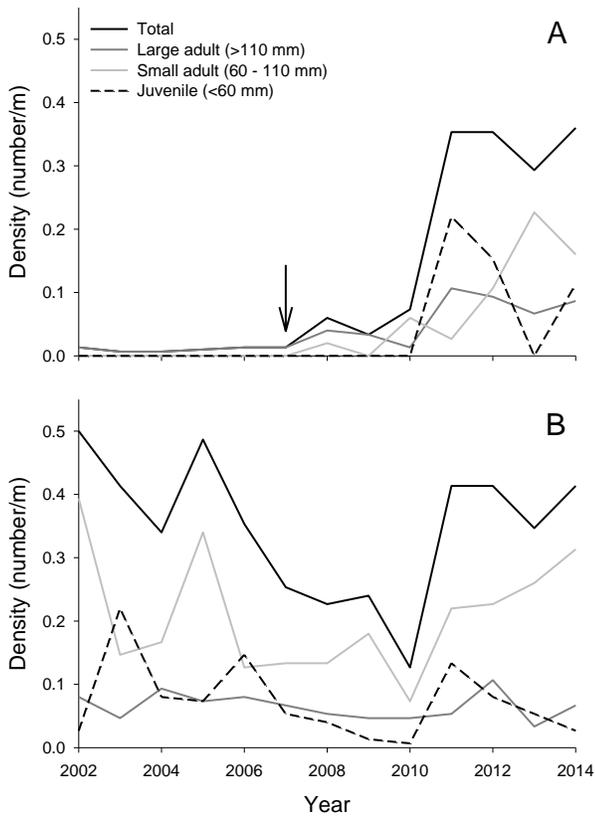
(0.64) in the treatment and circumneutral control sites, respectively. Prior to limestone treatment, Brook Trout within the treatment site existed at very low densities ( $\leq 0.013/m$ ) and were characterized by a single size class (i.e., large adults; Figure 2). Brook Trout were present in the circumneutral site at much higher densities ( $\leq 0.5/m$ ), with all three size classes represented each year. Immediately following limestone treatment, densities of both small and large adults increased within the treatment site but remained relatively low until 2011. In 2011, however, densities of juveniles and large adults exhibited a very large increase in the treatment site, resulting in total trout densities that mirrored those of the circumneutral control stream in subsequent years (Figure 2).

### Brook Trout Response to Barrier Removal

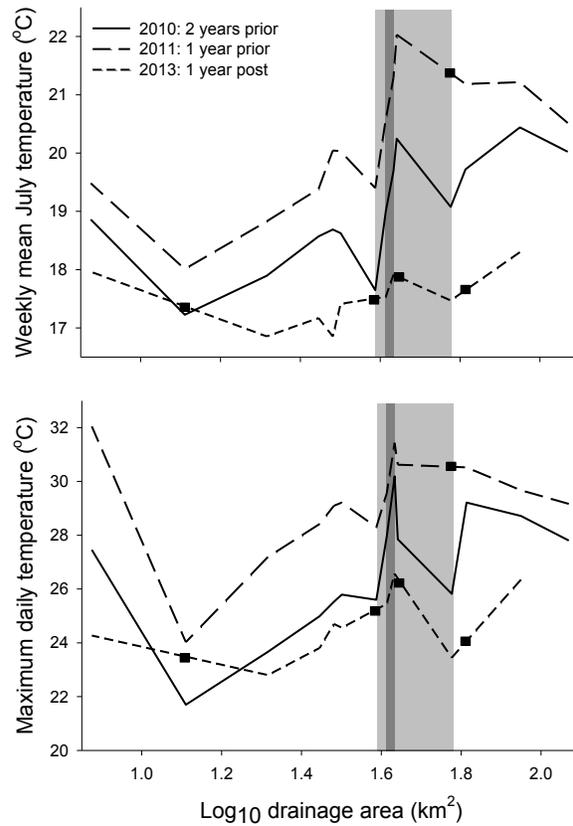
Prior to culvert replacement, 23 of 24 (96%) individuals from Beaver Creek were genetically assigned back to Beaver Creek, indicating a high degree of isolation from the broader Shavers Fork metapopulation (Aunins et al. 2014). After culvert replacement, five of 23 individuals were assigned to sources other than Beaver Creek. Furthermore, 15 of 38 (39%) could not be assigned to any other sampled sources, suggesting that they, along with the previous five, represented immigrants into Beaver Creek.

### Main-Stem Restoration Monitoring

Weekly mean July and maximum daily temperatures were highest in 2011 and lowest in 2013 across all sites (Figure 3). Temperatures tended to increase with drainage area across all years (Figure 3). However, temperatures within the most upstream temperature site exceeded those in several subsequent downstream sites. These higher temperatures likely reflect the release of warmer water from the Snowshoe reservoir. Moreover, there were decreases in water temperature immediately up- and down-stream of the restoration section that represent coldwater inputs from Rocky Run and Second Fork (Figures 1 and 3). Prior to restoration, one stream reach (dark grey box in Figure 3) consistently exhibited among the greatest increases in maximum daily (2.22 and 1.87 °C in 2010 and 2011) and weekly mean July (0.70 and 0.73 °C) temperatures. Following restoration (i.e., 2013), increases in maximum daily (1.12 °C) and weekly mean July (0.38 °C) temperatures within this section were much lower.



**Figure 2.** Time series plots of Brook Trout densities in a limestone treated (A) and circumneutral (B) tributary within the upper Shavers Fork watershed. Total density and densities of small adults, large adults, and juveniles are shown. Arrow denotes the initiation of treatment in 2007 within the treatment site.



**Figure 3.** Weekly mean July and maximum daily water temperatures vs. drainage area in main-stem sites from 2010 to 2012. Light grey boxes indicate the extent of habitat restoration and dark grey boxes indicate a reach consistently exhibiting among the greatest increases in stream temperature. Black squares denote missing data.

Seven of eight sites showed improved mean Brook Trout HSI scores in 2013 as compared to 2011 (Table 1). Improvements tended to be greater in treatment sites compared to control sites.

Prior to restoration (i.e., 2011), 92% of habitat readings across all treatment sites had HSI scores <0.50 and 68% had scores <0.25 (Figure 4). Similarly, 93% of habitat readings across all control sites had HSI scores <0.50 and 68% had scores <0.25. Following restoration (i.e., 2013), 81% of habitat readings in treatment sites had HSI scores <0.50 and 9% had scores <0.25. In contrast, 96% of habitat readings across control reaches had HSI scores <0.50 and 59% had scores <0.25 (Figure 4).

We collected Brook Trout, Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* from the Shavers Fork main stem. Total Brook Trout densities increased and Brown Trout and Rainbow Trout densities decreased across all control sites from 2011 to 2013 (Figure 5). All three trout species tended to decline or show little change across all treatment sites from 2011 to 2013; however, one treatment site (#4) showed an increase of 0.011/m in Brook Trout density (Figure 5). Brook Trout showed little change in total density across all control sites from 2013 to 2014, with moderate increases in two sites [#1 (0.006/m) and #4 (0.013/m)] and a corresponding decrease in one site [#2 (0.008/m)] (Figure 5). There was an increase in total Brook Trout abundance across all treatment sites from 2013 to 2014 due in part to a large increase in one site [#3 (0.027)] and a moderate increase in another site [#1 (0.012)].

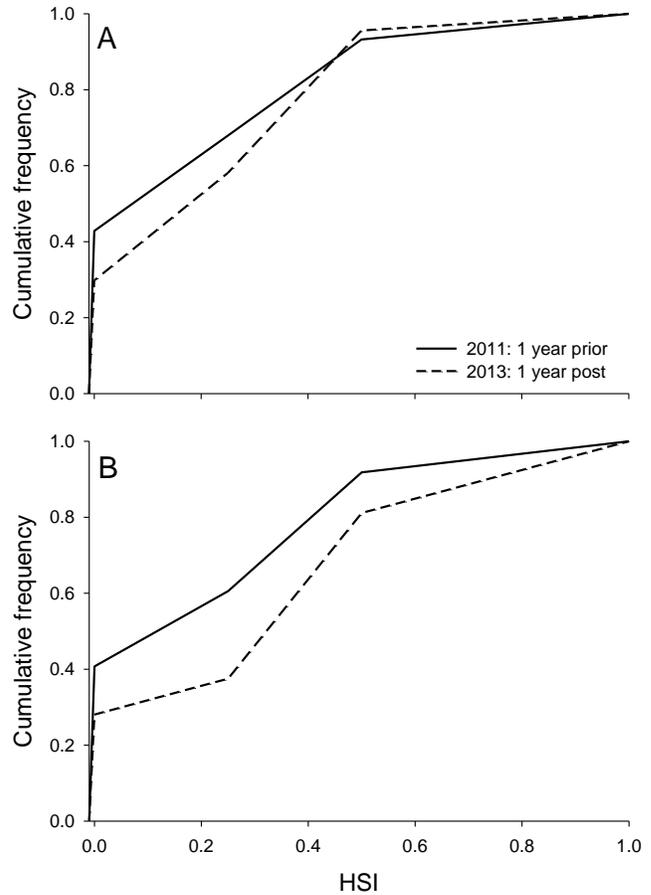


Figure 4. Habitat suitability index (HSI) cumulative frequency distributions representing continuous data from the control (i.e., not restored) (A) and treatment (B) main stem reaches prior to (2011) and 1 year post restoration.

Table 1. Mean (SD) Brook Trout habitat suitability scores for each control and treatment main-stem site in 2011 and 2013. Percent change between the two years is shown. Site numbers correspond to numbering scheme in Figure 1.

	2011	2013	% change
Control sites			
1	0.21(0.03)	0.25(0.03)	19.0
2	0.26(0.02)	0.31(0.02)	19.2
3	0.23(0.02)	0.35(0.02)	52.2
4	0.39(0.03)	0.31(0.03)	-20.5
Treatment sites			
1	0.22(0.03)	0.41(0.04)	86.4
2	0.33(0.05)	0.38(0.04)	15.2
3	0.24(0.04)	0.43(0.04)	79.2
4	0.27(0.04)	0.40(0.04)	48.2

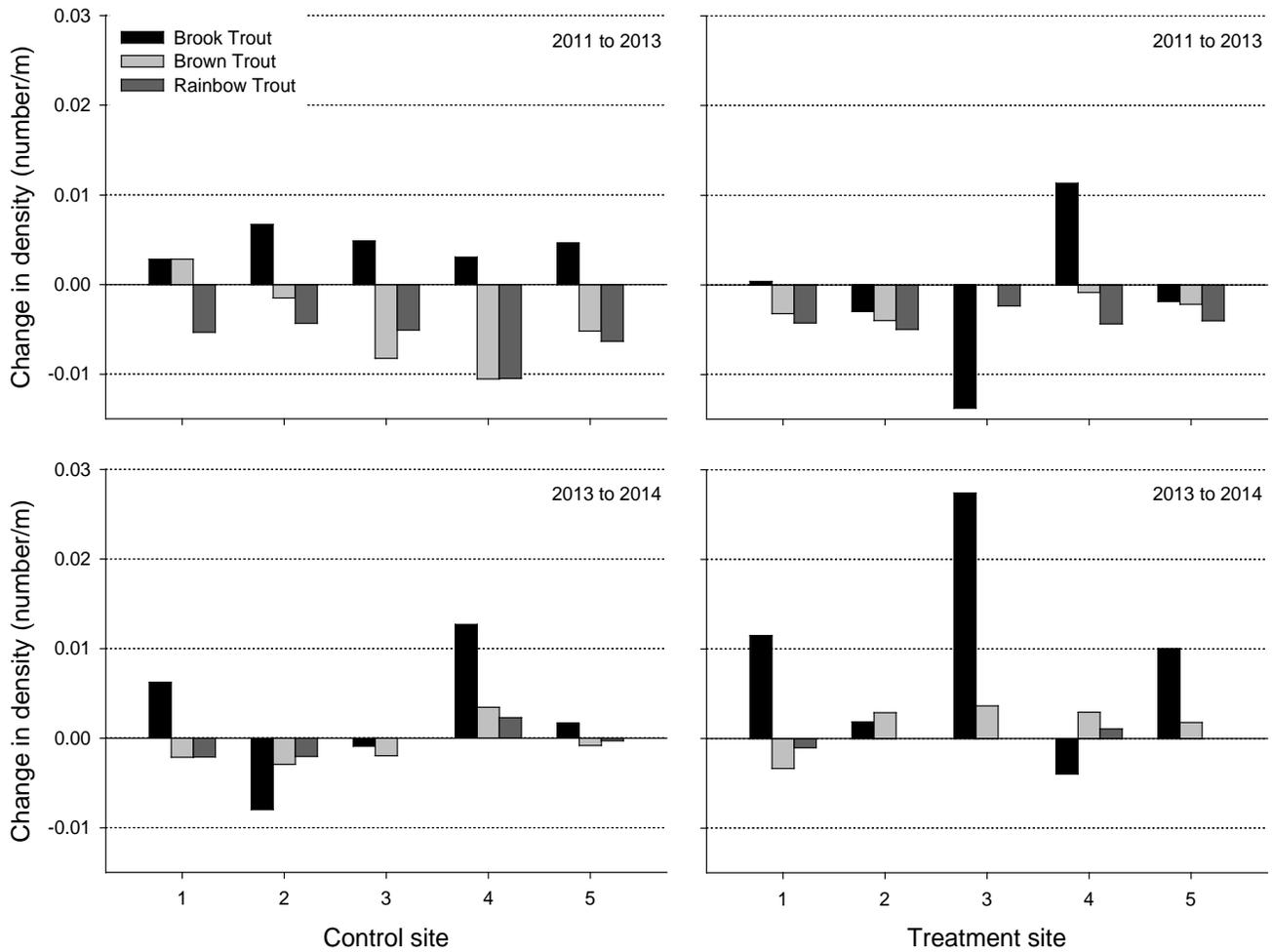


Figure 5. Change in Brook Trout, Brown Trout, and Rainbow Trout densities from 1 year prior to (2011) to 1 year post (2013) restoration and 1 year post to 2 years post (2014) restoration within and across (Total) control and treatment sites.

At the channel unit scale, Brook Trout densities were greatest in riffles, whereas Brown Trout, Rainbow Trout, and total trout densities were greatest in pools prior to restoration (Table 2). Brook Trout and total trout densities were greatest in riffles 1 year after habitat restoration (i.e., 2013). Natural pools and pools constructed during restoration (i.e., ‘structure pools’) had the highest densities of Brown Trout and Rainbow Trout in 2013, respectively. Structure pools had the highest densities of Brook Trout, Rainbow Trout, and total trout 2 years after restoration (i.e., 2014; Table 2). Brown Trout were most dense in riffles in 2014.

### DISCUSSION

Brook Trout populations in the upper Shavers Fork watershed are currently limited by factors that affect life history requirements and processes occurring at the watershed scale. We demonstrate direct benefits of a restoration plan designed to target multiple limiting factors (i.e., acidification of spawning habitats, barriers to dispersal, and degraded main-stem habitats) impacting populations within the context of watershed-scale metapopulation processes (Petty and Merriam 2012).

We observed successful and strong recruitment within an acid impacted headwater stream 4 years after the initiation of limestone treatment. Total Brook Trout densities increased relative to those of the circumneutral control stream. Our results add to a growing number of studies documenting direct benefits of individual restoration actions to Brook Trout populations within the Shavers Fork (McClurg et al. 2007) and other watersheds throughout the region (Clayton et al. 1998; Hudy et al. 2002). However, our results further suggest that moderately acidified streams may be functioning as attractive sinks to large, mobile individuals. This was evidenced by the presence of large, mobile adults and the complete lack of juveniles and small adults prior to remediation.

Genetic impacts of barriers on highly mobile species such as Brook Trout are widely understood e.g. reduced genetic variation and greater extinction risk (Wofford et al. 2005; Whiteley et al. 2013). However, few studies have directly measured benefits to Brook Trout populations following barrier removal. The results presented herein demonstrate rapid and extensive dispersal into a previously isolated tributary following the replacement of an impassible culvert.

**Table 2. Brook Trout, Brown Trout, Rainbow Trout, and total trout densities (number/m) found in channel unit types (riffle, low gradient complex, intermediate gradient complex, pool, and structure pool) across all sites in 2011, 2013, and 2014.**

	Riffle	Low gradient complex	Int. gradient complex	Natural pool	Structure pool
2011: 1 year prior to restoration					
Brook Trout	<b>0.012</b>	0.003	0.009	0.009	--
Brown Trout	0.005	0.003	0.007	<b>0.016</b>	--
Rainbow Trout	0.009	0.002	0.004	<b>0.010</b>	--
Total	0.026	0.008	0.019	<b>0.034</b>	--
2013: 1 year post restoration					
Brook Trout	<b>0.036</b>	0.002	0.007	0.009	0.018
Brown Trout	0.004	0.002	0.004	<b>0.010</b>	0.000
Rainbow Trout	0.000	0.002	0.001	0.001	<b>0.004</b>
Total	<b>0.040</b>	0.007	0.011	0.021	0.022
2014: 2 years post restoration					
Brook Trout	0.022	0.007	0.015	0.021	<b>0.031</b>
Brown Trout	<b>0.011</b>	0.000	0.005	0.007	0.007
Rainbow Trout	0.000	0.000	0.001	0.001	<b>0.002</b>
Total	0.033	0.007	0.020	0.030	0.040

Prior to restoration, only one individual could not be assigned back to the Beaver Creek population. Following restoration, however, 20 of the 38 (53%) Brook Trout were not genetically assigned back to Beaver Creek, indicating a high level of connectedness with the broader metapopulation. We know of no other study documenting such rapid and extensive dispersal into a previously isolated stream. Further research should be conducted to better understand genetic benefits to this and other wild trout populations associated with barrier removals. More efficient methods for identifying and prioritizing barrier removal efforts (see Poplar-Jeffers et al. 2009) should be utilized to maximize restoration benefits.

We also quantified increased habitat suitability and decreased temperature following stream channel restoration in the main stem. Moreover, Brook Trout appear to be responding to improved habitats at the reach and channel-unit scales. It is important to note, however, that Brook Trout populations within the upper Shaver's Fork main stem exhibit a high degree of temporal variability driven by factors occurring at the watershed scale (i.e., local density-dependent and independent factors, as well as source-sink dynamics and dispersal from tributaries). Current Brook Trout densities within the main stem are near long-term (2002-2014) averages in four of the study sites (two control and two reference; *data not presented*). Continued monitoring will be necessary to quantify Brook Trout response to main-stem habitat enhancement within the context of other watershed-scale factors and restoration efforts.

Our results demonstrate the importance of addressing all relevant limiting factors at appropriate spatial scales. Because Brook Trout populations are often influenced by multiple limiting factors that operate across multiple scales, single-factor restoration actions will likely have limited benefits (Petty and Merriam 2012). By targeting multiple processes known to limit Brook Trout population dynamics (i.e., spawning, dispersal, main-stem foraging) within the upper Shavers Fork, the current restoration framework has been successful at enhancing localized Brook Trout populations within the context of important metapopulation processes that will likely determine long-term population persistence. Restoration efforts that use foundational research to identify and integrate multiple actions to achieve watershed-scale goals will likely result in the greatest benefits to declining native salmonid populations across the U.S.

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## LITERATURE CITED

- Aunins, A. W., J. T. Petty, T. L. King, M. Schilz, and P. M. Mazik. 2014. River mainstem thermal regimes influence population structuring within an Appalachian brook trout population. *Conservation Genetics* doi:10.1007/s10592-014-0636-6.
- Clayton, J. L., E. S. Dannaway, R. Menendez, H. W. Rauch, J. J. Renton, S. M. Sherlock, and P. E. Zurbuch. 1998. Application of limestone to restore fish communities in acidified streams. *North American Journal of Fisheries Management* 18:347–360.
- Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *BioScience* 52: 483–498.
- Hansbarger, J. L., J.T. Petty, and P.M. Mazik. 2008. Microhabitat use by brook trout inhabiting small tributaries and a large river main stem: implications for stream habitat restoration in the Central Appalachians. *Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 62:142–148.
- Hense, Z., R. W. Martin, and J. T. Petty. 2011. Electrofishing capture efficiencies for common stream fish species to support watershed-scale studies in the central Appalachians. *North American Journal of Fisheries Management* 30:1041–1050.
- Hudy, M., D. M. Downey, and D. W. Bowman. 2000. Successful restoration of an acidified stream through mitigation with limestone sand. *North American Journal of Fisheries Management* 20:453–466.
- Huntsman, B. M. and J. T. Petty. 2014. Density-dependent regulation of brook trout population dynamics along a core-periphery distribution gradient in a central Appalachian watershed. *PLoS ONE* 9: e91673 doi:10.1371/journal.pone.0091673.
- McClurg, S. E. 2007. Stream ecosystem response to limestone treatment in acid impacted watersheds of the Allegheny Plateau. *Ecological Applications* 17:1087–1104.
- Petty, J. T., J. Freund, P. J. Lamothe, and P. M. Mazik. 2001. Quantifying the microhabitat characteristics of hydraulic channel units in the upper Shavers Fork basin. *Proceedings of the Southeastern Association of Fish and Wildlife Agencies* 55:81–94.
- Petty, J. T., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook trout movement in response

- to temperature, flow, and thermal refugia within a complex Appalachian riverscape. *Transactions of the American Fisheries Society* 141:1060–1073.
- Petty, J. T., P. J. Lamothe, and P. M. Mazik. 2005. Spatial and seasonal dynamics of brook trout populations in a central Appalachian watershed. *Transactions of the American Fisheries Society* 134:572–587.
- Petty, J. T., D. Thorne, B. M. Huntsman, and P. M. Mazik. 2014. The temperature–productivity squeeze: constraints on brook trout growth along an Appalachian river continuum. *Hydrobiologia* 727:151–166.
- Petty, J. T. and E. R. Merriam. 2012. Brook trout restoration. *Nature Education Knowledge* 3–17. (Available from: <http://www.nature.com/scitable/knowledge/library/brook-trout-restoration-83031062>).
- Piry S., A. Alapetite, J. M. Cornuet, D. Paetkau, L. Baudouin, and A. Estoup. 2004. GeneClass2: A software for genetic assignment and first-generation migrant detection. *Journal of Heredity* 95:536–539.
- Poplar-Jeffers, I. O., J. T. Petty, J. T. Anderson, S. J. Kite, M. P. Strager, and R. H. Fortney. 2009. Culvert replacement and stream habitat restoration: implications from brook trout management in an Appalachian watershed, U.S.A. *Restoration Ecology* 17:404–413.
- Roni, P., T. J. Beechie, R. E. Bilby, F. E. Leonetti, M. M. Pollock, and G. R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. *North American Journal of Fisheries Management* 22:1–20.
- Whiteley, A. R., J. A. Coombs, M. Hudy, Z. Robinson, A. R. Colton, K. H. Nislow, and B. H. Letcher. 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal of Fisheries and Aquatic Sciences* 70:678–688.
- Wofford, J. E. B., R. E. Gresswell, and M. A. Banks. 2005. Influence of barriers to movement on within-watershed genetic variation of coastal cutthroat trout. *Ecological Applications* 15:628–637.

## THE IMPORTANCE OF SCALE: ASSESSING AND PREDICTING BROOK TROUT STATUS IN ITS SOUTHERN NATIVE RANGE

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**Abstract**—Occupancy models are of increasing interest to managers and natural resource decision makers. Assessment of status and trends, as well as the specific drivers influencing occupancy, both may change as a function of scale, and analyses conducted at multiple scales can help identify important mechanisms leading to changes in distributions. We analyzed extensive fine-scale occupancy data across the southern historic range of the Brook Trout, *Salvelinus fontinalis* to determine which landscape metrics and thresholds were useful in predicting Brook Trout presence across three relevant spatial scales and how Brook Trout occupancy varied by scale. Percentage occupancy declined markedly with increased spatial resolution, as 52% of watersheds but only 32% of sub-watersheds and 14% of catchments were occupied. Across all three scales, habitats which were exclusively occupied by native Brook Trout (without nonnative trout) were rare (<10%). Classification and regression tree models using derived landscape predictor variables were developed for three classification cases: Case 1:(Brook Trout; no Brook Trout), Case 2 (Brook Trout; nonnative trout only; no trout), and Case 3 (Brook Trout only; Brook Trout and nonnative trout; nonnative trout only and no trout). Model results were sensitive to both scale and the number of classification categories with respect to classification accuracy, variable selection, and variable threshold values. Classification accuracy tended to be lowest at the finest (catchment) scale potentially reflecting stochastic population processes and barriers to movement. Classification rates for the overall models were: Case 1: Watershed (80.19%); Sub-watershed (85.06%); Catchment (71.13%); Case 2: Watershed (69.31%); Sub-watershed (68.72%); Catchment (57.38%); Case 3: Watershed (58.91%); Sub-watershed (59.83%); Catchment (47.59%). Our multiscale approach revealed soil permeability (positive) and atmospheric pollution (negative) to be important predictors. The predicted occupancy and observed status of Brook Trout appear to be influenced by the scale at which the data are collected and reported.

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### INTRODUCTION

Maintaining sustainable and resilient wild trout populations depends on the availability of a distinct set of habitat conditions that are threatened by a wide range of anthropogenic factors operating at multiple spatial and temporal scales. These concerns, along with apparent declines in distribution and abundance in some systems, have led to calls for systematic analysis of status and trends, particularly at large landscape scales (Rieman et al. 1997; Thurow et al. 1997; Hudy et al. 2008). In addition, given likely changes in habitat suitability in the near- and longer-term, managers need tools, which will help them identify, conserve, and restore priority populations and habitats. Occupancy models, which identify habitat and landscape variables

that are associated with occurrence, can be useful for these purposes, and are increasingly used in the context of wild trout conservation (Wagner et al. 2013).

Brook Trout *Salvelinus fontinalis* provide an excellent example of these issues. Native populations, particularly in the southern portion of their range, are under threat from landscape change (deforestation and development), nonnative species (particularly naturalized Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta*), atmospheric pollution, and most recently, regional climate warming. These concerns have led to the creation of the Eastern Brook Trout Joint Venture (EBTJV 2006) a multiagency effort to document status and trends over the entire

historic range. Previous work accomplished under the EBTJV produced an initial status assessment (Hudy et al. 2008). This assessment was conducted at relatively coarse resolution (sub-watershed) and confirmed that populations appeared to be at risk and declining, and that an initial predictive model identified forest cover as an important determinant of Brook Trout occurrence. However, the determination of status and the identification of critical habitat factors are highly dependent on the spatial scale of analysis. For Brook Trout, these issues are particularly relevant. Many populations exist in small isolated, headwater patches and Brook Trout presence in some sub-watersheds may only be represented by one or a few of these small populations, which are potentially highly vulnerable to extirpation. Similarly, at these fine spatial scales, the factors that best account for Brook Trout presence may change, with consequent implications for management actions. To address these issues, in this study we used fine-scale (catchment) occupancy data, along with an expanded list of Geographic Information System (GIS) based landscape variables, to assess status of both native and nonnative trout and the factors contributing to presence or absence of these species over the southern historic range of the Brook Trout. Our goal was to refine our assessment of status, and to increase our ability to identify priority habitats and effective management strategies.

## METHODS

### Study Area, Assessment Scale, and Classifications of Reproducing Trout

Through over 100 years of sampling efforts, an extensive and fine-scale database of coldwater habitats supporting naturally reproducing trout has been developed within the southern historic range of the Brook Trout (Pennsylvania, New Jersey, Maryland, West Virginia, Virginia, North Carolina, Tennessee, Georgia, South Carolina; Hudy et al. 2008). These states are unique within the EBTJV in that they have a census of the downstream extant of reproducing trout. Detection probabilities are unknown for the majority of the datasets but ranged from 89 to 99 % in Pennsylvania streams (Wagner et al. 2013).

We created a 50-km buffer zone around a 1969 map of the species' native distribution in the

study area (developed from fish collections and personal communications with fisheries experts; MacCrimmon and Campbell 1969; Hudy et al. 2008) and classified all 808 watersheds (Hydrologic Unit Code 10 (HUC10); 3,804 sub-watersheds (HUC12), and 132,321 catchments (HUC14) that were situated wholly or partially within the region and buffer zone according to occupancy of reproducing populations of native Brook Trout, and nonnative Rainbow Trout and Brown Trout. A total of 107 sub-basins (HUC 8) were within the study area but we did not include these in this analysis because of the small sample sizes in some of the wild trout classes we were trying to predict.

There were 8 possible classifications (Table 1). We grouped these classifications and developed models to predict wild trout status for 3 different cases of interest to biologists participating in the EBTJV. Case 1 models predicted two categories either Brook Trout (defined as watershed units classified as 1, 2, 3 or 4) or no Brook Trout (defined as watershed units classified as 5,6,7,or 8). Case 2 models predicted three categories; Brook Trout (defined as watershed units classified as 1, 2, 3 or 4), nonnative trout (defined as watershed units classified as 5, 6, or 7) and no trout (defined as watershed units classified as 8). Case 3 models predicted 4 categories; allopatric Brook Trout (defined as watershed units classified as 1), sympatric Brook Trout (defined as watershed units classified as 2, 3 or 4), nonnative trout (defined as watershed units classified as 5, 6, or 7) and no trout (defined as watershed units classified as 8). Models were developed for all three cases for all three watershed scales for a total of 9 models.

**Table 1. Eight wild trout occupancy categories used to classify 808 watersheds; 3,804 sub-watersheds and 132,321 catchments. 1 = present; 0 = absent. Data collected from EBTJV members (Hudy et al. 2008).**

	Brook Trout	Rainbow Trout	Brown Trout
Occupancy classifications			
1.	1	0	0
2.	1	1	0
3.	1	0	1
4.	1	1	1
5.	0	0	1
6.	0	1	0
7.	0	1	1
8.	0	0	0

## Candidate Metrics, Metric Screening, Metric Calculations

We calculated and evaluated 85 candidate landscape metrics (Thieling 2006; Esselman 2011), and these metrics were used instead of site-specific variables (Moyle and Randall 1998) (complete list available from author). Each metric was summarized by the relevant watershed (HUC10); sub-watershed (HUC12) or 4 catchment (HUC14) categories (LC= local catchment; NC= network catchment (sum of all upstream catchments); LB = local catchment buffer (sum of 100-m buffer around National Hydrography Dataset (NHD+) stream layer in the local catchment) and NB= network buffer (sum of 100-m buffer of all upstream NHD+ streams). Landscape metrics can provide an indicator of watershed health when many anthropogenic factors potentially contribute to a problem, and such metrics can assist in identification of key limiting factors (Marschall 1996; McCormick et al. 2001).

## Model Development

The data were analyzed with classification and regression tree models (CART) (CART version 7.0 (<http://www.salford-systems.com>), Brieman et al., 1984). Classification trees are popular as they are relative easy to understand and are nonparametric methods. A classification tree is a series of binary splits that results in nodes and branches that produces a prediction model for a class variable. At each node a split of the data is made based on a threshold value for one of the independent variables. Each series of nodes leads to a terminal node, provides a classification rule, and is associated with independent variables and associated thresholds. The decision as to what variable is used and the threshold is based on a measure of change in a classification metric. For this analysis, the Gini index measure of “purity” of the classification was used (Breiman et al., 1984). A tree grows until no improvements may be made and often results in over-fitting of a model. Part of the goal is to produce a simple tree. To do this we used ten-fold cross-validation and used a one-standard-error rule. With cross-validation, the data are split ten times into groups consisting of 90% of the data and 10% of the data. The model is fit using the 90% group and evaluated using the 10% group. The process is

repeated 10 times using a different subset each time. A “cost” or classification function is used to measure the overall quality of the tree, and cross-validation results in an estimate of the variance of the measure. A simple tree is one that has a cost that is similar to the best tree (i.e. within one standard error of the best tree) but has fewer nodes. Following selection of the tree variables, importance measures are calculated along with prediction rates. Variable importance measures how much of the reduction in cost is associated with a particular variable. CART allows use of all variables (including those never used in the tree) to be included or the use of variables associated with splitting of the tree. Variable importance measures are scaled so the greatest value is 100. We used just the variables associated with splits in the calculations. Prediction rates were also calculated on test data to provide a conservative estimate of prediction success. The catchment data have a large number of observations, and this lead to difficulties with the memory for the CART analysis. To simplify the analysis and to use all the observations, we first used the R package (rpart) to identify important variables and used a subset of the variables in the analysis.

## RESULTS AND DISCUSSION

Using extensive, fine-scale, catchment occupancy data, we found that Brook Trout currently occupy 51.6% of the watersheds; 31.9% of the sub-watersheds and 14.0% of the catchments in the southeastern United States within their historic native range (Table 2). In the original EBTJV assessment, the analysis was limited to sub-watersheds because the lack of extensive fine-scale data in the northeastern United States (Hudy et al. 2008). These patterns of occupancy have important implications for status and vulnerability assessment. Although there is some uncertainty with respect to historic occupancy rates at the finest (catchment) scale, our observation that < 14% of catchments are currently occupied, suggest a high level of vulnerability to current and future threats, with Brook Trout restricted to one or two small populations in isolated headwater habitats. While current and historic data collected from EBTJV members clearly show that unoccupied watersheds and sub-watersheds historically had Brook Trout and now have been extirpated (Hudy et al. 2008), our results suggest that these analyses may underestimate risk.

**Table 2. Occupancy and classification rates (cross validation) for watersheds (HUC10); sub-watersheds (HUC12) and catchments (HUC14) for three cases of trout classification. Case 1: brook trout, no brook trout, no trout; Case 2: brook trout, nonnative trout, no trout; Case 3: allopatric brook trout, sympatric brook trout, nonnative trout, no trout).**

Table Base Name	Attribute Base Name	Description	Units	Source	Dataset	Scale/Resolution	Current-ness	Source Website
Categorical_Variables	LITHO_1	Carbonate Residual Material	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_3	Non-Carbonate Residual Material	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_5	Silicic Residual Material	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_8	Colluvial Sediment	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_9	Glacial Till, Clayey	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_10	Glacial Till, Loamy	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_11	Glacial Till, Coarse-Textured	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_12	Glacial Outwash and Glacial Lake Sediment, Coarse-Textured	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_13	Glacial Lake Sediment, Fine-Textured	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_14	Glacial Outwash and Glacial Lake Sediment, Coarse-Textured	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_15	Hydric, Peat and Muck	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_16	Eolian Sediment, Coarse-Textured (Sand Dunes)	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_17	Eolian Sediment, Fine-Textured (Glacial Loess)	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_19	Alluvium and Fine-Textured Coastal Zone Sediment	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_20	Coastal Zone Sediment, Coarse-Textured	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_22	Water	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	LITHO_ND	No Data	proportion	USGS	Surficial Lithology	1 km	2004	<a href="http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml">http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml</a>
Categorical_Variables	NLCD2001_11	Open Water	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_21	Developed, Open Space	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_22	Developed, Low Intensity	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_23	Developed, Medium Intensity	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_24	Developed, High Intensity	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_31	Barren Land (Rock/Sand/Clay)	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>

Table Base Name	Attribute Base Name	Description	Units	Source	Dataset	Scale/Resolution	Currentness	Source Website
Categorical_Variables	NLCD2001_41	Deciduous Forest	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_42	Evergreen Forest	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_43	Mixed Forest	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_52	Shrub/Scrub	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_71	Grassland/Herbaceous	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_81	Pasture/Hay	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_82	Cultivated Crops	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_90	Woody Wetlands	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_95	Emergent Herbaceous Wetlands	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2001_ND	No Data	proportion	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_11	Open Water	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_21	Developed, Open Space	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_22	Developed, Low Intensity	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_23	Developed, Medium Intensity	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_24	Developed, High Intensity	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_31	Barren Land (Rock/Sand/Clay)	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_41	Deciduous Forest	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_42	Evergreen Forest	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_43	Mixed Forest	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_52	Shrub/Scrub	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_71	Grassland/Herbaceous	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_81	Pasture/Hay	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_82	Cultivated Crops	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_90	Woody Wetlands	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>

Table Base Name	Attribute Base Name	Description	Units	Source	Dataset	Scale/Resolution	Current-ness	Source Website
Categorical_Variables	NLCD2006_95	Emergent Herbaceous Wetlands	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Categorical_Variables	NLCD2006_ND	No Data	proportion	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Continuous_Variables	BFI	Baseflow Index (% groundwater contribution to baseflow)	percentage	USGS	Base-flow index grid for the conterminous United States	1 km	2003	<a href="http://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml">http://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml</a>
Continuous_Variables	DEPNO3_MEAN	Annual NO3 wet deposition averaged for 1994 - 2010	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	DEPNO3_MAX	Maximum NO3 wet deposition value taken from 1994 - 2010 averaged grid (maximum value within spatial zone)	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	DEPNO3_MAXALL	Maximum NO3 wet deposition value taken across entire time span (1994 - 2010) on a grid cell basis (average maximum within spatial zone using highest value for each grid cell across all years)	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	DEPSO4_MEAN	Annual SO4 wet deposition averaged for 1994 - 2010	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	DEPSO4_MAX	Maximum SO4 wet deposition value taken from 1994 - 2010 averaged grid (maximum value within spatial zone)	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	DEPSO4_MAXALL	Maximum SO4 wet deposition value taken across entire time span (1994 - 2010) on a grid cell basis (average maximum within spatial zone using highest value for each grid cell across all years)	kilograms/hectare	National Atmospheric Deposition Program	Atmospheric Deposition Isoleth Maps	2,338 km	1994-2010	<a href="http://nadp.sws.uiuc.edu/">http://nadp.sws.uiuc.edu/</a>
Continuous_Variables	ELEV_MAX	Maximum catchment elevation	centimeters	USGS	National Elevation Dataset (acquired from NHDPlus v.1)	30 m	2005	<a href="http://www.horizon-systems.com/nhdplus/">http://www.horizon-systems.com/nhdplus/</a>
Continuous_Variables	ELEV_MEAN	Average catchment elevation	centimeters	USGS	National Elevation Dataset (acquired from NHDPlus v.1)	30 m	2005	<a href="http://www.horizon-systems.com/nhdplus/">http://www.horizon-systems.com/nhdplus/</a>
Continuous_Variables	ELEV_MIN	Minimum catchment elevation	centimeters	USGS	National Elevation Dataset (acquired from NHDPlus v.1)	30 m	2005	<a href="http://www.horizon-systems.com/nhdplus/">http://www.horizon-systems.com/nhdplus/</a>

Table Base Name	Attribute Base Name	Description	Units	Source	Dataset	Scale/Resolution	Currentness	Source Website
Continuous_Variables	POPDENS	Population density	#/km <sup>2</sup>	US Census Bureau	2010 U.S. Census	1:100,000 (base unit is census block group)	2010	<a href="http://www.census.gov/govs/www/tiger/tgrshp2010/tgrshp2010.html">http://www.census.gov/govs/www/tiger/tgrshp2010/tgrshp2010.html</a>
Continuous_Variables	HUDENS	Housing unit density	#/km <sup>2</sup>	US Census Bureau	2010 U.S. Census	1:100,000 (base unit is census block group)	2010	<a href="http://www.census.gov/govs/www/tiger/tgrshp2010/tgrshp2010.html">http://www.census.gov/govs/www/tiger/tgrshp2010/tgrshp2010.html</a>
Continuous_Variables	NLCD2001_FC	Tree canopy coverage	percentage	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Continuous_Variables	NLCD2001_IS	Impervious surface coverage	percentage	MRLC	2001 National Land Cover Database	30 m	2001	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Continuous_Variables	NLCD2006_IS	Impervious surface coverage	percentage	MRLC	2006 National Land Cover Database	30 m	2006	<a href="http://www.mrlc.gov/">http://www.mrlc.gov/</a>
Continuous_Variables	SOILPERM	Average soil permeability rates	inches/hour * 100	USGS	STATSGO	1:250,000	1995	<a href="http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml">http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml</a>
Continuous_Variables	PPT2010	Average annual precipitation (1981-2010)	millimeters * 100	PRISM Climate Group	U.S. Climate Normals (1981-2010)	800 m	1981-2010	<a href="http://www.prism.oregonstate.edu/index.phtml">http://www.prism.oregonstate.edu/index.phtml</a>
Continuous_Variables	TMAX2010	Average maximum annual air temperature (1981-2010)	degrees C * 100	PRISM Climate Group	U.S. Climate Normals (1981-2010)	800 m	1981-2010	<a href="http://www.prism.oregonstate.edu/index.phtml">http://www.prism.oregonstate.edu/index.phtml</a>
Continuous_Variables	TMEAN2010	Average annual air temperature (1981-2010)	degrees C * 100	PRISM Climate Group	U.S. Climate Normals (1981-2010)	800 m	1981-2010	<a href="http://www.prism.oregonstate.edu/index.phtml">http://www.prism.oregonstate.edu/index.phtml</a>
Continuous_Variables	TMIN2010	Average minimum annual air temperature (1981-2010)	degrees C * 100	PRISM Climate Group	U.S. Climate Normals (1981-2010)	800 m	1981-2010	<a href="http://www.prism.oregonstate.edu/index.phtml">http://www.prism.oregonstate.edu/index.phtml</a>
Density_Variables	AREASQKM	Zone area	km <sup>2</sup>	N/A	N/A	N/A	N/A	N/A
Density_Variables	Dam_Dens	Dam density	#/km of stream network (used Netlen_km field for network length)	USGS	2012 National Anthropogenic Barrier Dataset (primarily derived from 2009 National Inventory of Dams)	N/A	2012	<a href="http://mrdata.usgs.gov/mineral-resources/active-mines.html">http://mrdata.usgs.gov/mineral-resources/active-mines.html</a>
Density_Variables	Mine_Dens	Mine/mineral processing plant density	#/km of stream network (used Netlen_km field for network length)	USGS	Active Mines and Mineral Processing Plants	N/A	2003	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Density_Variables	CERC_Dens	EPA Superfund National Priority (CERC) site density	#/km of stream network (used Netlen_km field for network length)	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>

Table Base Name	Attribute Base Name	Description	Units	Source	Dataset	Scale/Resolution	Current-ness	Source Website
Density_Variables	PCS_Dens	EPA National Pollutant Discharge Elimination System site density from the Permit Compliance System (PCS)	#/km of stream network (used Netlen_km field for network length)	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Density_Variables	TRI_Dens	EPA Toxics Release Inventory site density	#/km of stream network (used Netlen_km field for network length)	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Density_Variables	Roadcr_Dens	Road/stream network crossing density	#/km of stream network (used Netlen_km field for network length)	US Census Bureau	TIGER 2011 Roads/NHDPlus v.1	1:100,000	2011	<a href="http://www.census.gov/geography/tiger/tgrshp2011/tgrshp2011.html">http://www.census.gov/geography/tiger/tgrshp2011.html</a>
Density_Variables	Road_Dens	Road length density	km of road/km of stream network (used Netlen_km field for network length)	US Census Bureau	TIGER 2011 Roads	1:100,000	2011	<a href="http://www.census.gov/geography/tiger/tgrshp2011.html">http://www.census.gov/geography/tiger/tgrshp2011.html</a>
Sum_Variables	Dam_Count	2009 National Inventory of Dams count	count	USACE	2009 National Inventory of Dams	N/A	2009	<a href="http://geo.usace.army.mil/pgis/f?p=397:1:0">http://geo.usace.army.mil/pgis/f?p=397:1:0</a>
Sum_Variables	Mine_Count	Mine/mineral processing plant count	count	USGS	Active Mines and Mineral Processing Plants	N/A	2003	<a href="http://mrdata.usgs.gov/mineral-resources/active-mines.html">http://mrdata.usgs.gov/mineral-resources/active-mines.html</a>
Sum_Variables	CERC_Count	EPA Superfund National Priority (CERC) site count	count	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Sum_Variables	PCS_Count	EPA National Pollutant Discharge Elimination System site density from the Permit Compliance System (PCS)	count	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Sum_Variables	TRI_Count	EPA Toxics Release Inventory site count	count	US EPA	Geodata Shapefile	N/A	2007	<a href="http://www.epa.gov/geospatial/">http://www.epa.gov/geospatial/</a>
Sum_Variables	Roadcr_Count	Road/stream network crossing count	count	US Census Bureau	TIGER 2011 Roads/NHDPlus v.1	1:100,000	2011	<a href="http://www.census.gov/geography/tiger/tgrshp2011/tgrshp2011.html">http://www.census.gov/geography/tiger/tgrshp2011.html</a>
Sum_Variables	Roadlen_km	Total road length	km	US Census Bureau	TIGER 2011 Roads	1:100,000	2011	<a href="http://www.census.gov/geography/tiger/tgrshp2011/tgrshp2011.html">http://www.census.gov/geography/tiger/tgrshp2011.html</a>
Sum_Variables	Netlen_km	Total NHDPlus v.1 hydrography network length (includes artificial paths through waterbodies)	km	US EPA/USGS	NHDPlus v.1	1:100,000	2005	<a href="http://www.horizon-systems.com/nhdplus/">http://www.horizon-systems.com/nhdplus/</a>
Sum_Variables	Strlen_km	Total NHDPlus v.1 stream network length (includes only reaches identified as "streams/rivers" for the national NFHAP assessment)	km	US EPA/USGS	NHDPlus v.1	1:100,000	2005	<a href="http://www.horizon-systems.com/nhdplus/">http://www.horizon-systems.com/nhdplus/</a>

Reevaluating sub-watersheds at the catchment level has improved identification of these at risk sub-watersheds and helped set more informed priorities for restoration and conservation efforts. For example, approximately 19 % of the catchments in North Carolina lost Brook Trout since the 2005 assessment (Hudy et al. 2008). In other cases, previously unoccupied catchments were recolonized or restored (less than 2%). Based on this new analysis, agencies managing the EBTJV and the Chesapeake Bay Executive Order have adopted catchment level metrics for monitoring status and trends.

The majority of Brook Trout populations throughout the southern range co-occur with nonnative trout (Rainbow Trout and/or Brown Trout (watersheds: 7.55% allopatric; 44.06% sympatric; sub-watersheds: 9.75% allopatric; 22.75% sympatric; catchments: 7.81% allopatric; 6.17% sympatric). While the establishment of nonnative trout in Brook Trout watersheds has been previously addressed in a number of studies (Kelly et al. 1980; Larson and Moore 1985; Wagner et al. 2013), ours is the first to broadly document these patterns of co-occurrence across multiple scales. The data suggest that even catchments that currently contain only native Brook Trout are vulnerable to invasion from nonnative trout established within their sub-watersheds. These invaded populations may be at increased risk, as some studies have found negative impacts of nonnative trout on wild Brook Trout (Kelly et al. 1980; Wagner et al. 2013) and nonnative trout may also be better able to persist in anthropogenically altered habitats (Wagner et al. 2013). Monitoring efforts need to focus on rates of nonnative establishment at the catchment scale and the fate and status of Brook Trout populations currently in sympatry, particularly as compared to the few remaining allopatric populations. If negative impacts are detected, this would place particular emphasis on keeping those few sub-watersheds that currently contain only Brook Trout free of nonnative species.

Using CART models to predict occupancy, yielded relatively high classification accuracy in most cases. Model results were sensitive to both scale and the number of classification categories with respect to classification accuracy, variable selection,

and variable threshold values (Table 3). Overall prediction rates were: Case 1 (watershed 80.19%; sub-watershed 85.06%; catchment 71.13%); Case 2 were (watershed 69.31%; sub-watershed 68.72%; catchment 57.38%), and Case 3 (watershed 58.91%; sub-watershed 59.83%; catchment 47.59%)(Table 2). For all three cases, classification accuracy was lowest at the catchment scale, potentially reflecting stochastic population processes and barriers to movement, which would complicate prediction based on landscape variables. Our best predictive models were for Case 1 at the sub-watershed scale. A total of 39 of the original 85 metrics were used at least once in the 9 different models (Table 3). The metric of soil permeability was the most important variable for watershed and sub-watershed models but was not important at the catchment scale (Table 3). Many of the important prediction metrics are fixed (i.e. elevation), but the majority can be influenced both short term and long term by management actions (i.e. soil permeability; canopy cover; land use; road density, S04 and N03 deposition). These models are therefore useful in targeting actions (increasing canopy cover, decommissioning roads, liming watersheds) that would increase Brook Trout population resilience.

Most of the data used here were provided by state and federal agencies and had not been published or peer reviewed. Despite the criteria developed for status classification, there remains some element of subjectivity in the assessment of status and occupancy. It was impossible to generate a comprehensive review without such data (Reiman et al. 1997). We attempted to limit errors, reduce subjectivity, and provide consistency in data by using consistency rules and data standards (quality and age); developing broad classification categories; and employing standard, validated procedures in consulting experts (Hudy et al. 2008). Moving forward, continued improvement and standardization of decision rules and data collection protocols, along with increasing understanding of the factors limiting Brook Trout population and incorporation of these factors into new models, will further increase our ability to assess status, predict trends, and target management actions.



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## REFERENCES

- Breiman, L., J. Friedman, R. Olshen, and C. Stone. Classification and Regression Trees. Pacific Grove:Wadsworth, 1984. <http://www.salford-systems.com>.
- EBTJV (Eastern Brook Trout Joint Venture). 2006. About the Eastern Brook Trout Venture. Available: [www.easternbrooktrout.org](http://www.easternbrooktrout.org). (December 2006).
- Esselman, P.T., D.M. Infante, L. Wang, D.Wu, A.R. Cooper, and W.W. Taylor. 2011. An Index of Cumulative Disturbance to River Fish Habitats of the Conterminus United States from Landscape Anthropogenic Activities. *Ecological Restoration* 29:1-2
- Hudy, M., T. M. Thieling, N. Gillespie, and E. P. Smith. 2008. Distribution, status, and perturbations to brook trout within the eastern United States. *North American Journal of Fisheries Management* 28:1069 -1085.
- Kelly, G. A., J. S. Griffith, and R. D. Jones. 1980. Changes in distribution of trout in Great Smoky Mountains National Park, 1900–1970. U.S. Fish and Wildlife Service Technical Paper 102.
- Larson, G. L., and S. E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian Mountains. *Transactions of the American Fisheries Society* 114:195–203.
- MacCrimmon, H. R., and J. S. Campbell. 1969. World distribution of brook trout, *Salvelinus fontinalis*. *Journal of the Fisheries Research Board of Canada* 26:1699– 1725.
- Marschall, E. A., and L. B. Crowder. 1996. Assessing population responses to multiple anthropogenic effects: a case study with brook trout. *Ecological Applications* 6:152–167.
- McCormick, F. H., R. M. Hughes, P. R. Kaufmann, D. V. Peck, J. L. Stoddard, and A. T. Herlihy. 2001. Development of an index of biotic integrity for the mid-Atlantic Highlands region. *Transactions of the American Fisheries Society* 130:857–877.
- Moyle, P. B., and P. J. Randall. 1998. Evaluating the biotic integrity of watersheds in the Sierra Nevada, California. *Conservation Biology* 12:1318–1326.
- Reiman, B. E., D. C. Lee, and R. F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins, North American *Journal of Fisheries Management* 17:1111–1125.
- Thieling, T. M. 2006. Assessment and predictive model for brook trout (*Salvelinus fontinalis*) population status in the eastern United States. Master's thesis. James Madison University, Harrisonburg, Virginia.
- Thurow, R. F., D. C. Lee, and B. E. Reiman. 1997. Distribution and status of seven native salmonids in the interior Columbia River basin and portions of the Klamath River and Great basins. *North American Journal of Fisheries Management* 17:1094–1110.
- Wagner, T., J.T. Deweber, J. Detar and J.A. Sweka. 2013. Landscape-Scale Evaluation of Asymmetric Interactions between Brown Trout and Brook Trout Using Two-Species Occupancy Models. *Transactions of the American Fisheries Society* 142:353-361.

## PATCH-BASED METRICS: A COST EFFECTIVE METHOD FOR SHORT- AND LONG-TERM MONITORING OF EBTJV WILD BROOK TROUT POPULATIONS?

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**Abstract**—The wild Brook Trout *Salvelinus fontinalis* resource throughout the range of the Eastern Brook Trout Joint Venture (EBTJV) has been significantly reduced over the last 150 years and faces ongoing and future threats from climate change, land use changes, invasive species, and loss of genetic integrity. Monitoring both short- and long-term trends on individual Brook Trout populations and the resource as a whole are important needs of managers. Currently, standard population estimates using mark-recapture and depletion removal estimates are not viable for large scale monitoring because of expense, inability to detect trend (i.e. large coefficient in variation), and problems expanding the sample to the entire population. However, extensive fine-scale occupancy data (at the catchment level) exist for many states. We used this fine-scale catchment data to identify unique “patches” of Brook Trout. We define a “patch” as a group of contiguous catchments occupied by wild Brook Trout. Patches that are not connected physically (separated by a dam, unoccupied warm water habitat, downstream invasive species, etc) and are generally assumed to be genetically isolated. The median patch size from Pennsylvania to the southern range distribution edge is 850 ha and 85.3% of patches were less than 3,000 ha in area. With preliminary patch-level genetic data from Virginia, we found a strong positive relationship between patch size and effective number of breeders ( $N_b$ ), with notable outliers associated with patches that contain reclaimed habitat (positive residuals) and the presence of invasive Rainbow Trout *Oncorhynchus mykiss* (negative residuals). We also found that subsamples from large patches yield similar estimates of genetic metrics, which suggests that our patch-based approach should be applicable even to potentially problematic large patches. We recommend the use of patches for large-scale monitoring of eastern Brook Trout. Recommended patch metrics include: number of patches with allopatric populations (Brook Trout only), number of patches with sympatric nonnative trout populations (Brook Trout with Rainbow Trout or Brown Trout *Salmo trutta*), average size of patches, number of patches increasing in size (connectivity), number of patches decreasing in size, number of patches with decreasing or stable genetic diversity, and number of patches with increasing, decreasing or stable number of effective breeders ( $N_b$ , an indicator of reproductive output and success). A monitoring design combining fixed annual “sentinel” patches and a rotating panel design for other patches has the potential to be a cost effective tool for managers to detect trends in wild Brook Trout populations.

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### INTRODUCTION

The Brook Trout *Salvelinus fontinalis* is a sentinel species that serves as an excellent indicator of headwater ecosystem health in its native range in eastern North America. Multiple anthropogenic stressors have eliminated or severely reduced Brook Trout populations over the last 200 years (Hudy et al. 2008). Monitoring efforts are needed to assess Brook Trout population status. These monitoring efforts should be scale-appropriate and attempt to monitor demographic and genetic contributions to population resilience.

We suggest that the ‘habitat patch’ concept would be highly useful for eastern Brook Trout conservation. A habitat patch for a headwater salmonid is generally defined as a continuous network of thermally suitable habitat (Isaak et al. 2010). Brook Trout in their native range tend to occur in discrete patches of habitat, especially in the southern portion of their native range. Southern Brook Trout populations (approximately from Pennsylvania south) have been more anthropogenically influenced than northern populations (Hudy et al. 2008), and tend to occur in small habitat patches, often isolated by dams (Hudy et

al. 2008; Bain and Wine 2010). Even suitable Brook Trout habitat below anthropogenic (dams) or natural (waterfall) barriers may show effects of isolation due to warmwater habitat (Meisner 1990) or downstream invasive species (Moore et al. 1983; Moore et al. 1986; Strange and Habera 1998). Patch size may be a readily obtainable metric with high conservation utility for eastern Brook Trout populations if it is closely related to population persistence and resilience. Further, the patch concept may provide the optimal scale to collect a wide variety of demographic and genetic metrics related to Brook Trout population status.

Genetic metrics collected at the patch scale offer an opportunity to understand historical effects and current demography and may offer an integrative assessment of population status. Two genetic metrics, in particular, can be used across a wide array of taxa and allow inference of two critical components of population resilience. The first indicator, the effective number of breeders ( $N_b$ ) provides information about reproductive output and success (Waples and Do 2010; Hare et al. 2011; Whiteley et al. 2012). This metric combines information from the number of families produced by the parents of a given cohort, the variance in reproductive success among those parents, and early family-dependent survival of the offspring produced (Waples and Do 2010; Christie et al. 2012). Estimates of  $N_b$  can be used to rank population risk and can serve as the foundation for monitoring efforts. The second indicator, genetic diversity (allelic diversity and heterozygosity), provides information about past events such as population bottlenecks that render a population less able to adapt to future conditions (Gienapp et al. 2008; Allendorf et al. 2013). Low genetic diversity is associated with reduced resistance to disease, increased levels of inbreeding, and lower efficacy of natural selection associated with directional and episodic environmental change.

Here, we use extensive fine-scale Brook Trout occupancy data at the catchment level to identify and provide summary statistics for Brook Trout habitat patches in the southern portion of the species' native range. We define a patch as a group of contiguous catchments occupied by wild Brook Trout. Patches that are not connected physically (separated by a dam, unoccupied warm water habitat, downstream invasive species, etc) and are generally assumed to be genetically divergent from one another. We then test for a relationship between patch size and both genetic

diversity and  $N_b$  in a set of 19 patches from Virginia. Finally, we present a case study of a large patch to demonstrate the application of our patch concept to potentially problematic larger patches.

## METHODS

### Habitat Patches and Sampling

We defined a patch for Brook Trout as a group of occupied contiguous catchment polygons from the U.S. Geological Survey (USGS) National Hydrology Dataset (NHD) Plus catchment GIS layer (7<sup>th</sup> level, 14-digit hydrologic unit codes (HUCs)). We began a patch in the catchment polygon where a Brook Trout population had been documented based on previous occurrence data and then expanded that patch (dissolving catchment polygon boundaries) to include all catchment polygons upstream until a barrier to fish passage, such as a dam or lake, was encountered or the stream ran dry. Patches above barriers began in the catchment polygon above the reservoir and continued until the stream ran dry or another barrier was reached. Patch area was calculated by summing the area of all catchments contained within that patch. Patches were delineated in the following states: Pennsylvania, New Jersey, Maryland, West Virginia, Virginia, Tennessee, North Carolina, South Carolina, and Georgia.

We developed a sampling protocol designed to obtain samples from patches that yield unbiased estimates of various genetic metrics, with particular focus on  $N_b$  (effective number of breeders). The key consideration is that samples must be close to random with respect to family membership of the individuals collected (Whiteley et al. 2012). Our goal was to spread out sampling locations within a patch for the purpose of reducing full-sibling overrepresentation while increasing family representation to minimize bias in  $N_b$  estimates. To accomplish this, we calculated the length of the main stem within a patch using a geographic information system GIS and divided it into three equal reaches. In larger or irregular patches, supplemental reaches were added, or main-stem reaches were replaced by large tributary reaches to enable better spatial sampling of the patch.

To examine genetic variation and the effective number of breeders ( $N_b$ ) within a patch and relate these metrics to patch size, we attempted to sample 25 young-of-year (YOY) trout from each reach to achieve a target sample size of 75 YOY. Reaches were

sampled in a downstream to upstream order. Fin clips were collected and additional data such as presence or absence of invasive trout and the presence of age-1 and older Brook Trout were collected. If YOY were extremely abundant at the start of a reach, the sample was spread over approximately 100 m to prevent family over-representation. If YOY were not found in a reach after sampling 100 m, additional sampling sites within that reach were attempted by dividing reach length by two and spacing the sites approximately 1 to 2 km apart. If fish were not obtained in downstream reaches, upstream reaches were supplemented, if possible, to achieve a goal of at least 50 YOY per patch. A total of 19 patches were sampled, ranging in area from 590 to 10,880 ha.

We exhaustively sampled YOY Brook Trout from a large patch in the Dry River Basin of Rockingham County, Virginia to determine how within-patch differentiation may influence patch-level genetic metrics. We obtained nine samples from five sites within this patch (Table 1). Sampling methods followed Whiteley et al. (2013).

### Genetic Methods

We used eight microsatellite loci following the procedures of Whiteley et al. (2013). We also followed

the procedures of Whiteley et al. (2013) to estimate all population genetic summary statistics, including observed ( $H_o$ ) and expected ( $H_e$ ) heterozygosity per locus and population, mean number of alleles ( $A$ ), mean allelic richness per population ( $AR$ ; mean number of alleles scaled to the smallest sample size), and  $N_b$ . Details regarding testing for Hardy-Weinberg proportions and linkage disequilibrium can also be found in Whiteley et al. (2013). We used a linear model to examine the effect of patch area on estimates of genetic variation within patches and  $N_b$ . Response variables in separate models included mean observed number of alleles ( $A_o$ ), mean observed heterozygosity, or point estimates of  $N_b$ . We used a logit transformation for heterozygosity (Warton and Hui 2011). All analyses were performed with the *stats* package in R version 2.15.0 (R Development Core Team 2006).

We followed the procedures of Whiteley et al. (2013) to estimate  $F$ -statistics and test for genic differentiation. We used Meirmans and Hedrick's unbiased estimator  $G''_{ST}$  (Meirmans and Hedrick 2011) for estimates of overall and pairwise  $F'_{ST}$ . We used Nei's unbiased estimator of  $G_{ST}$  (Nei 1987) for estimates of overall and pairwise  $F_{ST}$ . We combined locus-specific exact tests for allele frequency (genic

**Table 1. Genetic summary statistics for young-of-the-year (YOY) Brook Trout (captured in five sites in the Dry River Basin, Virginia. In the site names, the initial 'a' corresponds to above-dam and the initial 'b' corresponds to below-dam. The year of sampling is shown for each sample. There were two main stem Dry River below-dam sites, labeled '1' and '2'. Summary statistics are based on all individuals sampled ( $N$ ). Measures are as follows: mean expected heterozygosity ( $H_s$ ), mean number of observed alleles per population ( $A_o$ ), allelic richness standardized to  $N = 27$  ( $AR$ ), and LDNe-based single-sample estimates of the effective number of breeders that gave rise to the cohort examined ( $N_b$ ).**

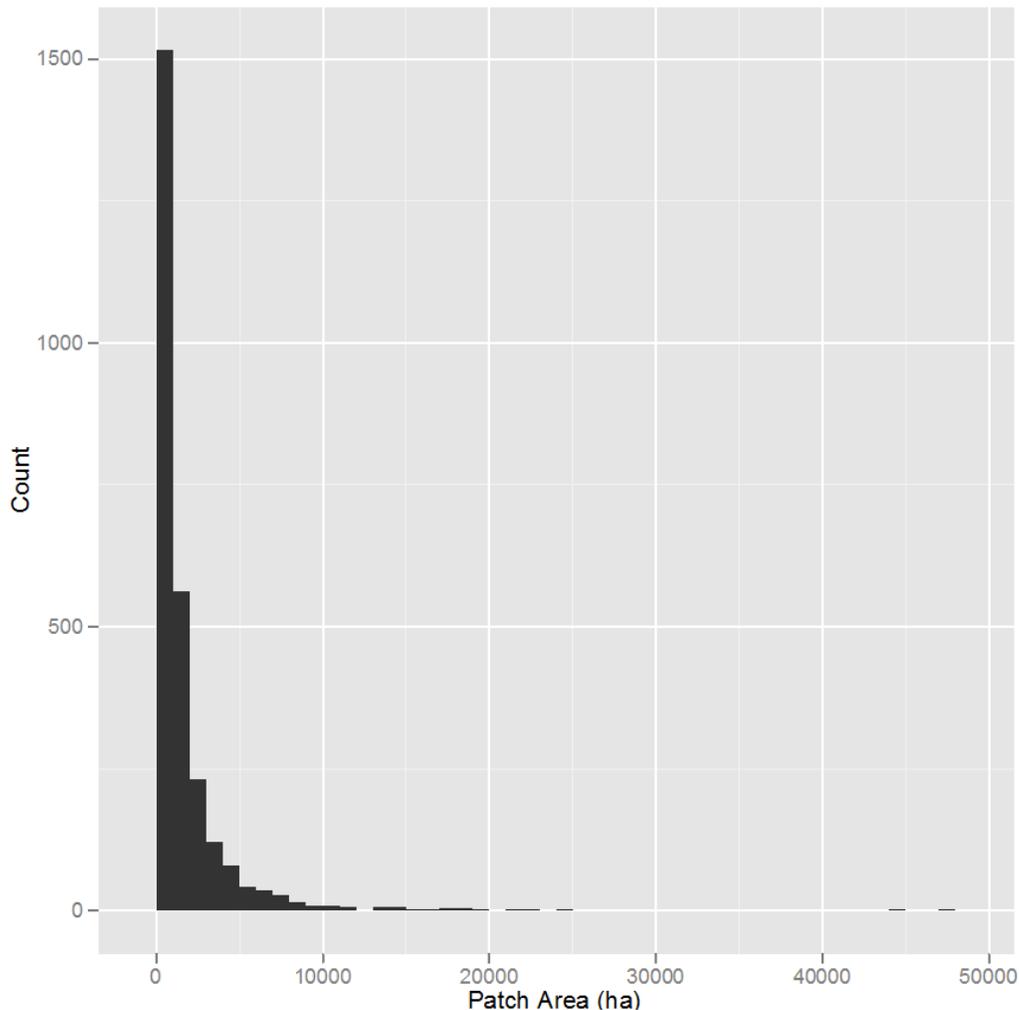
Site name	Patch area (ha)	$N$	$H_s$	$A_o$	$AR$	$N_b$
DV-b-mainstem-1-2010	10,880	99	0.777	8.8	7.8	191.2 (140.3-279.8)
DV-b-mainstem-1-2011	10,880	67	0.770	9.3	7.9	146.4 (100.9-238.8)
DV-b-mainstem-2-2010	10,880	44	0.774	9.4	8.5	375.5 (174.2-INF)
DV-b-tributary-2012	10,880	86	0.761	10.3	8.2	125.2 (90.1-186.3)
DV-a-2010	3,807	379	0.780	10.9	8.2	66.6 (57.8-76.5)
DV-a-2011	3,807	510	0.797	11.6	8.8	75.0 (60.9-91.4)
DN-a-2010	1,217	46	0.565	3.4	3.4	4.9 (3.8-8.7)
DN-a-2011	1,217	27	0.392	2.8	2.8	40.2 (12.6-INF)

differentiation with Fisher's method (Ryman 2006). We used the B-Y FDR correction method to control the type I error rate for results from this combined test (Benjamini and Yekutieli 2001; Narum 2006). To minimize any biases associated with family-level structure, we first reconstructed full-sibling families within each sample with COLONY version 1.2 (Wang 2004) and then randomly sampled one full-sib per family to create a separate data set for tests of genetic differentiation. We also followed the procedures of Whiteley et al. (2013) to test for population-level genetic structure with STRUCTURE ver. 2.3.1 (Pritchard et al. 2000). We performed five runs for each of  $K = 1$  to 4 with and without location as a prior.

## RESULTS

### Habitat patches

Brook Trout patch area from Pennsylvania south through Georgia ranged from 21 to 47,766 ha (Figure 1). Mean patch area was 1,854 ha and median patch area was 850 ha. The vast majority of patches were small, for example, 85.3% (2,310 out of 2,708 patches) were less than 3,000 ha in area. If we remove the 202 patches less than 200 ha, which may cause downward bias in measures of central tendency, the mean patch area becomes 1,993 ha (+139 ha), the median becomes 935 ha (+85 ha), and 84% (2,108 of 2,506) of the patches are less than 3,000 ha.



**Figure 1. Histogram of patch area (in hectares ) for eastern Brook Trout patches from Pennsylvania to Georgia. Patches were defined with extensive Brook Trout occupancy data and the approach described in the text.**

### Patch-Based Genetic Monitoring

We observed a strong positive relationship between  $\hat{N}_b$  and patch area for 19 Virginia Brook Trout habitat patches (Figure 2a). Patch area explained 49% of the variation in  $N_b$  ( $t_{17} = 4.0, P = 0.0009$ ). While this is a substantial portion of the variation in  $N_b$ , these data indicate that factors other than patch area influence  $N_b$ . Two pH-remediated patches (Hudy et al. 2000) that have low hydrologic variability had

high  $N_b$  for their patch area (Figure 2a, triangles). Three patches with invasive Rainbow Trout had low  $N_b$  for their patch area (Figure 2a, squares). We also observed a positive but weaker relationship between patch area and within-population mean heterozygosity (Figure 2b) and mean number of alleles (data not shown). Patch area explained 20% of the variation in heterozygosity ( $t_{17} = 2.1, P = 0.05$ ; Figure 2b) and only 6% of the variation in mean number of alleles ( $t_{17} = 1.0, P = 0.32$ ).

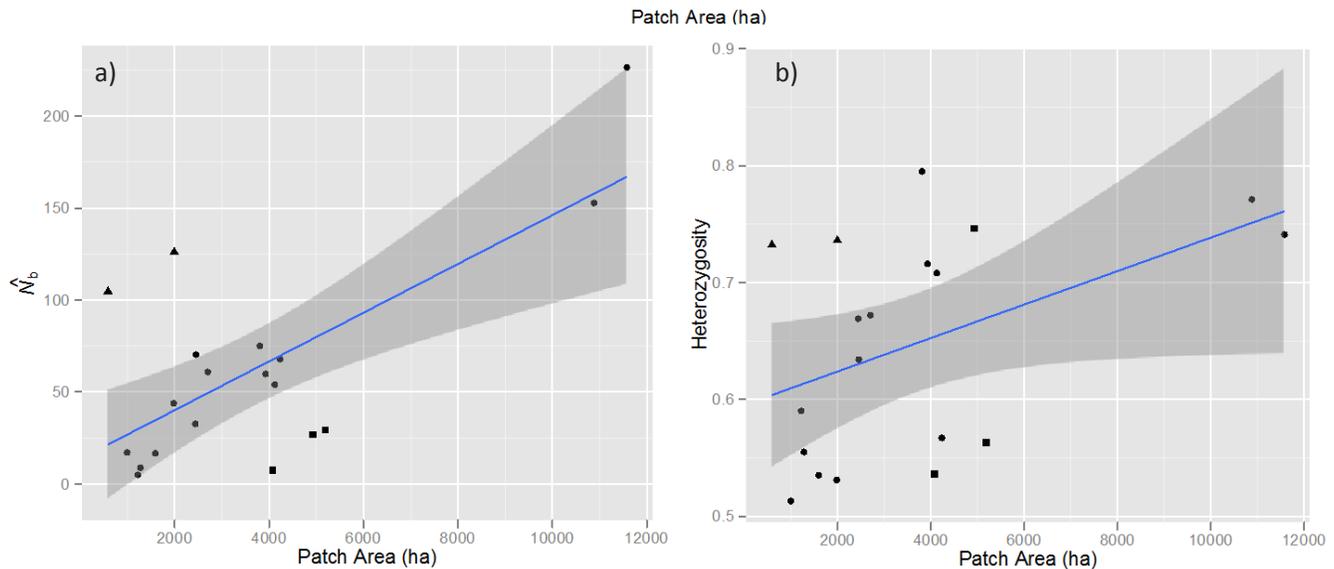


Figure 2. Effective number of breeders ( $N_b$ ; panel A) and genetic diversity (mean within-population heterozygosity; panel B) regressed against patch area (ha) for 19 habitat patches of Brook Trout in Virginia. Habitat patches that have been pH-remediated and have stable flow patterns relative to all others are shown as triangles. Habitat patches that contain invasive Rainbow Trout are shown as squares. All other sites lack these characteristics.  $R^2 = 0.49$  for the regression in panel A.  $R^2 = 0.20$  for the regression in panel B.

Table 2. Genetic differentiation among eight samples of YOY Brook Trout from five sites in the Dry River Basin, Virginia.  $F_{ST}$  is above the diagonal,  $F'_{ST}$  is below the diagonal. Bold values were not significant following Fisher’s method for combining P-values across eight exact tests per sample (B-Y FDR correction, nominal  $P = 0.013$ ).

Site	DVb-mainstem-1-2010	DVb-mainstem-1-2011	DVb-mainstem-2-2010	DVb-tributary-2012	DVa-2010	DVa-2011	DNa-2010	DNa-2011
DV-b-mainstem-a-2010	--	<b>0.001</b>	<b>0.005</b>	<b>0.031</b>	<b>0.020</b>	<b>0.018</b>	<b>0.150</b>	<b>0.230</b>
DV-b-mainstem-a-2011	<b>0.005</b>	--	<b>0.003</b>	<b>0.020</b>	<b>0.014</b>	<b>0.014</b>	<b>0.141</b>	<b>0.230</b>
DV-b-mainstem-b-2010	<b>0.023</b>	<b>0.014</b>	--	<b>0.021</b>	<b>0.017</b>	<b>0.012</b>	<b>0.147</b>	<b>0.240</b>
DV-b-tributary-2012	<b>0.135</b>	<b>0.090</b>	<b>0.091</b>	--	<b>0.029</b>	<b>0.026</b>	<b>0.158</b>	<b>0.258</b>
DV-a-2010	<b>0.095</b>	<b>0.065</b>	<b>0.079</b>	<b>0.130</b>	--	<b>0.002</b>	<b>0.153</b>	<b>0.245</b>
DV-a-2011	<b>0.084</b>	<b>0.066</b>	<b>0.055</b>	<b>0.119</b>	<b>0.011</b>	--	<b>0.142</b>	<b>0.244</b>
DN-a-2010	<b>0.462</b>	<b>0.438</b>	<b>0.454</b>	<b>0.477</b>	<b>0.484</b>	<b>0.449</b>	--	<b>0.155</b>
DN-a-2011	<b>0.570</b>	<b>0.570</b>	<b>0.595</b>	<b>0.629</b>	<b>0.620</b>	<b>0.618</b>	<b>0.304</b>	--

## Large Patch Case Study

Location within the Dry River Basin relative to a dam had a strong influence on within-sample genetic diversity and  $N_b$  (Table 1). The above-dam Dry Run patch (DN-a) had the least genetic variation and the smallest  $N_b$  (Table 1). The above-dam Dry River patch (DV-a) had the largest estimates for genetic diversity ( $H_s$ ,  $A_o$ , and  $AR$ ) but smaller  $N_b$  estimates than below-dam sites. All below dam sites, including the tributary sample, had similar values of genetic diversity and  $N_b$  (Table 1). Two  $N_b$  estimates had upper CI limits that included infinity (Table 1). These are likely due to smaller sample sizes relative to a larger true  $N_b$  and are not likely to be reliable estimates.

We examined genetic divergence among sites by taking a random subsample of one full-sib per family for all analyses. Overall  $F_{ST}$  in the entire Dry River Basin was 0.331 (0.258–0.408) and overall  $F_{ST}$  was 0.096 (0.068 – 0.132). Pairwise  $F_{ST}$  ranged from 0.001 to 0.258. Pairwise  $F_{ST}$  ranged from 0.005 to 0.629 (Table 2). Only one of the 28 exact tests for genetic differentiation was not significant based on Fisher's method and controlling the FDR with the B-Y correction method ( $\alpha = 0.05$ ; Table 2).

STRUCTURE analyses were consistent with two or three genetic groups in the Dry River patch as a whole. All models clustered the above-dam Dry Run patch (DN-a) separately as one group. All models also clustered the below dam samples (DV-b-main stem a & b, DV-b-main stem b, and DV-b-tributary) together in a single group. There was some discrepancy among models related to the above-dam Dry River (DV-a) samples, which is consistent with the moderate genetic differentiation between DV-a and the below-dam sites (Table 2). With a location prior,  $K = 3$  clearly outperformed other models and split DV-a into a third genetic group (Fig. 3a). With no location prior, log-likelihoods increased from  $K = 1$  to  $K = 4$  then decreased.  $K = 2$  grouped DN-a separately and the other group contained the remainder of the sites (fig. 3c).  $K = 3$  had an additional group that occurred primarily in DV-a (Fig. 3b).  $K = 4$  was biologically implausible; a fourth group was scattered throughout each of the DV-a and DV-b sites (data not shown).

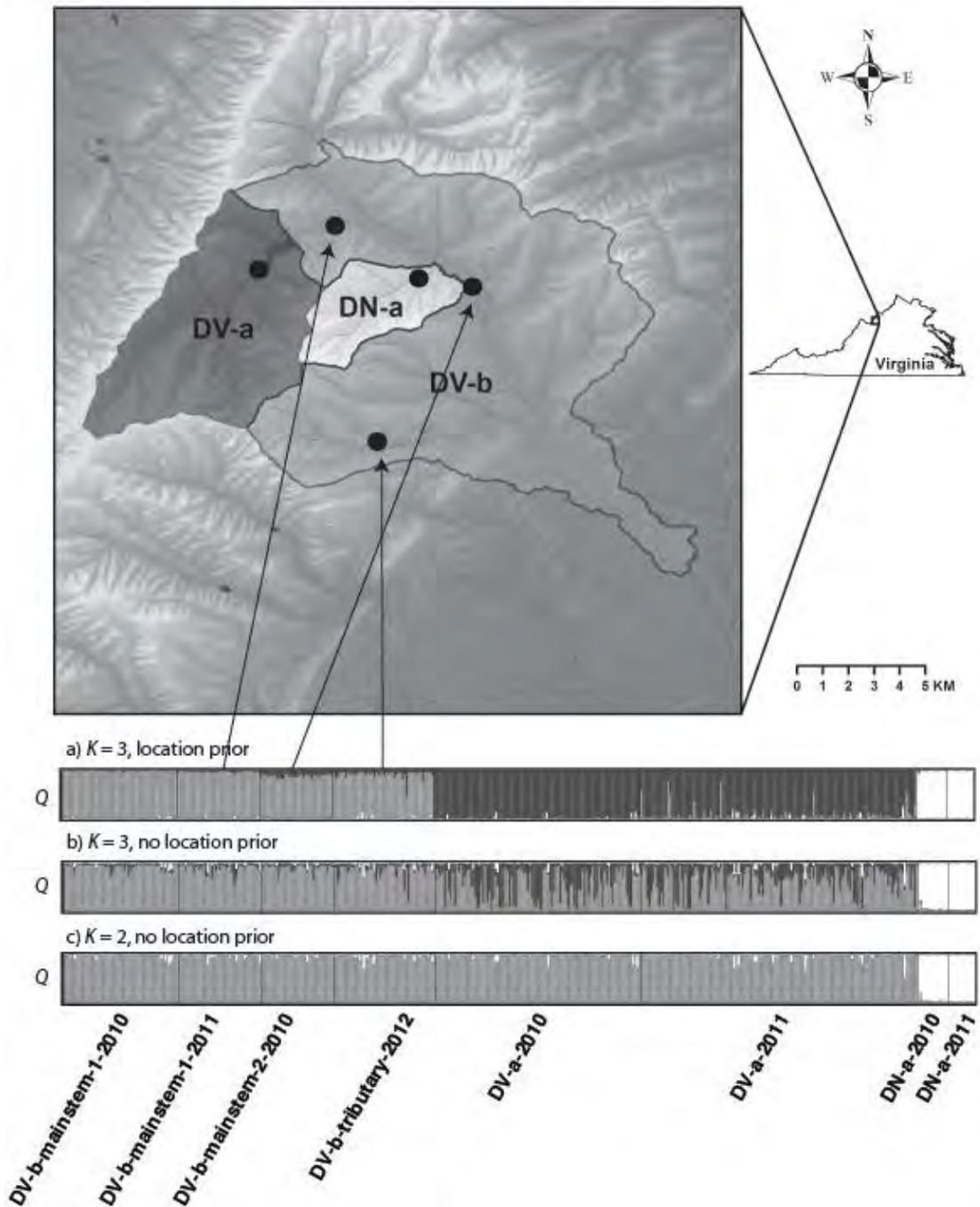
## DISCUSSION

### Habitat Patches

The patches we defined appear to be the most appropriate spatial scale for eastern Brook Trout management. Our approach provides a workable method to define the scale at which demographic and genetic monitoring could be performed for this species. Because we focus on both Brook Trout presence and population discontinuities, our approach defines what are likely to be demographically independent units. It is clear that even if there is downward bias due to artificially small patches in our analysis, our results reveal a striking tendency towards small and fragmented populations in the southern portion of their native eastern Brook Trout range. It is highly likely that patches of approximately 3,000 ha or less contain single populations, therefore roughly 85% of Brook Trout patches are likely to contain single populations that may suffer from the variety of well-described small population effects (Gienapp et al. 2008). Another possible weakness of our approach occurs with very large patches, which may contain metapopulations and multiple demographically independent subpopulations (see below). Our patch-based approach appears to be highly effective for the vast majority of the southern portion of the Brook Trout eastern range, application to more intact and potentially continuous northern habitat may present a challenge that we are currently working to address.

### Patch-Based Genetic Monitoring

The strong positive relationship between  $N_b$  and patch area indicates that patch area alone serves as an important driver of reproductive success and output in this set of patches. Our results also provide some indication regarding additional factors that influence among-patch variation in  $N_b$ . Two pH-remediated patches (Hudy et al. 2000) that have low hydrologic variability had relatively large  $N_b$  for their patch area. A likely cause for this is the high proportion of available quality habitat compared to patches with lower productivity or increased flow variability.



**Figure 3.** STRUCTURE analysis of large Dry River case study Brook Trout patch from Virginia. This entire patch is 15,904 ha but was divided according to our methodology into a large downstream patch (DV-b, 10,880 ha), a small above-dam patch (DN-a; 1,217 ha), and a large above-dam patch (DV-a, 3,807 ha). Sample locations are shown as black dots. STRUCTURE plots show the proportion of the genome ( $Q$ ) of each individual assigned to each population sample. One full-sibling was randomly chosen from each family for all analyses. Shown in (a) is the best-supported STRUCTURE admixture model with a location prior. Shown in (b)  $K = 3$ , and in (c)  $K = 2$ ; both with an admixture model and no location prior. Each row corresponds to an individual and sample sites are separated by horizontal bars. Each of the clusters was given a color that corresponds to the colors in the map. The below-barrier shade of gray was used for the combined DV-a and DV-b cluster in (c).

On the other hand, the three patches that contained invasive Rainbow Trout and had relatively low  $\hat{N}_b$  for their patch area are likely to have a low proportion of available quality habitat due to displacement. The weaker relationship between within-patch genetic diversity and patch area indicates that factors other than patch area influence the maintenance of genetic diversity and evolutionary potential within patches. There was a cluster of patches with low heterozygosity for their patch area and another cluster of patches with high heterozygosity for their patch area. Patches with low genetic diversity for their size may have undergone bottlenecks in the past. Aspects of hydrological variability, fragmentation effects, and presence of invasive species could have caused bottlenecks. Patches with high genetic diversity for their size are likely to have maintained population sizes above levels that lead to precipitous loss of genetic variation. These patches are likely to be relatively un-fragmented, have high habitat quality throughout a greater proportion of the patch, and be less influenced by invasive species.

These preliminary results indicate that factors beyond patch size must be considered if we are to comprehensively model Brook Trout genetic indicators of resilience. In addition to patch size, important drivers of variation in genetic indicators of resilience are likely to be hydrologic variability, stream temperature, fragmentation, and presence of invasive species. We are currently working to expand our analysis to include a greater number of patches that vary more widely in ecological characteristics. A critical next step is to understand how environmental and landscape factors influence genetic metrics and to integrate them with ecological models to improve forecasts of future population status.

### Large Patch Case Study

Larger patches may present a difficulty for our patch-based genetic monitoring approach. Large patches are more difficult to effectively sample and smaller subsamples may yield biased estimates of genetic metrics. The rarity of large patches reveals that these potential problems only apply to a very limited portion of eastern Brook Trout populations. Furthermore, our large patch case study provides promising results that suggest that subsamples of large patches should be representative of the patch as a whole. In the large below-dam patch, we sampled

two main-stem sites and a tributary site closer to the headwater limits of the patch. We observed statistically significant allele frequency divergence among the tributary site and the main stem sites. However, all STRUCTURE models grouped the below-dam sites together. These results suggest that metapopulation structure occurs below the dam and that populations may be demographically independent. However, the important point relative to our patch sampling approach is that values of genetic diversity and  $N_b$  were similar within all below-dam sites. Therefore, if we had sampled only a small portion of this large patch, we would have obtained representative values of the focal genetic metrics.

The likely evolutionary mechanism responsible for the similarity of values of genetic diversity for the within-patch subpopulations is gene flow. Gene flow among multiple genetically differentiated populations in larger patches would maintain genetic diversity within each of the subpopulations (Jorde and Ryman 1996). The mechanistic explanation for the similarity in  $N_b$  estimates among sites within the large below-dam patch is less clear. The DV-b-tributary, a headwater tributary site that is connected to the below-dam metapopulation, had similar  $\hat{N}_b$  values to the other below-dam sites and much greater  $\hat{N}_b$  than the adjacent but above-dam DN-a. Small amounts of gene flow are less likely to influence the LD signal (relative to genetic diversity) within each subpopulation (Jorde and Ryman 1996; Palm et al. 2003). Therefore, gene flow may not provide a mechanistic explanation of the similarity of  $N_b$  estimates in the below-dam patch estimates of  $N_b$ . We previously suggested that consistently lower  $\hat{N}_b$  in above-dam relative to below-dam patches in a larger series of Brook Trout patches was due to limited spawning habitat in above-dam patches (Whiteley et al. 2013). We predict that greater spawning site availability in the connected stream (DV-b-tributary) relative to the two isolated patches (DN-a and DV-a) is the primary cause of these differences.

We recommend a patch-based monitoring program for eastern Brook Trout population status. The program could center on patches defined as we describe here. We recommend the following patch metrics: number of patches with allopatric populations (Brook Trout only), number of patches with sympatric nonnative trout populations (Brook Trout with Rainbow Trout or Brown Trout), average

size of patches, number of patches increasing in size (connectivity), number of patches decreasing in size, number of patches with decreasing or stable genetic diversity, and number of patches with increasing, decreasing or stable  $N_b$  (as an indicator of reproductive output and success). The program could focus on a set of sites that are visited every year (sentinel sites) and other sets of sites that are visited in a rotating manner such that each set would be visited once every 5 years. It might be possible to use future estimates of  $N_b$  from these sites, obtained with the appropriate sampling strategy (Whiteley et al. 2012), to monitor population trend (Tallmon et al. 2010).

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## REFERENCES CITED

- Allendorf, F. W., G. Luikart, and S. N. Aitken. 2013. Conservation and the Genetics of Populations. John Wiley & Sons, West Sussex, UK.
- Bain, M. B., and M. L. Wine. 2010. Testing predictions of stream landscape theory for fish assemblages in highly fragmented watersheds. *Folia Zoologica* 59:231-239.
- Christie, M. R., M. L. Marine, R. A. French, R. S. Waples, and M. S. Blouin. 2012. Effective size of a wild salmonid population is greatly reduced by hatchery supplementation. *Heredity* 109:254-260.
- Gienapp, P., C. Teplitsky, J. S. Alho, J. A. Mills, and J. Merila. 2008. Climate change and evolution: disentangling environmental and genetic responses. *Molecular Ecology* 17:167-178.
- Hare, M. P., L. Nunney, M. K. Schwartz, D. E. Ruzzante, M. Burford, R. S. Waples, K. Ruegg, and F. Palstra. 2011. Understanding and estimating effective population size for practical application in marine species management. *Conservation Biology* 25:438-449.
- Hudy, M., D. M. Downey, and D. W. Bowman. 2000. Successful restoration of an acidified native brook trout stream through mitigation with limestone sand. *North American Journal of Fisheries Management* 20:453-466.
- Hudy, M., T. M. Theiling, N. Gillespie, and E. P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. *North American Journal of Fisheries Management* 28:1069-1085.
- Isaak, D. J., C. H. Luce, B. E. Rieman, D. E. Nagel, E. E. Peterson, D. L. Horan, S. Parkes, and G. L. Chandler. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. *Ecological Applications* 20:1350-1371.
- Jorde, P. E., and N. Ryman. 1996. Demographic genetics of brown trout (*Salmo trutta*) and estimation of effective population size from temporal change of allele frequencies. *Genetics* 143:1369-1381.
- Meirmans, P. G., and P. W. Hedrick. 2011. Assessing population structure: F<sub>ST</sub> and related measures. *Molecular Ecology Resources* 11:5-18.
- Meisner, J. D. 1990. Effect of climatic warming on the southern margins of the native range of brook trout, *Salvelinus fontinalis*. *Canadian Journal of Fisheries and Aquatic Sciences* 47:1065-1070.
- Moore, S. E., G. L. Larson, and B. Ridley. 1986. Population control of exotic rainbow trout in streams of a natural area park. *Environmental Management* 10:215-219.
- Moore, S. E., B. Ridley, and G. L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smoky Mountains National Park. *North American Journal of Fisheries Management* 3:72-80.
- Palm, S., L. Laikre, P. E. Jorde, and N. Ryman. 2003. Effective population size and temporal genetic change in stream resident brown trout (*Salmo trutta*, L.). *Conservation Genetics* 4:249-264.
- Pritchard, K., M. Stephens, and P. Donnelly. 2000. Inference of population structure using multilocus genotype data. *Genetics* 155:945-959.
- R Development Core Team. 2006. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Strange, R. J., and J. W. Habera. 1998. No net loss of brook trout distribution in areas of sympatry with rainbow trout in Tennessee streams. *Transactions of the American Fisheries Society* 127:434-440.
- Tallmon, D. A., D. Gregovich, R. S. Waples, C. S. Baker, J. Jackson, B. L. Taylor, E. Archer, K. K. Martien, F. W. Allendorf, and M. K. Schwartz. 2010. When are genetic methods useful for estimating contemporary abundance

- and detecting population trends? *Molecular Ecology Resources* 10:684-692.
- Waples, R. S., and C. Do. 2010. Linkage disequilibrium estimates of contemporary  $N_e$  using highly variable genetic markers: a largely untapped resource for applied conservation and evolution. *Evolutionary Applications* 3:244-262.
- Warton, D. I., and F. K. C. Hui. 2011. The arcsine is asinine: the analysis of proportions in ecology. *Ecology* 92:3-10.
- Whiteley, A. R., J. A. Coombs, M. Hudy, Z. Robinson, A. R. Colton, K. H. Nislow, and B. H. Letcher. 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal Fisheries and Aquatic Sciences* online early:
- Whiteley, A. R., J. A. Coombs, M. Hudy, Z. Robinson, K. H. Nislow, and B. H. Letcher. 2012. Sampling strategies for estimating brook trout effective population size. *Conservation Genetics* 13:625-637.

## GENETIC ANALYSIS OF NORTH CAROLINA'S BROOK TROUT WITH EMPHASIS ON PREVIOUSLY UNCHARACTERIZED COLLECTIONS

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**Abstract**—Salmonid fishes inhabiting lower latitudes present significant challenges to fishery managers who attempt to maintain ecological and evolutionary processes within and among populations. The Brook Trout *Salvelinus fontinalis* is the only salmonid native to the southern Appalachian region and functions as a keystone species in some headwater streams. The dramatic decrease in the range of Southern Appalachian Brook Trout combined with the historic use of hatchery-reared fishes for supplemental and restorative stocking throughout the species' range underscores the need to recognize the ecological and evolutionary relationship among stream populations. Although the North Carolina Wildlife Resources Commission (NCWRC) routinely monitors Brook Trout populations to evaluate population characteristics, genetic and evolutionary relationships among most populations have not been extensively investigated using contemporary molecular methods. To address this research need, an extensive survey of genetic diversity and variation at 13 microsatellite loci is being conducted. This research effort, focused initially on previously uncharacterized stream collections, indicated the presence of highly significant differentiation at all hierarchical levels (collection, stream, and watershed). Moreover, these findings have allowed NCWRC to (1) resolve the evolutionary relationships at the population and phylogeographic scales; (2) shed light on the historical demography of each collection; (3) assess the degree to which collections have been impacted by supplemental or restorative stockings; and (4) provide long-term guidance in management of the genetic resources identified. Future research will attempt to determine whether the genetic divergence observed reflects adaptive differences (e.g., natural selection), variation due to stochastic processes (e.g., random genetic drift), or some quantifiable combination of the two evolutionary processes.

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### INTRODUCTION

The Brook Trout *Salvelinus fontinalis* is the only salmonid native to North Carolina, and as such, managers and trout anglers deem it important to specifically devote resources to the management of the species (Responsive Management 2007). Anthropogenic alterations to the landscape and introductions of nonnative salmonids (Rainbow Trout *Oncorhynchus mykiss* and Brown Trout *Salmo trutta*) have greatly reduced its range. Intensive stockings of northern strain Brook Trout also diminished the genetic integrity of many native Brook Trout populations (Hudy et al. 2008). The North Carolina Wildlife Resources Commission (NCWRC) has been involved in a long-term effort to identify and genetically type wild Brook Trout populations

within the state. To date, over 600 wild Brook Trout populations have been identified and of these, 480 have been genotyped at the creatine kinase locus (Galbreath 2002; Cornelison et al. 2005). Results from allozyme testing indicate that 38.3% of the populations are southern origin, 9.6% are northern origin and 52.1% are of mixed genetic origin. Additionally, quantitative and qualitative data concerning Brook Trout population dynamics have been collected by the NCWRC.

Although these historic data have contributed to the NCWRC's understanding of the State's Brook Trout populations, knowledge gaps concerning genetic relationships of the species within North Carolina persist. Thus, the NCWRC chose to use contemporary molecular methods to obtain additional

genetic data for populations under its management. Focused on previously uncharacterized Brook Trout collections, this study sought to develop a baseline of genetic diversity, variation, and interrelatedness. Specific objectives of this research were to (1) provide basic conservation genetics information on diversity and variation, (2) expand the survey of variation at microsatellite loci to resolve the evolutionary relationships among Brook Trout at the population and phylogeographic scales, (3) compare this structure with other collections from throughout its native range, and (4) provide long-term guidance in management of the genetic resources identified.

## METHODS

**Study Area**—Wild Brook Trout persist within eight of the nine primary water basins of western North Carolina, and as a result, populations are located within both the Gulf of Mexico (interior) and Atlantic Ocean (Atlantic) drainages (Figure 1). In addition, populations are often confined to waters at elevations approximately 914 m or greater. Given the predominant isolation to headwater areas, long-term persistence of many populations will be challenging (Whiteley et al. 2013).

**Hatchery Stocks**—Armstrong State Fish Hatchery (Marion, NC) and Bobby N. Setzer State Fish Hatchery (Pisgah Forest, NC) produce approximately 335,000 Brook Trout annually to support NCWRC stocked-trout resources. Although current NCWRC management practices require the use of sterile, triploid trout, diploid brood stock have been maintained from historic hatchery strains. Fifty individuals from each hatchery's brood stock collection were used for comparison to wild fishes.

**Tissue Samples**—A portion of tissue samples were obtained originally for allozyme analysis via non-lethal muscle biopsy, and stored at  $-70^{\circ}\text{C}$  (Galbreath 2002; Cornelison et al. 2005); samples were ultimately transferred into absolute 95% ethanol. Additional samples were collected via anal fin clips and placed directly into chilled absolute 95% ethanol. All samples were contained within individually labeled vials.

Molecular analyses were performed by the United States Geological Survey (USGS) Leetown Science Center, Kearneysville, WV. Genomic DNA was extracted from tissue using the Puregene Kit (Gentra Systems, Minneapolis, MN). All samples were screened for 13 microsatellite loci designed specifically for Brook Trout (*SfoB52*, *SfoC24*, *SfoC28*, *SfoC38*, *SfoC79*, *SfoC86*, *SfoC88*, *SfoC113*, *SfoC115*,

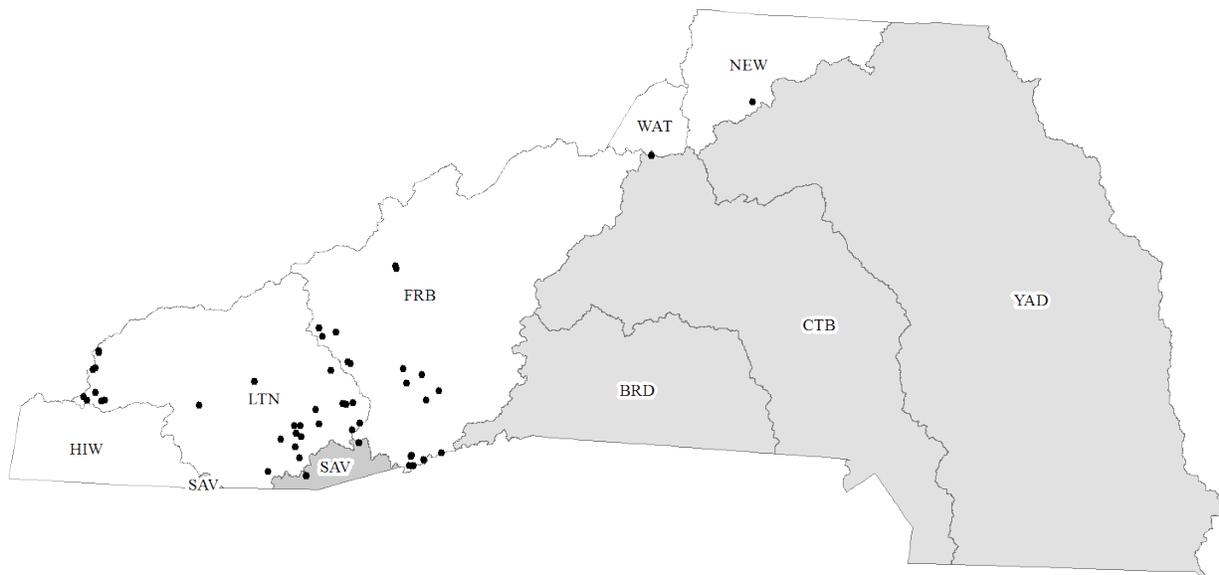


Figure 1—Map of 51 North Carolina Brook Trout collections (dots) within primary river basins of western North Carolina. Interior (unshaded) and Atlantic (shaded) drainages are noted. BRD = Broad River; CTB = Catawba River; FRB = French Broad River; HIW = Hiwassee River; LTN = Little Tennessee River; NEW = New River; Savannah River; WAT = Watauga River; and YAD = Yadkin River.

*SfoC129*, *SfoD75*, *SfoD91*, *SfoD100*; King et al. 2012). Master mix composition, thermal cycling parameters, and multiplexing were as provided in King et al. (2012) with slight changes to polymerase chain reaction (PCR) composition (unpublished). PCR amplifications were carried out on either PTC-200 or PTC-225 thermal cyclers (Bio-Rad Laboratories, Hercules, CA), and microsatellite allele sizes were characterized on an Applied Biosystems (Foster City, CA) ABI 3100XL Genetic Analyzer. Genmapper™ 3.7 Fragment Analysis software (Applied Biosystems) was used to score, bin, and output allelic data.

**Genetic Analyses**—Allelic data generated for all collections were examined initially using MicroChecker (Van Oosterhout et al. 2004) and the microsatellite Toolkit (Parks 2001) to identify the presence of null alleles, scoring errors, or large allele drop-out. Genetic diversity of all collections was quantified using GenAlEx (Peakall and Smouse 2006) to calculate allelic frequencies, number of alleles per locus ( $N_a$ ), effective number of alleles ( $A_e$ ), unbiased expected heterozygosity ( $uH_e$ ), and inbreeding coefficient ( $F$ ). Tests for conformance to Hardy-Weinberg equilibrium and genotypic linkage disequilibrium were performed using (GENEPOP,

v. 4.0; Raymond and Rousset 1995). Sequential Bonferroni adjustments (Rice 1989) were used to determine statistical significance for these and all other multiple tests. Where possible, estimates of the effective population size ( $N_e$ ) for each collection were generated using the linkage disequilibrium algorithm of the program LDNe (Waples 2006). GENECLASS (Wilberg and Dreher, 2004) calculated the unbiased probability of identity, which is the probability that two individuals drawn at random from a population will have the same genotype at the assessed loci (Paetkau and Strobeck, 1994).

Because past supplementation efforts within North Carolina's watersheds used hatchery strains of northern Atlantic slope origins, it is possible that hatchery fish or their descendants were among those sampled. In addition, hatchery strains used by the NCWRC were of northern Atlantic slope origins; thus, a detectable molecular signal may be present. To identify the presence or influence of supplementation on population diversity, the Bayesian option (Rannala and Mountain 1997) of GeneClass (Cornuet et al. 1999) was used to determine the likelihood of each individual's multilocus genotype being found among 16 hatchery source collections (Table 1) used

**Table 1—Hatchery Brook Trout stocks used for comparisons to wild collections.**

Hatchery Strain	State	Year Sampled	Sample Size
Phillips Hatchery	Maine	2005	60
Sandwich Hatchery	Massachusetts	2003	37
Hyde Pond Strain	New York	2005	35
Mountain Pond Strain	New York	2005	31
Big Hill Pond Strain	New York	2005	55
Rome Hatchery	New York	2005	50
Pequest Trout Hatchery	New Jersey	2000	20
Bellefonte Hatchery	Pennsylvania	2004	31
Edray Hatchery	West Virginia	2003	21
Berlin Fish Hatchery (Gilbert Strain 3 and 4 yr)	New Hampshire	2008	50
Milford Fish Hatchery (Rome Strain, 1 yr)	New Hampshire	2009	50
Milford Fish Hatchery (Rome Strain, 2 yr)	New Hampshire	2009	50
Milford Fish Hatchery (Rome Strain, 3 yr)	New Hampshire	2009	50
Paint Branch Hatchery	Virginia	2012	50
Pisgah Hatchery	North Carolina	2012	50
Armstrong Hatchery	North Carolina	2012	50

for supplementation throughout the Brook Trout's range. Similarly, a "northern" baseline consisting of individuals sampled from Atlantic and Great Lakes basin drainages (N = 6,524 fish) and a "southern" baseline from interior basin drainages (N = 2,120) was used to determine the phylogeographic origins or affinity of each North Carolina collection.

The evolutionary relationships among the Brook Trout collections from the different drainages were estimated by calculation of genetic distances between each pair of collections summarized using the Cavalli-Sforza and Edwards (1967) chord distance. These relationships were visualized through the construction of a neighbor-joining tree (Saitou and Nei 1987) in MEGA5 (Tamura et al. 2011). The strength of support for each node in the phylogenetic tree was tested by bootstrapping over loci using *njbpop* (J. M. Cornuet, INRA, personal communication).

## RESULTS

**Collections**—Fifty-one collections (946 individuals) were evaluated in this study (Table 2). Collection sizes ranged from three (Cold Branch) to 40 (Tellico River) individuals (mean = 18.5; SE = 0.9). Limited sample sizes were the result of collection efforts to fulfill previously defined allozyme analysis protocols (20 individuals) and the inability to capture individuals within low-density populations.

**Diversity Statistics**—The allelic diversity was sufficient to produce unique multilocus genotypes for 95.8% of the 946 Brook Trout sampled; the average allelic diversity was 3.3 alleles/locus (SE = 0.1; Table 2). Matching genotypes of two or more individuals were observed in 11 (21.6%) collections prompting the removal of 40 individuals from the dataset; a single individual representing each multilocus genotype was used for estimating allelic diversity and variation. The average number of effective alleles was 2.2 (SE = 0.1), with values ranging from 1.2 (Laurel Branch-above falls; SE = 0.1) to 6.6 (Pigeon Branch; SE = 0.5). The average unbiased heterozygosity was 41.6% (SE = 1.1%); ranging from 6.5% (SE = 4.5%) in Laurel Branch-above falls to 72.4% (SE = 4.6%) in Silver Run Creek. Deviations from Hardy-Weinberg expectations were observed in six of 51 (11.8%) collections, in all collections were observed to exhibit heterozygote deficiencies (overall  $\alpha = 0.05$ ,  $P < 0.0039$ ; Rice 1989). Limited linkage disequilibrium

was detected within the collections as 37 of 2,500 (1.5%) possible pair-wise comparisons were statistically significant (overall  $\alpha = 0.05$ ,  $P < 0.006$ ; Rice 1989). Inbreeding coefficients varied between -0.001 (UT Pine Swamp Creek; SE = 0.046) and 0.385 (Indian Creek; SE = 0.083) across collections averaging -0.023 (SE = 0.008). Estimates of effective population sizes ranged from 0.5 (South Prong Gladly Fork; 95% CI = 0.4–0.5) to 712.0 (Jane Cantrell Creek; 95% CI = 40.3– $\infty$ ).

### Origin Assignments and Genetic

**Relationships**—Phylogeographic assignment scores for the majority of collections (60.8%; N = 31) were southern (interior basin) origin, while 25.5% (N = 13) and 13.7% (N = 7) were of mixed and northern (Atlantic slope/Great Lakes basin) origins, respectively. Phylogeographic and hatchery assignment scores were in agreement for all collections except for Charley Creek (LTNC12), Mill Creek (LTNC17), and Pigeon Branch (PFBNC3; Table 2).

The ratio of assignment scores (i.e., northern/hatchery vs. southern/interior or northern/Atlantic slope/Great Lakes basin vs. southern/interior) within this study appear to group into four categories: northern; southern; mixed with little or no introgression; and mixed with high degree of introgression. For example, the Cold Creek (LTNC13) collection was identified as a mixed collection, but the majority of individuals received ratio scores that did not strongly indicate origin (i.e., individuals had ratio scores close to 1.00). Conversely, individuals within the Mill Creek (LTNC18) collection displayed higher likelihood scores for assignment to either northern or southern origins.

The phylogeographic relatedness among the 51 collections, including the effects of historical stockings by northern/Atlantic slope origin hatchery strains, is depicted in a neighbor-joining tree (Figure 2). While bootstrap support for most clades was low, phylogeographic signal was strong as collections exhibiting the presence of northern/Atlantic slope introgression formed clades distinct from those forming southern/interior basin groupings. Tree structure also confirms the evolutionary relatedness of collections and illustrates the differentiation that exists among major drainages. Moreover, collections representing Little Tennessee and Pigeon-French Broad drainages form distinct clades regardless of the degree of introgression from northern/Atlantic slope alleles.

Table 2—Diversity statistics and origin assignments for 51 North Carolina Brook Trout collections analyzed at 13 microsatellite loci. N = number of individuals analyzed per collection;  $N_a$  = number of alleles;  $A_e$  = effective number of alleles;  $uH_e$  = unbiased heterozygosity; F = inbreeding coefficient; and  $N_e$  = effective population size; S = proposed interior (southern) drainage assignment; N = proposed Atlantic slope/Great Lakes (northern) drainage assignment; and M = mixed drainage assignment. Mean values across all loci and populations are given with standard error (N;  $N_a$ ,  $A_e$ ,  $uH_e$ , and F) and 95% confidence interval ( $N_e$ ) values in parentheses. Estimates in bold and italics deviated from Hardy-Weinberg expectations. Collection codes identify individual collections and primary river basins of the eastern United States where the collection is found: Santee (SANR); Savannah (SAVR); Ohio (OHNK); Little Tennessee (LTNC); and French Broad (PFBNC) rivers.

Collection	Collection code	N	$N_a$	$A_e$	$uH_e$	F	$N_e$	Hatchery assign	Phylo assign
Little Grassy Creek	SANR1	7	2.8 (0.4)	2.2 (0.3)	0.459 (0.086)	-0.052 (0.064)	32.8 (5.8–∞)	S	S
Big Creek	SAVR1	14	4.5 (0.4)	3.1 (0.3)	0.665 (0.040)	-0.088 (0.031)	20.6 (12.4–43.7)	N	N
Silver Run Creek	SAVR2	16	6.4 (0.8)	4.2 (0.5)	0.724 (0.046)	-0.015 (0.040)	143.4 (49.5–∞)	N	N
UT Pine Swamp Creek	OHNK2	18	5.0 (0.7)	3.1 (0.4)	0.595 (0.072)	-0.001 (0.046)	17.9 (12.1–29.3)	S	S
Bob Branch	LTNC4	7	1.8 (0.2)	1.4 (0.1)	0.217 (0.066)	-0.233 (0.059)	NA	S	S
Cold Branch	LTNC5	3	1.8 (0.2)	1.6 (0.2)	0.349 (0.087)	0.020 (0.127)	NA	S	S
Ledford Branch	LTNC6	14	1.3 (0.1)	1.2 (0.1)	0.127 (0.053)	0.028 (0.057)	1.6 (0.1–∞)	S	S
Norton Prong	LTNC7	20	4.8 (0.5)	2.9 (0.3)	0.615 (0.057)	0.044 (0.025)	20.8 (13.8–35.6)	N	N
Upper Long Branch	LTNC8	20	3.2 (0.4)	1.7 (0.2)	0.296 (0.072)	0.014 (0.049)	14.9 (7.2–41.7)	S	S
UT Buck Creek	LTNC9	20	2.2 (0.3)	1.6 (0.2)	0.277 (0.076)	0.044 (0.087)	NA	S	S
UT Tennessee Creek	LTNC10	14	1.6 (0.1)	1.4 (0.1)	0.215 (0.064)	-0.108 (0.073)	3.4 (1.3–65.6)	S	S
Bracken Creek	LTNC11	20	4.4 (0.5)	2.8 (0.3)	<b>0.587 (0.055)</b>	-0.008 (0.056)	8.8 (5.5–14.3)	M	M
Charley Creek	LTNC12	20	4.8 (0.5)	2.4 (0.3)	0.528 (0.059)	-0.038 (0.044)	78.9 (30.9–∞)	S	M
Cold Creek	LTNC13	20	5.0 (0.5)	3.0 (0.2)	<b>0.633 (0.056)</b>	0.033 (0.049)	32.8 (19.0–81.3)	M	M
Gem Creek	LTNC14	19	3.9 (0.4)	2.5 (0.3)	0.518 (0.066)	-0.008 (0.041)	33.2 (16.7–142.0)	S	S
Jeff Creek	LTNC15	19	1.9 (0.2)	1.5 (0.2)	0.264 (0.072)	-0.083 (0.060)	2.9 (1.5–10.5)	S	S
Little Pine Creek	LTNC16	20	4.8 (0.6)	3.5 (0.4)	0.672 (0.049)	-0.007 (0.041)	12.5 (9.2–17.5)	M	M
Mill Creek	LTNC17	20	3.7 (0.4)	2.6 (0.3)	<b>0.567 (0.051)</b>	0.042 (0.065)	14.7 (10.7–21.2)	S	M
Mill Creek	LTNC18	20	4.2 (0.5)	2.9 (0.4)	<b>0.580 (0.063)</b>	-0.008 (0.060)	24.5 (14.2–56.8)	M	M
Sols Creek	LTNC19	20	4.9 (0.5)	2.8 (0.2)	0.614 (0.049)	0.026 (0.068)	13.3 (10.0–18.3)	M	M
Taylor Creek	LTNC20	10	3.3 (0.3)	2.2 (0.2)	0.506 (0.065)	-0.084 (0.062)	9.0 (4.0–20.9)	S	S
Trout Creek	LTNC21	16	4.7 (0.3)	3.4 (0.4)	<b>0.684 (0.046)</b>	0.060 (0.055)	3.5 (2.9–5.6)	N	N
UT Otter Creek	LTNC22	16	1.5 (0.2)	1.2 (0.1)	0.141 (0.058)	-0.093 (0.037)	NA	S	S
Mull Creek	LTNC30	8	2.0 (0.3)	1.7 (0.2)	0.338 (0.075)	-0.271 (0.063)	8.2 (1.6–∞)	S	S
Tellico River	LTNC31	40	3.2 (0.6)	1.8 (0.3)	0.284 (0.087)	0.016 (0.027)	27.5 (10.8–143.0)	S	S
Round Mountain Branch	LTNC32	34	2.5 (0.4)	1.8 (0.3)	0.292 (0.085)	-0.002 (0.021)	NA	S	S

Table 2—Continued

Collection	Collection code	N	N <sub>a</sub>	A <sub>e</sub>	uH <sub>e</sub>	F	N <sub>e</sub>	Hatchery assign	Phylo assign
Snowbird Creek	LTNC33	31	3.5 (0.4)	2.0 (0.3)	0.405 (0.072)	-0.026 (0.027)	114.1 (37.7–∞)	S	S
Sassafras Creek	LTNC34	18	2.2 (0.5)	1.7 (0.2)	0.254 (0.088)	-0.186 (0.032)	62.6 (6.9–∞)	S	S
Fall Branch	LTNC35	15	2.1 (0.4)	1.5 (0.2)	0.216 (0.081)	0.157 (0.070)	112.8 (7.6–∞)	S	S
Dark Ridge Creek	LTNC36	28	4.4 (0.7)	2.5 (0.4)	0.493 (0.074)	0.005 (0.043)	99.6 (40.1–∞)	S	S
Pigeon Branch	PFBNC3	20	6.6 (0.9)	3.7 (0.5)	0.647 (0.069)	0.078 (0.045)	4.9 (3.2–6.4)	N	M
Woody Branch	PFBNC4	20	5.2 (0.6)	3.1 (0.4)	0.609 (0.065)	0.089 (0.052)	4.2 (3.0–6.0)	S	S
Cherry Cove Creek	PFBNC5	20	3.0 (0.4)	1.8 (0.2)	0.332 (0.071)	0.348 (0.113)	0.9 (0.7–1.1)	S	S
Deep Gap Creek	PFBNC6	20	3.8 (0.7)	2.2 (0.4)	0.410 (0.084)	0.004 (0.044)	149.8 (34.3–∞)	S	S
Hungry Creek	PFBNC7	19	2.1 (0.4)	1.5 (0.2)	0.215 (0.070)	-0.079 (0.045)	1.8 (0.4–∞)	S	S
Mine Branch	PFBNC9	9	1.5 (0.1)	1.3 (0.1)	0.171 (0.055)	-0.208 (0.025)	81.4 (0.4–∞)	S	S
Old Bald Creek	PFBNC10	20	3.4 (0.5)	1.9 (0.3)	0.387 (0.076)	0.167 (0.106)	1.3 (1.1–1.6)	S	S
Shiny Creek	PFBNC11	20	4.3 (0.8)	2.5 (0.5)	0.430 (0.089)	-0.090 (0.024)	87.4 (37.8–∞)	S	S
West Fork Campbell Creek	PFBNC12	16	3.0 (0.6)	2.0 (0.3)	0.390 (0.084)	0.123 (0.062)	55.6 (16.8–∞)	S	S
Bradley Creek	PFBNC13	17	3.6 (0.6)	2.3 (0.3)	0.451 (0.085)	-0.068 (0.049)	23.9 (12.5–76.0)	M	M
North Prong Turkey Creek	PFBNC14	18	1.7 (0.3)	1.4 (0.2)	0.186 (0.075)	0.186 (0.075)	7.0 (1.0–∞)	S	S
Reasonover Creek	PFBNC15	7	3.5 (0.3)	2.5 (0.2)	0.607 (0.049)	-0.058 (0.069)	7.4 (3.0–19.6)	N	N
UT Friezland Creek	PFBNC16	20	4.8 (0.5)	3.1 (0.4)	0.617 (0.061)	0.290 (0.072)	1.6 (1.4–1.7)	S	S
Walker Branch	PFBNC17	20	3.6 (0.4)	1.9 (0.2)	0.419 (0.068)	0.221 (0.123)	1.3 (1.1–1.5)	N	N
Indian Creek	PFBNC21	20	3.2 (0.4)	1.6 (0.2)	0.303 (0.063)	0.385 (0.083)	0.6 (0.5–0.7)	S	S
South Prong Glady Fork	PFBNC24	20	2.8 (0.4)	1.3 (0.1)	0.195 (0.054)	0.279 (0.081)	0.5 (0.4–0.5)	M	M
Jane Cantrell Creek	PFBNC25	20	4.2 (0.3)	2.0 (0.2)	0.451 (0.052)	0.027 (0.049)	712.0 (40.3–∞)	M	M
Hickory Flat Creek	PFBNC26	9	1.2 (0.2)	1.2 (0.1)	0.083 (0.057)	0.346 (0.019)	NA	N	N
Laurel Branch – above falls	PFBNC27	18	1.2 (0.2)	1.1 (0.1)	0.065 (0.045)	0.331 (0.010)	NA	M	M
Laurel Branch – below falls	PFBNC28	20	5.2 (0.7)	2.5 (0.3)	0.529 (0.059)	0.063 (0.038)	16.4 (11.8–24.3)	M	M
Friezland Creek	PFBNC29	6	3.4 (0.4)	2.2 (0.3)	<b>0.507 (0.075)</b>	-0.030 (0.069)	NA	S	S
Grand mean over loci and collections		17.9 (0.3)	3.3 (0.1)	2.2 (0.1)	0.416 (0.011)	-0.021 (0.008)			

## DISCUSSION

This study was the first to investigate microsatellite loci for Brook Trout populations under management of the NCWRC. Focused upon previously uncharacterized collections as part of a larger effort to increase genetic understanding of the State's Brook Trout, molecular analyses provided a robust characterization of genetic and evolutionary relationships of these selected populations. Previous efforts to address such relationships for North Carolina's Brook Trout used protein electrophoresis (Galbreath 2002; Cornelison et al. 2005) and relied upon creatine kinase as the diagnostic locus (McCracken et al. 1993). Approximately 62.0% of the 480 collections examined previously via protein electrophoresis displayed influences of stockings.

Given the vast nature of historic stockings of Brook Trout derived from northern/Atlantic slope origin and data generated via allozyme analyses of Brook Trout populations, it was surprising to observe the apparent low impact of stockings to collections within this study. Only 39.2% (N = 20) of the collections were either assigned northern or mixed origins. Levels of supplemental (mixed collections) and restorative (northern collections) impacts within these data are encouraging.

Although the observed influence of stockings was relatively low, collections within this study appear to represent multiple categories: northern; southern; mixed with little or no introgression; and mixed with high degree of introgression. Homogenous assignment scores within collections could suggest greater introgression of northern alleles. Conversely, higher divergences of likelihood scores for assignment to either northern or southern origins may indicate limited introgression within selected collections. This detected degree of differentiation may indicate the occurrence of a recent stocking event or limited introgression of alleles and the presence of two co-existing populations. We lack information concerning all dates of stocking events for mixed populations within this study, so it is difficult to know if these observations are due to recent stockings or lack of interbreeding. Thus, more investigation is warranted to expound upon this preliminary observation.

Effects of historical stockings were also reflected within the neighbor-joining tree (Figure 2). Collections impacted by stockings formed northern or mixed

clades, while southern collections grouped together. In addition, influence of evolutionary signal was very strong within these data, so not surprisingly, collections grouped together by watershed.

Diversity statistics for collections were low compared to values throughout the species' range (King et al. 2012). However, collections impacted by stockings exhibited a higher degree of genetic diversity than collections classified as native. On average, northern and mixed collections have 4.1 (SE = 0.6) and 4.3 (SE = 0.4) alleles, respectively, while the average number of alleles for southern/interior collections is only 3.0 (SE = 0.2). These differences are likely the manifestations of introduced gene flow, or in the case of long-isolated native populations, the lack thereof.

Use of microsatellite loci and pooling both phylogeographic and hatchery collections as a baseline for assignment scores provided us with a sound methodology to examine hatchery influence and heritage within this study. We certainly recognize and appreciate the value of allozyme data to the conservation of Brook Trout; however, it is important to note that initial comparisons between allozyme and microsatellite assignments show inconsistent agreement (unpublished data set). Thus far, tissue samples from 57 collections have been compared via the two techniques and 42.1% (N = 24) of collections received different assignments than those provided by original allozyme analyses. This differentiation is important to managers as they reflect on historic data and its implications to past, present, and future conservation efforts.

## MANAGEMENT IMPLICATIONS

North Carolina's wild Brook Trout populations are restricted to headwater systems, where there are little or no opportunities for gene flow among or between populations. These processes can lead to reduced effective population sizes, lowered fitness owing to environmental stress and genetic problems such as inbreeding, and substantially increases the extinction probability of populations in changing environments. Theoretical population genetics suggests that small, fragmented populations are unlikely to remain viable for an extended period of time due to the likelihood of stochastic extinction.

This comparison was able to provide significant insight into demographic history of and

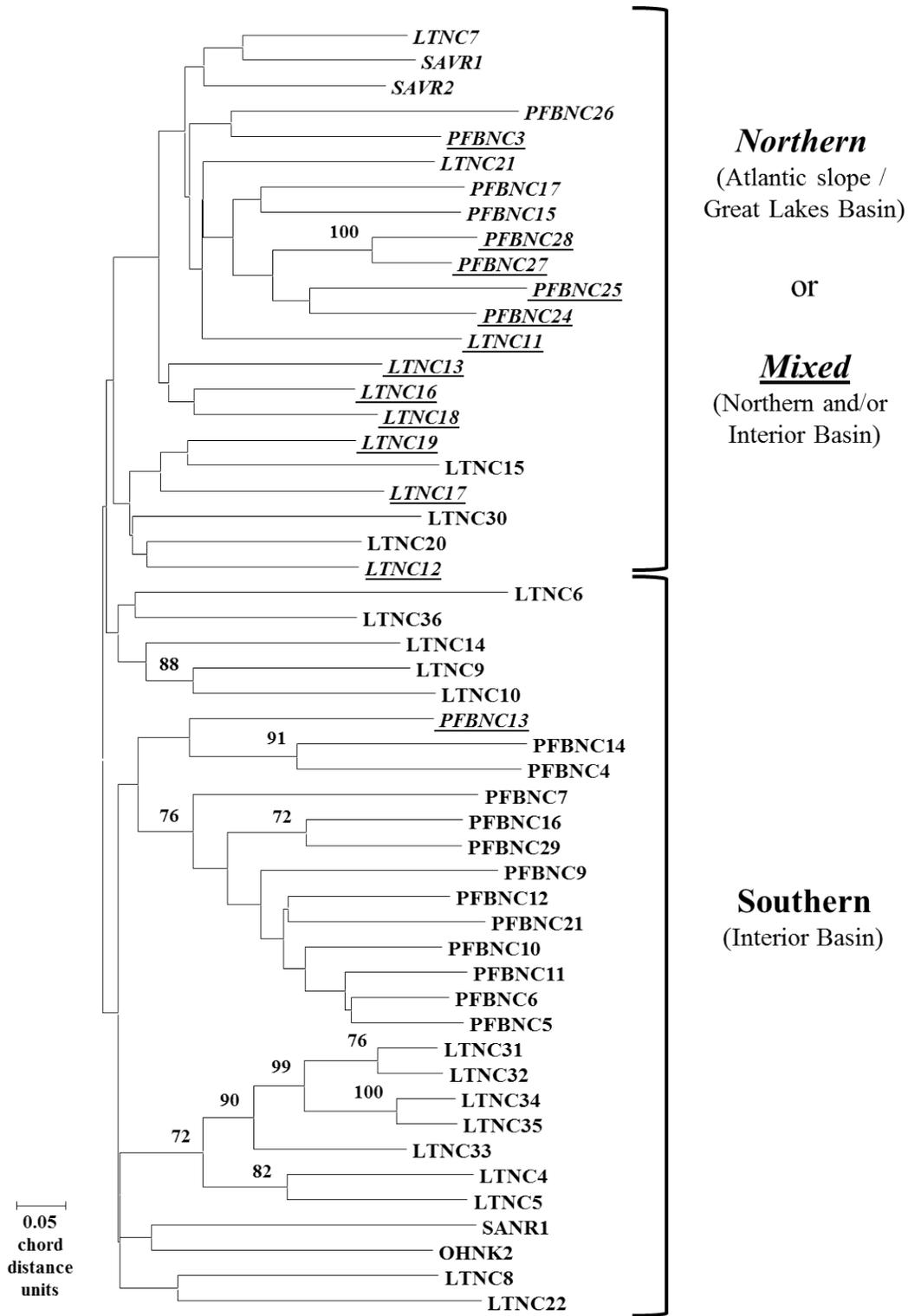


Figure 2—Neighbor joining phenogram depicting the underlying structure observed in the pairwise genetic distance (Cavalli-Sforza and Edwards chord) matrix among 51 North Carolina Brook Trout collections. Numbers indicate nodes with bootstrap support above 70% in 10,000 replications across loci. Collections assigned as northern (italics) and mixed (italics and underlined) are noted.

the evolutionary relatedness among previously uncharacterized Brook Trout populations. These data provide managers with an increased understanding of the Brook Trout populations within North Carolina; however, the collections examined within this study represent but a portion of those being examined via microsatellite DNA loci. In total, over 300 collections will be evaluated to provide a vast genetic baseline for the State's Brook Trout. By incorporating these data with those from subject areas that can have multiple-scale effects (e.g., contemporary assessments of climate change and land use patterns), managers will have valuable information to help guide management decisions. Over 600 Brook Trout populations are known within North Carolina, so that an effective conservation strategy will depend upon prioritization of limited time and resources. Ultimately, the use of and building upon data obtained within this study will assist in the efforts to conserve native Brook Trout.

Molecular data obtained within this study will prove useful as managers develop conservation strategies (Epifanio et al. 2003; SDAFSTC 2005; Jones et al. 2006). Protection and enhancement of already limited Brook Trout habitats is critical to the persistence of native populations. Results of this study will assist prioritization of those efforts by identifying those populations that are truly native, while comparisons among and between native collections will enable managers to refine that focus. Furthermore, information within this study will be central in future efforts to restore Brook Trout populations. Potential source populations for adult translocations must be evaluated as restoration opportunities arise. Should collections within this study be considered as source stocks, these data will allow managers to do more than confirm collection origin: they will assist in the selection of the preferred population to use for each translocation effort. By screening diversity statistics of potential source populations, the NCWRC can select native populations with the highest genetic diversities and effective population sizes to promote long-term success of restoration activities. Data from this study provide the initial characterizations of these populations, so managers will need to build upon them (e.g., collect additional samples to refine effective population size estimates; Whiteley et al. 2012) to effectively craft management plans.

## ACKNOWLEDGEMENTS

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## REFERENCES

- Cavalli-Sforza, L. L., and A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. *Evolution* 21:550–570.
- Cornelison, J. W., P. F. Galbreath, and T. H. Martin. 2005. Summary Report 2003–2005: genetic identification of Southern Appalachian Brook Trout populations in North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-68, Final Report, Raleigh.
- Cornuet, J. M., S. Piry, G. Luikart, A. Estoup, and M. Solignac. 1999. New methods employing multilocus genotypes to select or exclude populations as origins of individuals. *Genetics* 153: 1989–2000.
- Epifanio, J., G. Hass, K. Pratt, B. Rieman, P. Spruell, C. Stockwell, F. Utter, and W. Young. 2003. Integrating conservation genetic considerations into conservation planning. *Fisheries* 28:10–24.
- Galbreath, P. F. 2002. Genetic identification of Southern Appalachian Brook Trout populations in North Carolina. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-68, Final Report, Raleigh.
- Hudy, M., T. M. Thieling, N. Gillespie, and E. P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of Brook Trout in the eastern United States. *North American Journal of Fisheries Management* 28:1069–1085.
- Jones, J. W., E. M. Hallerman, and R. J. Neves. 2006. Genetic management guidelines for captive propagation of fresh water mussels (Unionoidea). *Journal of Shellfish Research* 25:527–535.
- King, T. L., B. A. Lubinski, M. K. Burnham-Curtis, W. Stott, and R. P. Morgan II. 2012. Tools for the management and conservation of genetic diversity in Brook Trout (*Salvelinus fontinalis*): tri- and tetranucleotide microsatellite markers for the assessment of genetic diversity, phylogeography, and historical demographics. *Conservation Genetic Resources* 4:539–543.
- McCracken, G. F., C. R. Parker, and S. Z. Guffey. 1993. Genetic differentiation and hybridization between stocked hatchery and native Brook Trout in Great Smoky Mountains National Park. *Transaction of the American Fisheries Society* 122:533–542.

- Parks, S. D. E. 2001. Trypanotolerance in West African cattle and the population genetic effects of selection. Ph.D. Dissertation, University of Dublin, Ireland.
- Peakall, R., and P. E. Smouse. 2006. GENALEX 6: genetic analysis in Excel. Population genetic software for teaching and research. *Molecular Ecology Notes* 6:288–295.
- Paetkau, D., and C. Strobeck. 1994. Microsatellite analysis of genetic variation in black bear populations. *Molecular Ecology* 3:489–495.
- Rannala, B., and J. L. Mountain. 1997. Detecting immigration by using multilocus genotypes. *Proceedings of the National Academy Sciences* 94:9197–9201.
- Raymond, M., and F. Rousset. 1995. An exact test for population differentiation. *Evolution* 49: 1280–1283.
- Rice, W. R. 1989. Analyzing tables of statistical tests. *Evolution* 43:223–225.
- Responsive Management. 2007. North Carolina trout anglers' participation in and satisfaction with trout fishing and their opinions on specific regulations. North Carolina Wildlife Resources Commission, Federal Aid in Sport Fish Restoration, Project F-86, Final Report, Raleigh.
- Saitou, N., and M. Nei. 1987. The neighbor-joining method: a new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution* 4:406–425.
- SDAFSTC (Southern Division of the American Fisheries Society Trout Committee). 2005. Managing southern Appalachian Brook Trout: a position statement. *Fisheries* 30:10–20.
- Tamura, K., D. Peterson, N. Peterson, G. Stecher, M. Nei, and S. Kumar. 2011. MEGA5: molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. *Molecular Biology and Evolution* 28:2731–2739.
- Van Oosterhout, C. V., W. F. Hutchinson, D. P. M. Wills, and P. Shipley. 2004. MICRO-CHECKER: software for identifying and correcting genotyping errors in microsatellite data. *Molecular Ecology Notes* 4:535–538.
- Waples, R. S. 2006. A bias correction for estimates of effective population size based on linkage disequilibrium at unlinked gene loci. *Conservation Genetics* 7:167–184.
- Whiteley, A. R., J. A. Coombs, M. Hudy, Z. Robinson, K. Nislow, and B. H. Letcher. 2012. Sampling strategies for estimating Brook Trout effective population size. *Conservation Genetics* 13:625–637.
- Whiteley, A. R., J. A. Coombs, M. Hudy, Z. Robinson, A. R. Colton, K. H. Nislow, and B. J. Letcher. 2013. Fragmentation and patch size shape genetic structure of Brook Trout populations. *Canadian Journal of Fisheries and Aquatic Sciences* 70:678–688.
- Wilberg, M. J., and B. P. Dreher. 2004. GENECAP: A program for analysis of multilocus genotype data for non-invasive sampling and capture-recapture population estimation. *Molecular Ecology Notes* 4:783–785.

## USING PATTERNS OF GENETIC DIVERSITY TO DETECT THE SIGNAL OF SUPPLEMENTAL AND RESTORATIVE STOCKING AMONG NATIVE BROOK TROUT POPULATIONS

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**Abstract**—The dramatic decrease in the range of Brook trout *Salvelinus fontinalis* combined with the historic use of hatchery-reared Brook Trout for supplemental and restorative stocking underscores the need to recognize the evolutionary relationship among stream populations. A suite (N=13) of microsatellite DNA markers has been surveyed of allelic variation in over 16,000 fish from 450 collections comprising the species' native range as well as, 13 hatchery populations. This survey identified evolutionary relationships among populations, yielded a wide range of allelic diversity, demonstrated high levels of genetic differentiation at all hierarchical levels studied (individual to watershed), and documented similar levels of differentiation among collections within drainages and among collections between drainage basins. Retrospective monitoring (i.e., coalescent simulations) of *S. fontinalis* populations has illuminated previously undetected demographic histories (e.g., supplemental or restorative stocking; bottlenecks) and shed light on past and future evolutionary trajectories of populations at previously intractable scales. The demographic history of each defined population is being determined through estimates of time (T; in generations) to the most recent common ancestor. This analysis also allowed determination of the demographic trend of each collection (i.e., increasing or decreasing effective population size; (r)), and provides a robust estimate of the current effective population size (Ne) for each population. The working assumption being - populations with greater T values have persisted longer and are more likely to be adapted to the physiological and immunological challenges of their current environment. In the absence of a defined suite of adapted genes, populations with greater T and Ne values would therefore serve as the more adaptable populations for use in restoration efforts.

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## BEHAVIORAL AND GENETIC DIVERSITY AMONG ECOTYPES OF LAKE SUPERIOR BROOK TROUT

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We used crosses between migrant and stream resident Brook Trout *Salvelinus fontinalis* caught from tributaries along the north shore of Lake Superior to test for genetic variation in behavioural traits believed to be tied to migratory behaviour. Two ecotypes of Brook Trout originate from tributaries in this part of Lake Superior: a large-bodied ecotype that migrates to lakes and a small-bodied ecotype that remains a stream resident. The abundance and distribution of the migrant ecotype has declined, and is the focus of conservation concern. In 2011, migrant and non-migrant adult Brook Trout were captured in the field and crossed to generate 26 families. The migratory behaviour of adult Brook Trout was determined in the field based on morphology, but was further verified using stable isotope analysis. In spring and summer of 2012 (young of the year) and 2013 (yearling), ten fish from each family were put through behavioural experiments to assess risk taking, general activity, sociability and propensity to disperse. To assess risk-taking behaviour, we used an exit chamber experiment measuring the amount of time it took an individual to exit a refuge and enter a novel environment. We measured general activity as the proportion of time an

individual spent moving. To assess social behaviour we used a mirror image stimulation test measuring the proportion of time an individual spent close to its reflection, as if it were a conspecific. To assess net displacement we used a compartmentalized dispersal chamber where we measured the net displacement of an individual from its starting compartment after 1 hour. At both developmental time points, (1) behaviours among individuals were considered repeatable, and repeatability estimates ranged from 0.05 to 0.71, (2) behaviours did not differ significantly between migrant and non-migrant cross types, (3) behaviours did differ significantly between families (4) behaviours had a heritable component, and narrow sense heritability estimates ranged from 0.04 to 0.33, and (5) there were genetic correlations between traits that ranged in value from 0.75 to 0.84. Results suggest that these behaviours have a genetic basis, but are not tied to the migratory behaviour of the parents. This research will help us understand whether the life history variation observed among Brook Trout populations in Lake Superior is due to genetic polymorphism or phenotypic plasticity, and will assist managers with efforts to conserve and restore these populations.

## STATUS ASSESSMENT OF COASTAL AND ANADROMOUS BROOK TROUT IN THE UNITED STATES

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**Abstract**—Brook Trout *Salvelinus fontinalis* in New England coastal streams can exhibit partial anadromy, but the status of Brook Trout and anadromous behavior is unknown for much of the region. We conducted a sub-watershed-scale (~12,000 ha) assessment of coastal and anadromous Brook Trout from Maine to Long Island, New York using data from regional fisheries professionals. Across 185 sub-watersheds, the status of coastal Brook Trout, and the presence of anadromous behavior, is highly variable and uncertain across New England. Brook Trout are thought to be extirpated from 40 sub-watersheds (22%), and the status is unknown in 39 (21%) sub-watersheds. There was low certainty regarding current status in 78 (42%) sub-watersheds, with a majority occurring in Maine. The status of Brook Trout was known with moderate-high certainty in at least some sub-watersheds in all states. The certainty of anadromy was low for 142 (77%) sub-watersheds, and was high for only two sub-watersheds in Massachusetts and four in Maine. This assessment can be used with other local information to initiate a regional anadromous Brook Trout conservation program focused on habitat protection and restoration, and for reducing the uncertainty of the status of coastal and anadromous Brook Trout through further targeted assessments.

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### INTRODUCTION

The Brook Trout *Salvelinus fontinalis* is a charr native to northeastern North America (Benke 2002). Brook Trout in small streams often have small home ranges, but some populations occupying interconnected habitats can exhibit seasonal movements into larger rivers (Petty et al. 2012). Brook Trout with access to lacustrine habitats can be adfluvial whereby individuals in ponds or lakes migrate into tributaries to spawn; those in Lake Superior that are adfluvial or completely lacustrine are commonly referred to as coaster Brook Trout (Schreiner et al. 2008). Populations with access to sea can exhibit partial (i.e., facultative) anadromy whereby some individuals, often called salters or sea-run Brook Trout, migrate to estuaries (or open ocean) to feed during various times of the year (Ryther 1997).

Anadromy in Brook Trout arises due to the species' propensity to move, over-production of juveniles, a physiological ability to tolerate saline environments, and the persistence of critical habitats (Curry et al. 2010). Individuals with lower food conversion efficiencies are more likely to exhibit anadromy, because prey are larger and more diverse

in saltwater environments (Morinville and Rasmussen 2003; Morinville and Rasmussen 2006), which can lead to higher growth rates (Thériault et al. 2007a). Larger Brook Trout are physiologically more tolerable of saline environments (McCormick and Naiman 1984), and of Brook Trout exhibiting anadromy, faster growing individuals typically migrate first (Morinville and Rasmussen 2003).

Vague historical accounts suggest that anadromous Brook Trout could be found in any suitable habitat to which they could return after spending a few months in salt water. This included streams as far north as Labrador's Atlantic coast and as far south as the Manasquan River, New Jersey (Karas 2002). While there are some historical accounts of specific Brook Trout populations exhibiting anadromy (Smith and Saunders 1958), little is known about historical anadromy for many watersheds within that general historical distribution. Likewise, some extant populations are known to be anadromous (Thériault et al. 2007b), but little information exists for Brook Trout in many watersheds with virtually no information on anadromous behavior.

Despite this uncertainty, anadromous Brook Trout are thought to have declined substantially due to the same factors impacting inland populations: land use, habitat deterioration and fragmentation, and nonnative species interactions (Ryther 1997; Hudy et al. 2008; Stranko et al. 2008). Given the need to move between fresh and salt water, the construction of dams and other impassable structures likely had a disproportionate impact on anadromous Brook Trout. For example, in Maine the access to riverine habitat by river herring (*Alosa pseudoharengus* and *Alosa aestivalis*) is only 20% of historical levels because of dams (Hall et al. 2011), many of which were built on coastal streams also used by anadromous Brook Trout. Competition with and predation by nonnative fishes have also been cited as reasons for declines (Ryther 1997). Last, because anadromous Brook Trout grow large from feeding in marine environs, they have been harvested for both subsistence and sport since European colonization (Smith 1833).

Our goal was to conduct a status assessment of coastal Brook Trout in the United States from Maine to New York at the sub-watershed-scale (~12,000 ha). Based on the status of Brook Trout populations, and the presence of anadromy, we identified opportunities to protect extant Brook Trout populations exhibiting anadromy, identified where anadromous Brook Trout may be restored, and identified additional assessment needs where Brook Trout information was sparse.

## METHODS

The status of coastal Brook Trout populations was assessed through data compilation (with a data review) by regional fisheries professionals (see Acknowledgements). Professionals were asked to

identify each coastal stream and river that currently has Brook Trout or was thought to have had Brook Trout historically and attribute it with information on: (1) the current status of Brook Trout, (2) the certainty associated with current status, and (3) the certainty of current anadromy. Current status was classified as Abundant, Frequently Present, Occasionally Present, Extirpated, or Unknown. Certainty of current status was classified as High, High-Moderate, Moderate, Moderate-Low, Low, and Unknown based on the type of data used to classify status (e.g., electrofishing survey, creel survey, angler logs, and anecdotal angler reports). Certainty of anadromy was classified as High, High-Moderate, Moderate, Moderate-Low, Low, and Unknown based on the quality of data used to determine the presence of anadromy (e.g., otolith microchemistry, telemetry, angler reports). The sub-watersheds in the Watershed Boundary Dataset (12-digit Hydrologic Unit Code or HUC 12; [www.nrcs.usda.gov](http://www.nrcs.usda.gov)) were then attributed accordingly with information on the current status, certainty of current status, and certainty of anadromy using the highest status or certainty level within each sub-watershed.

Next, we identified conservation and assessment strategies for each sub-watershed. The strategies were designed to mirror those defined by the Eastern Brook Trout Joint Venture ([www.easternbrooktrout.org](http://www.easternbrooktrout.org)), while considering the unique aspects of anadromous Brook Trout. To define strategies, we used information on the current status of Brook Trout, certainty of anadromy, and habitat integrity (from Trout Unlimited's Conservation Success Index; Williams et al. 2007) to identify Protect, Reconnect, Restore, Reintroduce, and Assessment (Anadromous, Population, and General) strategies at the sub-watershed scale (Figure 1; Table 1).

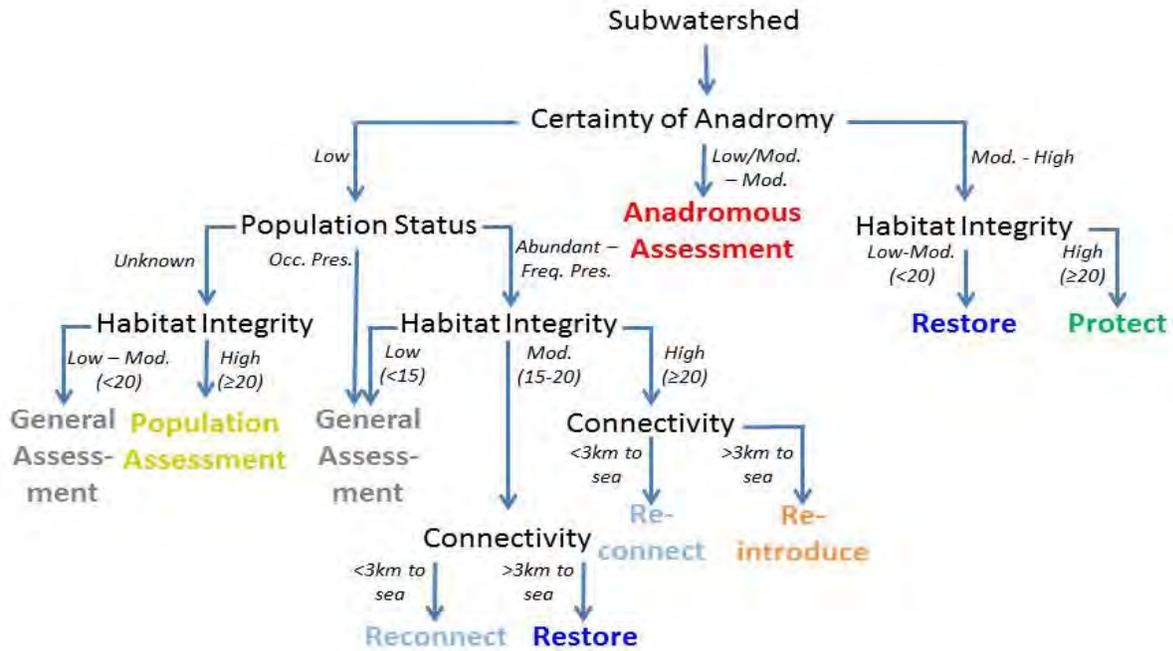


Figure 1. Flow chart used to identify general sub-watershed conservation and assessment strategies for coastal and anadromous brook trout in New England.

Table 1. Conservation and assessment strategies for coastal and anadromous brook trout in New England.

Strategy	Description
Protect	A protect strategy was defined for sub-watersheds with a moderate to high level of certainty of having anadromous Brook Trout that also has high habitat integrity indicating watershed conditions are intact.
Reconnect	A reconnect strategy was defined for sub-watersheds with a low certainty of having anadromous Brook Trout but where Brook Trout are frequently present or abundant, habitat integrity is moderate to high, and the amount of habitat connected to the sea is less than 3-km below the downstream-most dam (if present).
Restore	A restore strategy was defined for sub-watersheds with a moderate-high or high level of certainty of having anadromous Brook Trout and where habitat integrity was low to moderate-high, suggesting that some restoration could be needed to ensure the long-term persistence of anadromous Brook Trout. A restore strategy was also defined where the certainty of anadromy is low but Brook Trout are frequently present or abundant, habitat integrity is moderate-high, and connectivity to the sea was greater than 3-km.
Reintroduce	A reintroduce strategy was defined for sub-watersheds where there was low certainty regarding the presence of anadromy but where Brook Trout are frequently present or abundant and habitat integrity is high.
Anadromous assessment	In sub-watersheds where there is only a moderate level of certainty regarding the presence of anadromy, the streams in these sub-watersheds should be further assessed to confirm the presence of anadromous Brook Trout before a sub-watershed-specific conservation strategy can be identified.
Population assessment	In sub-watersheds where the current status of Brook Trout is unknown but habitat integrity is high, these sub-watersheds should be inventoried to determine both the status of Brook Trout and the presence of anadromy.
General assessment	Sub-watersheds with unknown Brook Trout status and moderate to low habitat integrity, with Brook Trout only occasionally present, or with Brook Trout present but poor habitat integrity, were defined as needing general overall assessment.

## RESULTS

Current or historical coastal Brook Trout streams were identified in 185 sub-watersheds from Maine to Long Island, New York. Ninety-four sub-watersheds were in Maine where the current status of Brook Trout was highly variable (and highly uncertain), whereas only five sub-watersheds were in Rhode Island (Table 2; Figure 2, top left panel). Brook Trout are thought to be extirpated from 40 sub-watersheds (22%), and

the status is unknown in 39 (21%) sub-watersheds. There was low certainty of current status in the majority of sub-watersheds (78 or 42%), and only one sub-watershed in New York state had a current status that was highly certain. The largest uncertainty in status was in Maine (Figure 2, top middle panel). Even more uncertain was the status of anadromy. The certainty regarding anadromy was low for 142 (77%) sub-watersheds and was unknown for 13 (7%) sub-watersheds. Only six sub-watersheds contained

**Table 2. Number of sub-watersheds by current status, certainty of current status, certainty of anadromy, conservation strategy, and assessment strategy by state.**

	Status	State						Total
		CT	MA	ME	NH	NY	RI	
Current population status	Abundant	0	3	3	0	2	0	8
	Freq. present	0	7	24	4	1	0	36
	Present	0	0	0	0	0	0	0
	Occ. present	5	12	40	0	3	2	62
	Extirpated	27	10	1	1	1	0	40
	Unknown	0	2	26	3	5	3	39
Current status certainty	High	0	0	0	0	1	0	1
	High-Mod.	20	20	10	5	5	3	63
	Moderate	12	4	6	0	4	2	28
	Mod.-Low	0	3	11	0	1	0	15
	Low	0	7	64	1	0	0	72
	Unknown	0	0	3	2	1	0	6
Anadromous certainty	High	0	2	4	0	0	0	6
	High-Mod.	0	0	0	0	0	0	0
	Moderate	0	5	10	0	2	0	17
	Mod.-Low	3	0	0	0	2	2	7
	Low	29	27	77	6	3	0	142
	Unknown	0	0	3	2	5	3	13
Conservation strategy	Protect	0	0	3	0	0	0	3
	Reconnect	0	0	1	0	0	0	1
	Restore	0	4	4	1	0	0	9
	Reintroduce	0	0	6	0	0	0	6
Assessment strategy	Population	0	0	12	0	0	0	12
	Anadromous	3	5	10	0	2	4	24
	General	29	25	58	7	10	1	130
Total sub-watersheds		32	34	94	8	12	5	185

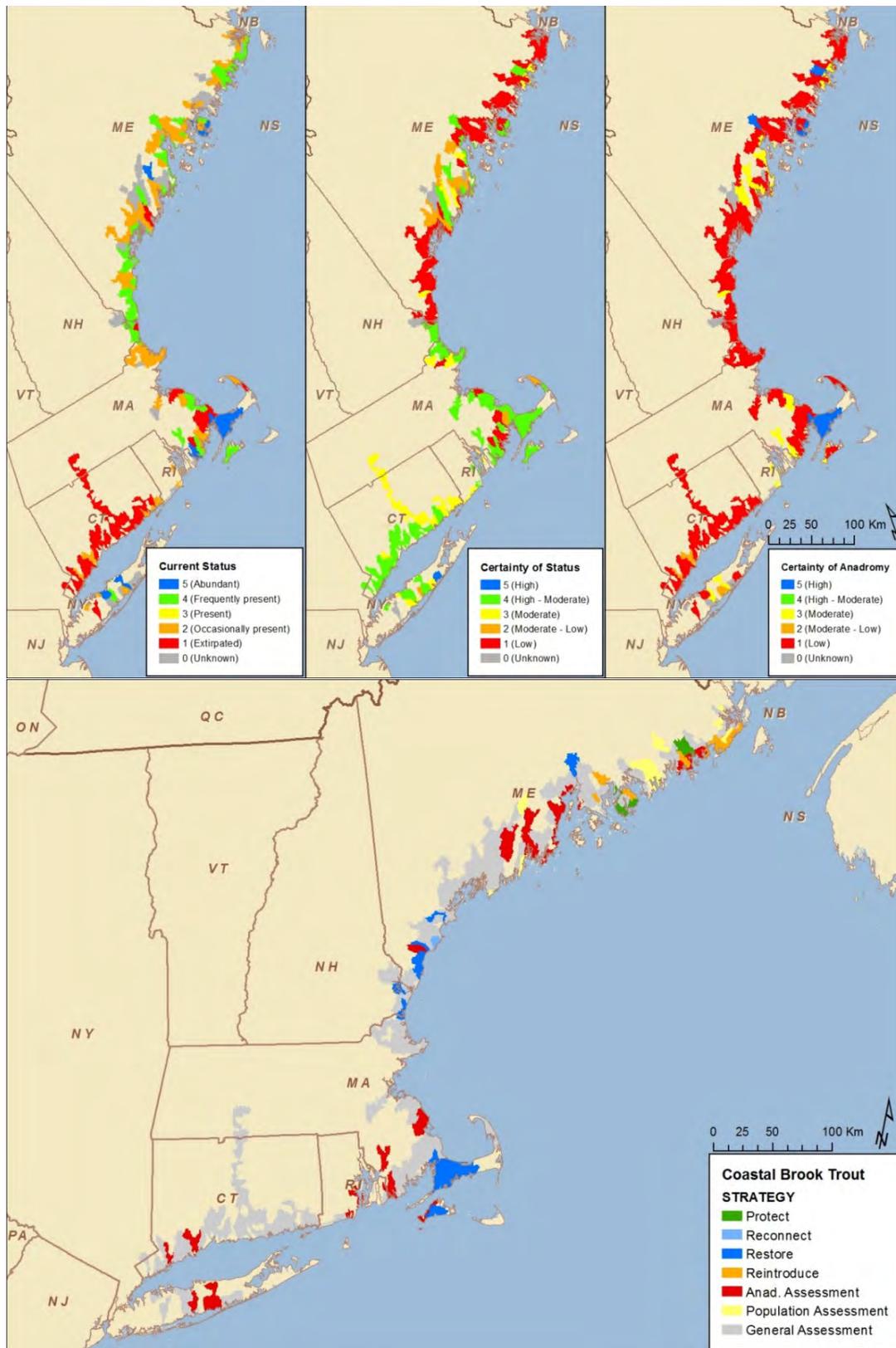


Figure 2. Coastal Brook Trout current status, certainty of current status, certainty of anadromy, and conservation and assessment strategies for coastal streams of New England.

anadromous Brook Trout with a high level of certainty – two in Massachusetts and four in Maine (Figure 2, top right panel). New Hampshire was the only state where the certainty regarding anadromy was low for all sub-watersheds.

Conservation strategies were identified for 19 sub-watersheds in New England, with Restore being the most commonly identified strategy (9 sub-watersheds) and Reintroduce being the next most common strategy (6 sub-watersheds; Table 2). The only protection strategies identified were for sub-watersheds in Maine, including those that already have some level protection (e.g., Acadia National Park; Figure 2 bottom panel). There are many sub-watersheds with further assessment needs based on the uncertainty regarding Brook Trout status and anadromy (Table 2; Figure 2, bottom panel).

## DISCUSSION

This assessment represents the first attempt to document the extent of coastal and anadromous Brook Trout at a sub-watershed scale (~12,000 ha) in the United States. The status of coastal Brook Trout in New England streams has declined since pre-colonial times (Ryther 1997), but our assessment data showed there is still a large amount of uncertainty regarding even the current status of populations; over two-thirds of all streams had little or no information on Brook Trout. Likewise, the status of an anadromous life history is thought to have declined faster than resident populations (Ryther 1997), but there is even more uncertainty surrounding the status of anadromy. Clearly there is a need to assess many coastal streams for extant populations and whether they exhibit anadromy. However, identifying anadromy at a regional scale will be difficult and costly unless new, cost efficient techniques are developed.

Despite the uncertainty in status, the conservation strategies we identified can offer some guidance to where watershed protection and restoration efforts could be focused. The strategies identified here focus on protecting abundant Brook Trout, Brook Trout populations exhibiting anadromy, and watersheds with intact habitat – strategies similar to those defined by the Eastern Brook Trout Joint Venture for inland populations. The strategies with the most uncertainty surrounding them are those where Brook Trout are abundant and habitat restoration or reconnection could result in the re-emergence of anadromy. However,

it is not clear if and when anadromy will emerge in populations, as efforts in this area have just begun with the first successful anadromous Brook Trout reintroduction in the Childs River, Massachusetts (Hurley 2011). Genetics data suggest that Brook Trout do not move between systems very often, except between tributaries with a common estuary (Annett et al. 2012). This suggests that re-emergence of anadromy from colonizers or strays from neighboring systems post restoration (or reconnection) is not likely without nearby source populations. While not prescriptive, these strategies are intended to suggest how different assessment information can be parsed to identify the general strategies needed in a particular sub-watershed, and this assessment information represents a starting point – to be used with local data and in coordination with local partners - to develop regional conservation strategies for anadromous Brook Trout (Hudy et al. 2008).

As an example, the Red Brook sub-watershed (Cape Cod, Massachusetts) has a Brook Trout population that is abundant, with a high certainty of anadromous behavior, because of ongoing research and monitoring associated with restoration projects (Snook et al. 2012). The conservation strategy identified for the sub-watershed was Restore because while the Brook Trout are abundant and exhibiting anadromous behavior, there are threats on the landscape to in-stream habitat and habitat restoration is needed to ensure long-term persistence. In fact, there have been ongoing restoration and land protection efforts in Red Brook for 25 years. This multi-faceted project has focused largely on habitat restoration (e.g., fish passage and cranberry bog restoration), but has also included land protection measures (e.g., establishment of the Red Brook Wildlife Management Area) and research. Other projects focused on restoration of anadromous Brook Trout are occurring throughout New England, ranging from fish passage projects near Acadia National Park in Maine, to restoration projects on two famous Brook Trout rivers on Long Island, New York – the Carmans and Connetquot rivers.

The Native Fish Conservation Area (NFCA) concept has application to the conservation of anadromous Brook Trout in New England. The concept focuses on cooperative management and restoration of watersheds for long-term persistence of native aquatic communities (Williams et al. 2011). Brook Trout are an indicator of watershed health

(Stranko et al. 2008), and managing entire watersheds for anadromous Brook Trout is likely to benefit other native species, especially diadromous fishes. Existing protected areas such as Acadia National Park, Cape Cod National Seashore, and Waquoit Bay National Estuarine Research Reserve already exist to anchor watersheds as NFCAs, including some currently inhabited by anadromous Brook Trout. Other watersheds may need to be cooperatively managed across complex patchworks of public and private lands, and the NFCA concept provides a framework for cooperative watershed management in these complex environs. Anadromous Brook Trout still persist in New England despite four centuries of anthropogenic development. This suggests that a strategic conservation program, potentially using the NFCA concept as a guiding framework and Red Brook as a model watershed, could enhance anadromous Brook Trout conservation across New England.

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## REFERENCES

- Annett, B., G. Gerlach, T. L. King, and A. R. Whiteley. 2012. Conservation genetics of remnant coastal brook trout populations at the southern limit of their distribution: population structure and effects of stocking. *Transactions of the American Fisheries Society* 141:1399-1410.
- Benke, R. J. 2002. *Trout and salmon of North America*. The Free Press, New York.
- Curry, R. A., L. Bernatchez, F. Jr. Whoriskey, and C. Audet. 2010. The origins and persistence of anadromy in brook charr. *Reviews in Fish Biology and Fisheries* 20:557-570.
- Hall, C. J., A. Jordann, and M. G. Frisk. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrological longitudinal connectivity. *Landscape Ecology* 26:95-107.
- Hudy, M., T. M. Thieling, N. G. Gillespie, and E. P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. *North American Journal of Fisheries Management* 28:1069-1085.
- Hurley, S. 2011. Restoration of a salter brook trout population to the Childs River, a Waquoit Bay tributary. Abstract of Southern New England Chapter, American Fisheries Society 2011 Winter Meeting, Woods Hole Oceanographic Institute, Redfield Auditorium Woods Hole, Massachusetts.
- Karas, N. 2002. *Brook trout*, second edition. The Lyons Press, Guilford, Connecticut.
- McCormick, S.D., and R.J. Naiman. 1984. Osmoregulation in the brook trout, *Salvelinus fontinalis*. II. Effects of size, age and photoperiod on seawater survival and ionic regulation. *Comparative Biochemistry and Physiology* 79A:17-28.
- Morinville, G. R., and J. B. Rasmussen. 2003. Early juvenile bioenergetic differences between anadromous and resident brook trout (*Salvelinus fontinalis*). *Canadian Journal of Fisheries and Aquatic Sciences* 60:401-410.
- Morinville, G. R., and J. B. Rasmussen. 2006. Marine feeding patterns of anadromous brook trout (*Salvelinus fontinalis*) inhabiting an estuarine river fjord. *Canadian Journal of Fisheries and Aquatic Sciences* 63:2011-2027.
- Petty, J. T., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook trout movement in response to temperature, flow, and thermal refugia within a complex Appalachian riverscape. *Transactions of the American Fisheries Society* 141:1060-1073.
- Ryther, J. H. 1997. *Anadromous brook trout: biology, status and enhancement*. Trout Unlimited, Arlington, Virginia.
- Schreiner, D. R., K. I. Cullis, M. C. Donofrio, G. J. Fischer, L. Hewitt, K. G. Mumford, D. M. Pratt, H. R. Quinlan, and S. J. Scott. 2008. Management perspectives on coaster brook trout rehabilitation in the Lake Superior Basin. *North American Journal of Fisheries Management* 28:1350-1364.
- Smith, J. V. C. 1833. *Natural history of the fishes of Massachusetts, embracing a practical essay on angling*. Allen and Ticnor, Boston, Massachusetts.
- Smith, M. W., and J. W. Saunders. 1958. Movements of brook trout, *Salvelinus fontinalis* (Mitchill) between and within fresh and salt water. *Journal of the Fisheries Research Board of Canada* 15:1403-1449.
- Snook, E.L., A.J. Danylchuk, B.H. Letcher, A.R. Whitely, T. Dubreuil, and S. Hurley. 2012. Movement patterns of anadromous brook trout in a restored coastal stream

- system in southern Massachusetts. Abstract for 142<sup>nd</sup> Annual Meeting of the American Fisheries Society, St. Paul, Minnesota.
- Stranko, S. A., R. H. Hilderbrand, R. P. Morgan II, M. W. Staley, A. J. Becker, A. Roseberry-Lincoln, E. S. Perry, and P. T. Jacobson. 2008. Brook trout declines with land cover and temperature changes in Maryland. *North American Journal of Fisheries Management* 28:1223-1232.
- Thériault, V., D. Garant, L. Bernatchez, and J. J. Dodson. 2007a. Heritability of life-history tactics and genetic correlation with body size in a natural population of brook charr (*Salvelinus fontinalis*). *Journal of Evolutionary Biology* 20:2266-2277.
- Thériault, V., L. Bernatchez, and J. Dodson. 2007b. Mating system and individual reproductive success of sympatric anadromous and resident brook charr, *Salvelinus fontinalis*, under natural conditions. *Behavioral Ecology and Sociobiology* 62:51-65.
- Williams, J. E., A. L. Haak, N. G. Gillespie, and W. T. Colyer. 2007. The Conservation Success Index: synthesizing and communicating salmonid condition and management needs. *Fisheries* 32:477-492.
- Williams, J. E., R. N. Williams, R. F. Thurow, L. Elwell, D. P. Philipp, F. A. Harris, J. L. Kershner, P. J. Martinez, D. Miller, G. H. Reeves, C. A. Frissell, and J. R. Sedell. 2011. Native Fish Conservation Areas: a vision for large-scale conservation of native fish communities. *Fisheries* 36:267-277.

## GILL LICE AS A PROXIMATE CAUSE OF BROOK TROUT LOSS UNDER CHANGING CLIMATIC CONDITIONS

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**Abstract**—Ongoing and future changes in climate are expected to impact stream temperatures and ultimately native Brook Trout *Salvelinus fontinalis* presence in Wisconsin streams. While climate change may be the ultimate cause of Brook Trout population declines or local extinctions, proximate causes may involve factors other than intolerance to high temperatures. Here we present data to support the hypothesis that species interactions between Brook Trout, Brown Trout, *Salmo trutta* and gill lice in the context of changing environmental conditions can lead to declines in Brook Trout recruitment and possibly extirpation. The gill lice species infecting Wisconsin Brook Trout is *Salmincola edwardsii*. *S. edwardsii* do not infect Brown Trout. Gill lice were recently documented in Ash Creek, Wisconsin in 2010 and became enzootic in 2012. Conditions in 2012 conducive to an increased prevalence of gill lice included unseasonably warm stream temperatures in March, drought conditions through summer, and a sympatric Brown Trout population effecting locally-high densities of Brook Trout. Infection prevalence for Brook Trout age  $\geq 1$  increased from 42% in April 2012 to 95% in October; 94% of age-0 Brook Trout in October were also infected. Infection intensity ranged up to 11 gill lice per age-0 trout and up to 70 per trout age 1 and older. Brook Trout (but not Brown Trout) recruitment in Ash Creek in 2012 was significantly less than expected based on long-term stock-recruitment data. Given the high infection prevalence and intensity among age-0 Brook Trout and their poor condition going into winter, we expected to see a decline in the Brook Trout population in 2013, which was evident in our spring survey. We present additional data from other sympatric trout populations in Wisconsin streams in which Brook Trout have declined or become extirpated, which supports the hypothesis that species interactions among trout and parasitic gill lice under stressful environmental and ultimately climatic conditions can be a proximate cause of native Brook Trout loss.

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### INTRODUCTION

The climate in Wisconsin has been warming in recent decades and this warming trend is expected to continue and intensify in coming years (WICCI 2011). These changes in climate are expected to impact stream temperatures and the distribution of stream fishes across Wisconsin, including the presence of Brook Trout *Salvelinus fontinalis*, which are native to Wisconsin streams (Lyons et al. 2010; Mitro et al. 2010; Mitro et al. 2011; Stewart et al. 2014).

Climate change may be thought of as an ultimate cause in the loss of trout because trout are physiologically incapable of living for extended periods of time at elevated temperatures outside of a defined tolerance zone (Elliott 1994; Wehrly et al. 2007). Proximate or primary causes may be defined as factors that are immediately responsible for some observed effect. A proximate cause of trout loss may in fact be intolerance to high temperatures, but other changes in the aquatic environment, ecological community, and individual behaviors

may also act as proximate causes of trout loss prior to water temperatures elevating beyond thermal tolerance limits. Cahill et al. (2013) recently reviewed 136 studies that associated climate change with local extinctions or declines in various species. In only 7 studies was a proximate cause identifiable, none of which included limited tolerances to high temperatures. Rather, proximate causes of local extinctions and declines were attributed to species interactions such as declines in prey species and increases in the spread of disease (Cahill et al. 2013).

Anecdotal observations by anglers and Wisconsin DNR fisheries biologists suggest a trout parasite commonly called gill lice may be infecting more fish and spreading to more streams. The gill louse species infecting Wisconsin Brook Trout is *Salmincola edwardsii* (Figure 1). *S. edwardsii* is an external parasitic copepod that only infects *Salvelinus* species such as Brook Trout and likely coevolved with Brook Trout given its host specificity. Brown Trout *Salmo trutta*, which occur in sympatry with Brook Trout in

many Wisconsin streams, are not susceptible to *S. edwardsii* infection.

The gill louse life cycle includes four larval stages and one adult stage. Egg sacs release free-swimming larvae known as copepodids. After finding a host, the copepodids will molt several times and attain maturity in 3-8 days after hatching for males and in 4-20 days for females. The female life cycle is complete in about 28-30 days. Egg development time is dependent on temperature, occurring faster under warmer conditions within the confines of a coldwater environment. There is a concern that climate warming may effect more complete life cycles of gill lice in a given annual period, which may lead to greater prevalence and intensity of infection. Mature gill lice remain permanently attached to gill arches and the branchial cavity and may accumulate over time.

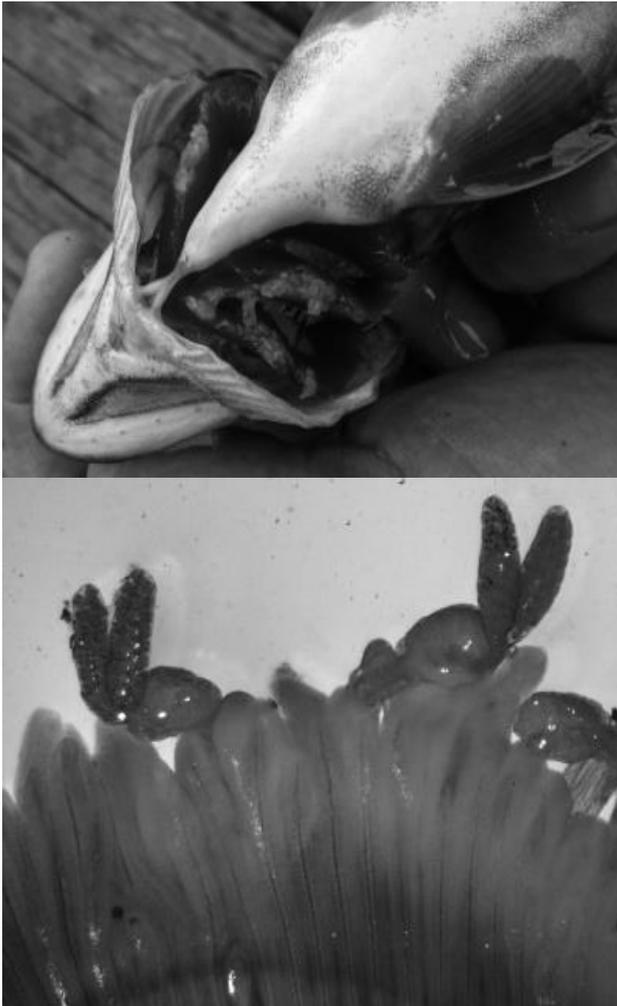


Figure 1. Brook Trout infected with gill lice *Salmincola edwardsii* (top) and close-up of *S. edwardsii* on gill filaments (bottom).

Gill lice can cause significant physical trauma to the gill filaments. Resulting deformities may affect respiration and efficient uptake of oxygen and release of carbon dioxide, ammonia, and other metabolites. Heavily infected Brook Trout may not be able to obtain sufficient oxygen when they are exercised, such as when caught by angling. Respiration may be particularly difficult for infected fish when water temperatures are high and dissolved oxygen levels are low. There is a concern that high rates of infection may slow the physiological processes of growth and sexual maturation, which in turn may negatively affect Brook Trout population growth rates.

Here we present data from an ongoing study of a Wisconsin trout stream to support the hypothesis that species interactions between Brook Trout, Brown Trout, and gill lice in the context of changing environmental conditions may lead to declines in Brook Trout recruitment and possibly extirpation. We have been monitoring the Brook Trout and Brown Trout populations in Ash Creek, Wisconsin since 2004 as part of a study on the long-term viability of source populations of wild trout for Wisconsin's trout stocking program (Mitro 2004). Gill lice were recently documented in Ash Creek in 2010 and became epizootic in 2012. We will use long-term monitoring data of trout abundance, the relation between stock size and recruitment, and environmental data related to climate change to show how species interactions in Ash Creek have the potential to be a proximate cause of Brook Trout loss in Wisconsin streams.

## METHODS

The Ash Creek study area is about 2 km long and flows through a 143-ha recreation area. The land in the recreation area is undeveloped and comprises a mixture of managed forest and prairie. Ash Creek is characterized by a series of pools (4-8 m wide) separated by riffles and runs (2-3 m wide) and a base flow that ranges from 0.05 to 0.10 m<sup>3</sup>/s.

We estimated the stream-wide abundance of Brook Trout and Brown Trout in Ash Creek each spring (April) and autumn (October) from autumn 2004 to spring 2013. We estimated the abundance of all trout at each of three sampling stations (133, 142, and 192 m) by three pass removal and extrapolated these estimates stream-wide. We used a single-pulsed DC backpack electrofisher to catch and remove all trout on three

successive passes through each station and estimated abundance using the Zippin removal estimator. We used block nets at either end of each station to prevent trout from entering or leaving a station during sampling.

The Brown Trout population in Ash Creek was suppressed by mechanical removal by Wisconsin DNR Fisheries Management through 2006 (removal following our October sampling) and in 2011-2012 (removal during June); no Brown Trout were removed in 2007-2010.

We estimated Brook Trout stock size as the number of eggs potentially spawned in Ash Creek in 2004-2011, which was based on estimates of female abundance and fecundity. Fecundity was estimated from Ash Creek Brook Trout spawned by Wisconsin DNR hatchery personnel each autumn. We estimated recruitment as the total abundance of age-0 Brook Trout in autumn 2005-2012.

We inspected Brook Trout for the presence of gill lice beginning in spring 2012. Infection prevalence was a measure of the percentage of Brook Trout infected with gill lice and infection intensity was a measure of the number of gill lice infecting individual trout. We counted the number of gill lice (up to 20) present on live fish during sampling, and any fish with more than 20 gill lice was noted as such. Individual gill lice were also counted for a sample of 30 male and 26 female Brook Trout that were killed and taken to a laboratory for fish health diagnostics in November 2012.

We obtained year-round hourly measurements of stream temperature and water level in Ash Creek and air temperature near Ash Creek from 2009 to 2013 using HOBO® U20 Water Level Loggers.

## RESULTS

Gill lice were documented in Ash Creek in 2010 and became enzootic in 2012. Wisconsin DNR Fish Health Specialist Sue Marcquenski noted in her autumn 2010 fish health diagnostics of Ash Creek Brook Trout that, “at least 4 of the 60 fish had *Salmincola* infections,” and in 2011, “virtually all 60 fish were infected.” Infection prevalence increased from 42% of all Brook Trout inspected in April 2012 to 95% in October, including 94% of age 0 Brook Trout (Table 1).

We counted the number of gill lice on 93 infected age-0 Brook Trout and 67 infected age-1 and older Brook Trout in October 2012. The intensity of infection ranged from 1 to 11 gill lice per age-0 Brook Trout (average=5); the range was from 2 to more than 20 gill lice per Brook Trout age 1 and older (Figure 2). A laboratory examination of 30 male and 26 female adult Brook Trout revealed infection intensities up to 70 gill lice on an individual trout (Figure 3).

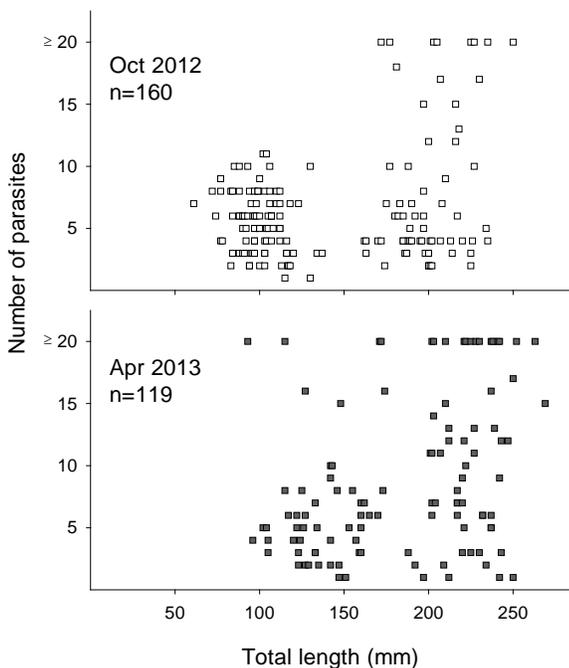
Brook Trout (but not Brown Trout) recruitment in Ash Creek was significantly less than expected in 2012 based on long-term stock-recruitment data. Stock-recruitment data for Ash Creek Brook Trout

**Table 1. Number of Brook Trout in Ash Creek observed with and without gill lice and infection rates for spring 2012, autumn 2012, and spring 2013 surveys.**

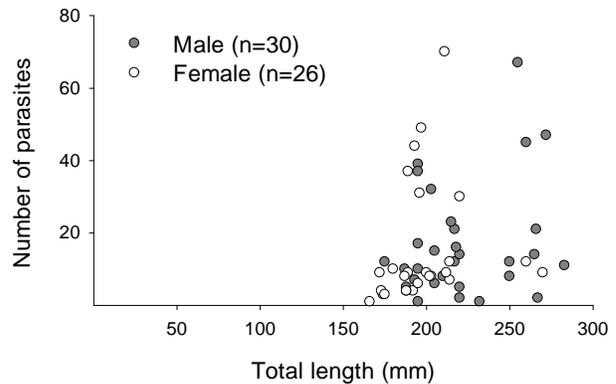
	Total no. of Brook Trout	No. without gill lice	No. with gill lice	Infection rate
<b>2-3 April 2012</b>				
Age 1	240	131	109	45%
Age ≥2	72	51	21	29%
All ages	312	182	130	42%
<b>1-2 October 2012</b>				
Age 0	115	7	108	94%
Age ≥1	155	7	148	95%
All ages	270	14	256	95%
<b>3, 22 April 2013</b>				
Age 1	50	9	41	82%
Age ≥2	83	5	78	94%
All ages	133	14	119	89%

suggested an average recruitment level over a broad range of stock size, with the average level varying over time (Figure 4). Recruitment in 2012 was about 71% lower than the average recruitment level observed for 2007-2011 and about 87% lower than that observed for 2005-2006.

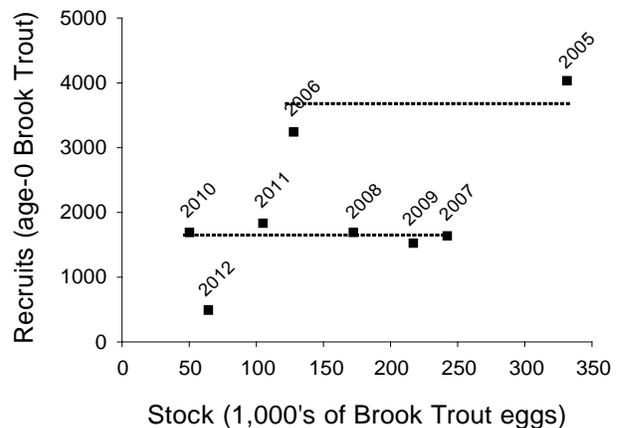
The recruitment of age-0 Brown Trout was significantly greater than the recruitment of age-0 Brook Trout in 2011 and 2012 (Figure 5A). Whereas Brook Trout recruitment decreased significantly in 2012 versus 2011, Brown Trout recruitment did not (Figure 5A). Prior to 2011, Brown Trout recruitment was significantly less than Brook Trout recruitment. The abundances of age 1 and older Brook Trout and Brown Trout were about equal in October 2009 (Figure 5B), and by April 2010 the abundance of Brown Trout exceeded that of Brook Trout (Figure 6). Following the renewal of Brown Trout removal in June 2011, the abundance of age 1 and older Brown Trout declined to previous levels in October 2011 and 2012 (Figure 5B), but remained greater compared to Brook Trout in April 2012 and 2013 (Figure 6).



**Figure 2.** Number of gill lice parasites per Brook Trout (total length in mm) in Ash Creek, Wisconsin in October 2012 (n=160) and April 2013 (n=119).



**Figure 3.** Number of gill lice parasites per male (n=30) and female (n=26) Brook Trout (total length in mm) in fish health check samples from Ash Creek, Wisconsin in November 2012.



**Figure 4.** Stock-recruitment relationship for Ash Creek Brook Trout with stock measured as 1,000's of eggs (2004-2011) and recruitment measured as age-0 Brook Trout abundance in October (2005-2012). Years on the graph indicate the year in which recruitment was measured. Dotted lines indicate hypothesized stock-recruitment relationships.

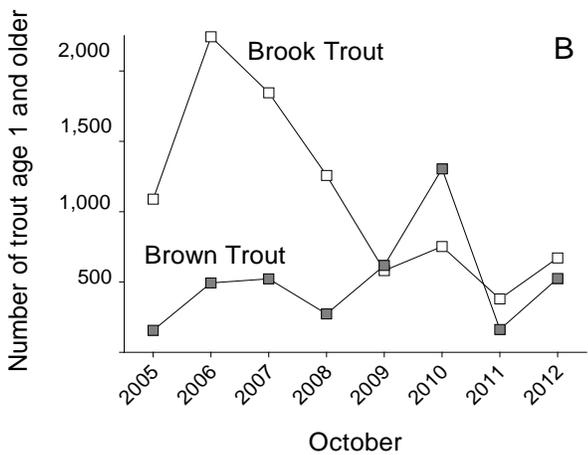
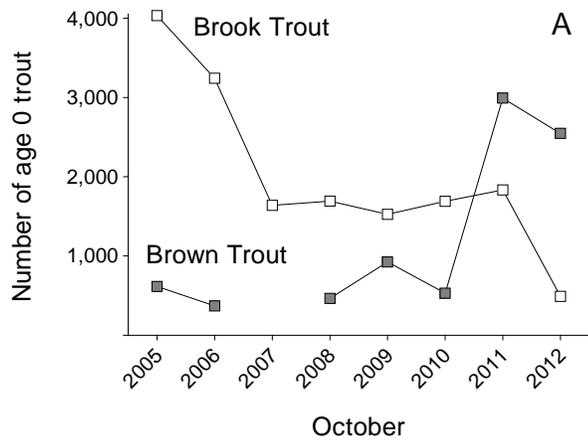


Figure 5. Number of age 0 trout (A) and number of trout age 1 and older (B) in Ash Creek, Wisconsin in autumn 2005-2012.

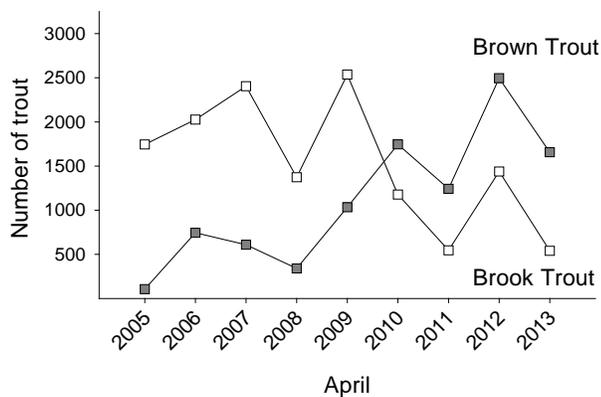


Figure 6. Number of Brook Trout and Brown Trout (age 1 and older) in Ash Creek, Wisconsin in April 2005-2013.

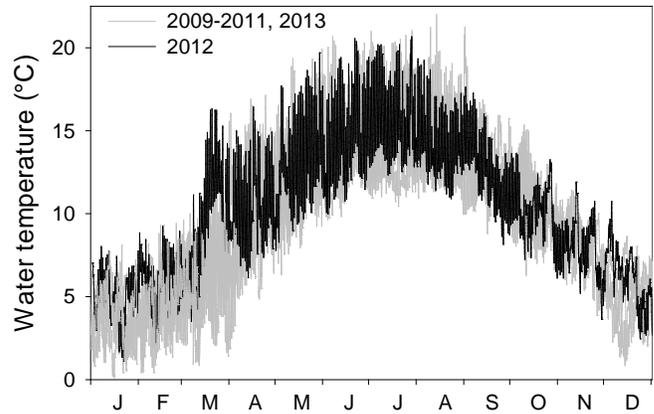


Figure 7. Hourly water temperature (°C) in Ash Creek, Wisconsin, for 2009-2013. Letters under the graph indicate months of the year from January to December.

Stream temperatures observed in Ash Creek in March 2012 were significantly greater than stream temperatures typically observed at that time in other years (Figure 7). The average stream temperature for 10-31 March was 10.4 °C in 2012 versus 6.5, 7.2, 5.6, and 4.4 °C in 2009-2011 and 2013. Drought conditions also persisted through spring and summer 2012, with no recorded flood events.

## DISCUSSION

Stock-recruitment data for Brook Trout in Ash Creek suggest that stock size has not limited recruitment; rather, recruitment is relatively fixed over a broad range of stock sizes with the level of recruitment varying in response to changes in environmental conditions. The variation in the Ash Creek stock-recruitment data as depicted by the two hypothesized stock-recruitment relationships in Figure 4 may be explained by precipitation events and interspecific interactions between Brook Trout, Brown Trout and gill lice. Large-scale flooding events occurred in Ash Creek and other southwestern Wisconsin streams in August 2007 and June 2008. Recruitment in 2007 and 2008 was lower than in previous years in which large-scale flooding did not occur. Stock sizes in 2006 and 2007 were intermediate to stock sizes in previous years in which higher levels of recruitment were observed. Such flooding events may limit recruitment via the loss of the more vulnerable age-0 trout.

No large-scale flooding events occurred after 2008, and we had expected that recruitment would return to higher levels previously observed. This was not the case, as recruitment of age-0 Brook Trout in 2009, 2010, and 2011 was similar to that in 2007 and 2008. Although flooding did not occur during these latter years, the abundance of Brown Trout had increased significantly (Figures 5 and 6) and may have acted to suppress Brook Trout recruitment. WDNR Fisheries Management had ceased the annual removal of Brown Trout out of Ash Creek after 2006 following the restrictions imposed on fish transfers by new rules in response to viral hemorrhagic septicemia being found in Wisconsin. In the absence of removal, Brown Trout numbers began to increase and soon exceeded Brook Trout in abundance. We arranged to resume the removal of Brown Trout in 2011 and 2012 and, should we be able to sufficiently suppress Brown Trout numbers again, we will determine if this competitive release will allow for increases in Brook Trout recruitment to levels last seen in 2006.

Given the observed stock size in 2011 (greater than in 2009 and less than in 2010) and environmental conditions similar to the previous five years (no major floods but continued presence of Brown Trout), we hypothesized that recruitment would remain relatively unchanged compared to the 2007-2011 time frame. A significant change occurred, however, with the presence of gill lice, which became enzootic in Ash Creek during 2012. Recruitment as measured in our October 2012 survey of age-0 Brook Trout was significantly lower than expected, and this low recruitment level may be attributable to the 94% gill lice infection rate among age-0 Brook Trout. Brown Trout, by contrast, exhibited relatively strong recruitment (Figure 5A), particularly given the suppression of Brown Trout stock size.

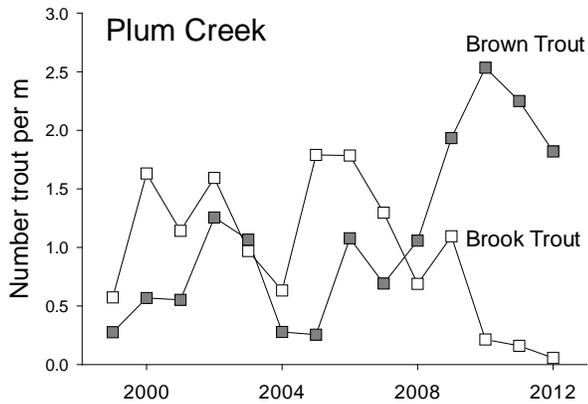
There are a number of reasons that may explain why gill lice infections became widespread in Ash Creek in 2012. Environmental conditions in 2012 conducive to the gill lice life cycle included unseasonably warm stream temperatures in March (Figure 7) and drought conditions through summer. The unseasonably warm stream temperatures in March 2012 may have stimulated gill lice maturation and reproduction (Conley and Curtis 1993), resulting in a greater number of completed life cycles over the course of the year and thus more opportunities for trout to become infected. Higher densities of host fish

and lower rates of stream flow may also contribute to increase success rates for larval attachment to gills. Gill lice larvae have a free-swimming stage during which they must find and attach to a host. Lower stream flow may improve the chances of the parasite finding a host, whereas higher flows associated with precipitation events or possibly higher base flow may disrupt this process.

Brook Trout abundance in Ash Creek in 2012 was not particularly high compared to previous years (Figure 5), but we hypothesize that the presence of Brown Trout may have effected locally-high densities of Brook Trout. Brook Trout and Brown Trout do not naturally occur in sympatry, and their co-occurrence may lead to interspecific competition and habitat segregation (Hearn 1987). In laboratory studies of native Brook Trout and hatchery Brown Trout, DeWald and Wilzbach (1992) found that the presence of Brown Trout resulted in changes in Brook Trout behavior. Brook Trout shifted location, lost weight, and were more susceptible to disease in the presence of Brown Trout. The authors suggested that if these changes in behavior and growth rates extended to sympatric populations in streams, they may help explain observed declines in native Brook Trout populations. Therefore, the presence of Brown Trout in Ash Creek may have facilitated the colonization of gill lice in Ash Creek.

More data are needed to confirm the extent to which gill lice are a factor in Brook Trout loss in sympatric trout populations. Wisconsin DNR stream survey data support this contention. Brook Trout and Brown Trout co-occur in Plum Creek, Wisconsin with relative abundances varying in approximate synchrony from 1999 to 2007 (Figure 8). Thereafter, gill lice were observed in the Brook Trout population, Brown Trout abundance increased significantly, and Brook Trout abundance decreased to near-extirpation (WDNR, unpublished data).

Ectoparasitic copepods have long been considered a threat to wild and farmed salmonids in the marine environment and have been implicated in the decline of wild populations via reduced juvenile survival (Krkosek and Hilborn 2011). Here we have presented data to support the hypothesis that a similar parasite in the freshwater environment, in combination with changing climatic conditions, can also act as a proximate cause of salmonid population loss. We are continuing our studies of gill lice impacts on Brook



**Figure 8. Number of Brook Trout and Brown Trout in Plum Creek, Wisconsin from 1999 to 2012.**

Trout in Wisconsin streams to better understand the interactions of gill lice infection and trout growth, survival and recruitment.

## REFERENCES

- Cahill, A. E., M. E. Aiello-Lammens, M. C. Fisher-Reid, X. Hua, C. J. Karanewsky, H. Y. Ryu, G. C. Sbeglia, F. Spagnolo, J. B. Waldron, O. Warsi, and J. J. Wiens. 2013. How does climate change cause extinction? *Proceedings of the Royal Society B* 280:20121890.
- Conley, D. C., and M. A. Curtis. 1993. Effects of temperature and photoperiod on the duration of hatching, swimming, and copepodid survival of the parasitic copepod *Salmincola edwardsii*. *Canadian Journal of Zoology* 71:972-976.
- DeWald, L., and M. A. Wilzbach. 1992. Interactions between native Brook Trout and hatchery Brown Trout: effects on habitat use, feeding, and growth. *Transactions of the American Fisheries Society* 121: 287-296.
- Elliott, J. M. 1994. *Quantitative ecology and the Brown Trout*. Oxford University Press, New York.
- Hearn, W. E. 1987. Interspecific competition and habitat segregation among stream-dwelling trout and salmon: a review. *Fisheries* 12(5):24-31.
- Krkosek, M., and R. Hilborn. 2011. Sea lice (*Lepeophtheirus salmonis*) infestations and the productivity of pink salmon (*Oncorhynchus gorbuscha*) in the Broughton Archipelago, British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 68:17-29.
- Mitro, M. G. 2004. Stocking trout of wild parentage to restore wild populations: an evaluation of Wisconsin's wild trout stocking program. Pages 255-264 in S. E. Moore, R. F. Carline, and J. Dillon, editors. *Working together to ensure the future of wild trout: Proceedings of Wild Trout VIII*. Yellowstone National Park, Wyoming.
- Mitro, M., J. Lyons, and S. Sharma. 2011. Wisconsin Initiative on Climate Change Impacts: Coldwater Fish and Fisheries Working Group Report. 31 pages. <http://www.wicci.wisc.edu/report/Coldwater-Fish-and-Fisheries.pdf>
- Stewart, J. S., S. M. Westenbroek, M. G. Mitro, J. D. Lyons, L. Kammel, and C. A. Buchwald. 2014. A model for evaluating stream temperature response to climate change in Wisconsin. USGS Scientific Investigations Report 2014-5186.
- Mitro, M. G., J. Lyons, and J. Stewart. 2010. Predicted effects of climate change on the distribution of wild Brook Trout and Brown Trout in Wisconsin streams. Pages 69-76 in R. F. Carline and C. LoSapio, editors. *Conserving wild trout: Proceedings of Wild Trout X*. Bozeman, Montana.
- Lyons, J., J. S. Stewart, and M. Mitro. 2010. Predicted effects of climate warming on the distribution of 50 stream fishes in Wisconsin, U.S.A. *Journal of Fish Biology* 77:1867-1898.
- Wehrly, K. E., L. Wang, and M. G. Mitro. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuation. *Transactions of the American Fisheries Society* 136:365-374.
- WICCI (Wisconsin Initiative on Climate Change Impacts). 2011. *Wisconsin's Changing Climate: Impacts and Adaptation*. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin. <http://www.wicci.wisc.edu/publications.php>

# Session 5

## Status and Management of Natives Salmonids





Photo courtesy of Matt Mitro.

## THE HOBACK RIVER: A TALE OF FISH SURVIVAL

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**Abstract**—The Hoback River is large free-flowing tributary to the Snake River located between the Gros Ventre and Wyoming mountain ranges in northwest Wyoming. The native fish community in the Hoback River is largely intact, with the exception of a few isolated populations of introduced salmonids. Finespotted Snake River Cutthroat Trout *Oncorhynchus clarkii behnkei*, and Mountain Whitefish *Prosopium williamsoni*, are the only native game fish and comprise the majority of the fish assemblage. Fish stocking was prominent in the Hoback River for most of the 20<sup>th</sup> century. Stocking practices during the majority of the 1980s and 1990s involved stocking large numbers of catchable Cutthroat Trout to improve angling quality in the lower reaches of the river, an area presumed to lack suitable recruitment and overwinter survival. Due to changes in angler “catch and release” ethics and an increased knowledge of overwinter survival, stocking was slowly phased out beginning in the late 1990s and was eliminated completely in 2005. Since the elimination of stocking, wild Finespotted Snake River Cutthroat Trout numbers have increased and angler catch rates have remained high. This story highlights fisheries management changes in river systems as a result of decreased consumptive angling and increased knowledge of fish survival.

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### INTRODUCTION

Wildlife and fisheries management in North America has changed significantly through time. These changes have been the result, not only of a growing body of knowledge about how species and populations survive, but of changes in social norms and public expectations regarding wildlife. We can track many of these changes from decade to decade even though they were slowly evolving ideas at the time. This paper will outline the changes over time and follow those changes through the history of one river, the Hoback River, while telling a story of fish survival.

#### History of Fisheries Management

Nielsen (1999) provides a concise overview of the history of fisheries management in the first chapter of *Inland Fisheries Management in North America, second edition*. The concept of wildlife as a public resource dates back to the English Monarchy, when royalty owned the land and wildlife and had the ability to choose who was able to harvest wildlife from the landscape. This idea transferred to North America in the form of the Public Trust Doctrine. In the mid to late 1600s, the acknowledgement of overexploitation led to the restriction of fish harvest. By the late 1700s, numerous restrictions were in place to protect

or reverse the effects of overfishing. While these restrictions were in place in eastern North America, there was a large push for people to begin settling the wilds of the west where resources were still abundant. As is obvious today, water was a major driver in how the west was settled and water development was an overriding feature of U.S. domestic policy. The water development that occurred during that time has forever altered the fisheries of the western U.S.

Fishing in the 1800s was wholly subsistence and commercial, with little to no recreational influence. The industrial revolution of the mid to late 1800s dramatically changed how fisheries were exploited. The invention of new fishing and harvest techniques sped up the rate at which fisheries were impacted and when the transcontinental railway was completed in 1869, European influence over the natural world was in full swing. The invention of new food storage techniques created a whole new market for fish products, and new fishing technology increased the efficiency of commercial fishermen. By the mid to late 1800s people began to notice declines in fish stocks, and in 1871, the U.S. Fish Commission was created to look into the decline of fisheries. As an answer to these declines, in 1872, the U.S. Fish Commission began raising and distributing fish across the USA. The technological advances seen in the industrial

revolution not only expedited exploitation of fish, it also allowed people to effectively raise and move fish around the country. The position of the U.S. government, and the belief of the public, was that commercial fisheries could be entirely sustained by stocking fish and people did a great job of putting fish everywhere that seemed to be able to support them. It was also during this time that numerous regulations were put into place to limit the season and method of commercial fishing. Generally, these restrictions protected spawning fish, but many regulations were politically motivated and promoted the advancement of some fishermen and not others (Nielsen 1976). Despite the attempt to regulate fishing, these restrictions did little good as there was no enforcement in place to ensure compliance.

In the late 1800s and early 1900s, in the face of overexploitation, a new attitude was cropping up in North America, a respect for nature and a need to have a scientific basis for management. The ideas of John Muir and Gifford Pinchot were heard across the USA and Theodore Roosevelt was elected president. These new ideas and new regulations regarding the management and utilization of public land and forestry were the beginning of the conservation movement. This movement overflowed into the world of fisheries. Despite what we think of as “conservation” today, fisheries were still foremost about providing food; however, instead of harvesting as many fish as possible, the theory of maximum sustained yield became the norm.

To remain true to the concept of maximum sustained yield, fisheries had to be surveyed, and many streams and rivers were surveyed as early as the first decade in the 1900s. Soon after surveys became more common, the field of limnology cropped up as scientists realized that understanding the fish’s environment was essential to proper management of the fish itself. As scientists learned more about the life history of fishes, they began to understand that the human disturbances of the past could have, and were having, devastating impacts on fisheries. It is these three things, surveys, limnology, and life history investigations, that formed the foundation of fisheries management as we know it today. It was also at this time (1950) that the Dingell-Johnson Act was passed, providing a funding mechanism for fisheries management. From the 1950s to today, fisheries management has become an ever growing field, and

much of the specific history of fisheries management for certain water bodies was undocumented prior to this time period.

Within the last century, population dynamics has become an important component to the way fisheries are managed. This began in the early to mid 1900s when biologists began looking at predator and prey interactions, densities of fish, and birth and death rates. Once these interactions were better understood, removal of undesirable species became very popular and managers spent much of their time removing species to increase densities of desirable fish. It was also at this time that recreational fishing began to expand. The widespread stocking that was so popular in the late 19<sup>th</sup> century, began to decline, and instead, a more organized system was initiated, which often involved holding fish in hatcheries for a longer period of time to be released at a size that was more popular with anglers. Despite a movement toward recreational fishing and away from commercial fishing, anglers were still oriented toward consumption; hence, early regulations on recreational fishing were quite restrictive. However, as scientists and biologist came to better understand population dynamics around the mid 1900s, regulations were liberalized. Today, regulations have once again reversed direction, resulting in more restrictive regulations, probably because this is one of the easiest management tools that biologists possess.

As the emphasis on commercial fishing declined and the prominence of recreational fishing increased, the traditional model of maximum sustained yield that had been used in the past, was reevaluated. Optimum sustained yield became the preferred model because it allowed managers more flexibility to determine what features were important to recreational anglers. This is still the model that is used today. Despite its flexibility, the optimum sustained yield model complicates fisheries management by adding public opinion into the equation. Fisheries managers now generally focus in three areas, management of habitats, management of aquatic organisms, and management of fisheries users.

Fisheries management in the late 1900s and early 2000s has seen further changes as it relates to the species that are receiving the most attention. Management has moved away from a single sport fish species focus and has started to concentrate on native fish communities and preserving rare, threatened, or endangered species, in addition to offering sport

fishing opportunities. This change is still in its infancy today. In addition to the changing mindset of managers, the mindset of the angling community is also changing. There has been a general trend away from consumptive angling and toward a “catch and release” mentality. This has greatly changed the dynamics within highly utilized fisheries by altering mortality rates. This ideology appears to be on an upward trend and managers can expect it to continue in the near future.

### Hoback River

The Hoback River is large free-flowing tributary to the Snake River located between the Gros Ventre and Wyoming mountain ranges in northwest Wyoming. From its headwaters to the confluence with the Snake River, the Hoback River is 49 mi long and drains an area roughly 613 mi<sup>2</sup>. Elevations in the drainage range from 11,682 ft to 5,900 ft at the confluence. Vegetation communities in the drainage reflect the considerable elevation gradient and include alpine and subalpine ecotypes, mixed conifer and aspen, and periodic meadows dominated by willows.

The native fish community in the Hoback River is largely intact, with the exception of a few isolated populations of introduced salmonids. Finespotted Snake River Cutthroat Trout *Oncorhynchus clarkii behnkei*, and Mountain Whitefish *Prosopium williamsoni*, are the only native game fish and comprise the majority of the fish assemblage. Native nongame fish in the Hoback River include Utah Sucker *Catostomus ardens*, Mountain Sucker *Catostomus platyrhynchus*, Speckled Dace *Rhinichthys osculus*, Longnose Dace *Rhinichthys cataractae*, Paiute Sculpin *Cottus beldingi*, and Mottled Sculpin *Cottus bairdi*.

Aquatic habitat in the Hoback River drainage is extremely dynamic, resulting from high annual flow variation and spring runoff events. Meadow sections in the upper portions of the watershed exhibit a relatively high degree of lateral migration with poor pool development caused by unstable cobble-gravel-sand substrates. Canyon sections are contained largely in bedrock formations with large boulder substrate and few gravel areas. Frazil ice and extensive anchoring occur frequently in the winter and likely impact overwinter habitat, particularly in altered and unstable sections.

Alterations to the watershed and the river channel have occurred periodically from land management

practices and highway construction. Roads associated with mineral exploration and timber harvest, and improper grazing practices have likely affected sediment transport in some tributary streams and resulted in negative impacts to the river channel. Dewatering and channel alterations are common in upper portions of the river. Construction and maintenance of a major highway has resulted in the loss of riparian vegetation and some channel alteration (Metsker 1967).

### History of Fisheries Management in the Hoback River

Following the trend across the USA, fish stocking was prominent in the Hoback River for most of the 20<sup>th</sup> century (WGFD File Data) with no consideration of native or introduced species. Brook Trout *Salvelinus fontinalis*, were the first known species stocked in the Hoback River. The first record of Brook Trout introduction was in 1933, and sporadic stocking continued annually for several years. Regular stocking of Finespotted Snake River Cutthroat Trout began in 1939, and continued annually through most of the 20<sup>th</sup> century. Around the time that fisheries management began in earnest, the first paper record of fisheries management in the Hoback River began, when creel reports showed native Cutthroat Trout being caught by anglers in 1949. At that time, fishing pressure in the Hoback River was identified as moderate with a fair reputation for catching fish.

A variety of sizes and numbers of trout were stocked into the Hoback River throughout the 20<sup>th</sup> century, including catchable, fingerling, and fry. Frequent stocking also occurred in several Hoback River tributaries, including Brook Trout and Finespotted Snake River Cutthroat Trout plants. Reasons for stocking were generally to create diversity and opportunity in uninhabited areas and improve overall angler catch rates. As the importance of native species grew in the 1980's, Finespotted Snake River Cutthroat Trout became the only species stocked. The majority of Cutthroat Trout stocked into the Hoback River were of catchable size to increase angling success. It was also believed that fish could not withstand the harsh winter conditions in the Hoback River and fish would leave the system, so that annual stocking was necessary to maintain a fishery in the river.

As knowledge of limnology and aquatic habitat began to grow across the USA, fisheries managers

on the Hoback River acknowledged the impacts that had occurred from the extensive human alterations of the past, specifically from land management practices and highway construction. There was a general lack of adequate pool habitat, which was mitigated using in-stream boulder structures and some woody debris manipulations in the late 1960's; however, present conditions in the canyon continue to reflect the impacts of these alterations (i.e. high sediment loads and associated channel aggradation).

One of the earliest records of fish sampling in the Hoback River was in 1955 as fisheries management was getting on its feet. No indication of the methods used is given other than an indication that the fish were “shocked.. Mountain Whitefish and Finespotted Snake River Cutthroat Trout were the predominant species collected. Additional sampling was conducted in 1961 with an “electrofishing apparatus.” Again, the majority of fish collected were Mountain Whitefish and Finespotted Snake River Cutthroat Trout. Sixteen of the Cutthroat Trout were hatchery reared and five were considered wild (WGFD file data). During 1996 and 1997 biologists sampled sections of the Hoback River using shore mounted electrofishing methods with limited success.

The first attempt to sample the Hoback River with raft electrofishing occurred in 1998, when it was necessary to more adequately evaluate the fishery available to the public. A single pass through a 3-mi section yielded 43% wild Cutthroat Trout and 57% hatchery Cutthroat Trout from previous stocking (WGFD 1998). A similar effort in April 1999 resulted in 58% wild Cutthroat Trout and 42% stocked Cutthroat Trout (WGFD 1999).

In 2000, the first attempts were made to calculate trout population estimates using raft electrofishing and multiple mark and recapture techniques. The objectives were to determine the status of the Cutthroat Trout population in 3 mi of the Hoback River, and to evaluate the catchable Cutthroat Trout stocking program. Previous sampling indicated that wild Cutthroat Trout were variable in size, were reproducing and appeared to be overwintering in the Hoback River. In addition, the “catch and release” angling mindset began to enter the area in the mid to late 1990s, reducing the consumptive pressure on the Cutthroat Trout population. For these reasons, beginning in 2000, biologists began to gradually decrease numbers of stocked Cutthroat Trout in the Hoback River. By 2005, fish no longer were stocked into the river.

Prior to 2001, regulations in the drainage were generally consistent with Wyoming's statewide regulations (six trout only one over 2 in) with a few exceptions and some seasonal closures. In 2004, the regulation on the river changed to 3 Cutthroat Trout only 1 over 12 inches, and fishing was open all year.

During population estimates on the Hoback River, Finespotted Snake River Cutthroat Trout were by far the most frequently collected trout species. Wild Cutthroat Trout population estimates ranged from 338/mi in 2005 to 998/mi in 2007, and hatchery Cutthroat Trout estimates ranged from 279/mi in 2004 to 0/mi in 2008, 2010, 2011, and 2012 (Figure 1). Population estimates of all wild Cutthroat Trout (> 6.0 in) varied greatly from 2000 to 2012. Estimates of hatchery Cutthroat Trout showed a sharp decline in 2005, and by 2008 the estimated number of hatchery Cutthroat Trout per mile was zero. After stocking ceased in 2005, the estimate of wild Cutthroat Trout jumped significantly (Figure 1). This was largely due to an increase in small, 6-in to 9-in fish. The population then returned to levels that more closely resemble those during the occurrence of stocking.

Wild Cutthroat Trout generally ranged from 3 to 18 in, the largest sampled was 18.5 in. Length frequency distributions show at least three easily identified year classes of wild Cutthroat Trout. Hatchery Cutthroat Trout had a much narrower length range each year, though the average appeared to vary yearly, likely reflecting annual differences in the average sized stocked.

## DISCUSSION

Sampling suggests that hatchery Cutthroat Trout were not persistent from year to year. In particular, length frequency distributions failed to show multiple modes during any single sampling event. Unimodal distributions indicate a single age cohort of stocked fish with no carryover from previous stocking events. In addition, following the final stocking event in 2004, subsequent sampling yielded significantly reduced abundance of hatchery Cutthroat Trout, indicating poor annual survival or emigration from the project area, similar to what managers anticipated of the entire Cutthroat Trout fishery. Poor annual survival of hatchery-reared Cutthroat Trout in flowing water is not uncommon, and previous work has shown that excessive energy expenditure and the absence of natural selection on early life stages are the likeliest reasons (Miller 1954; Mesa 1991). Wild Cutthroat

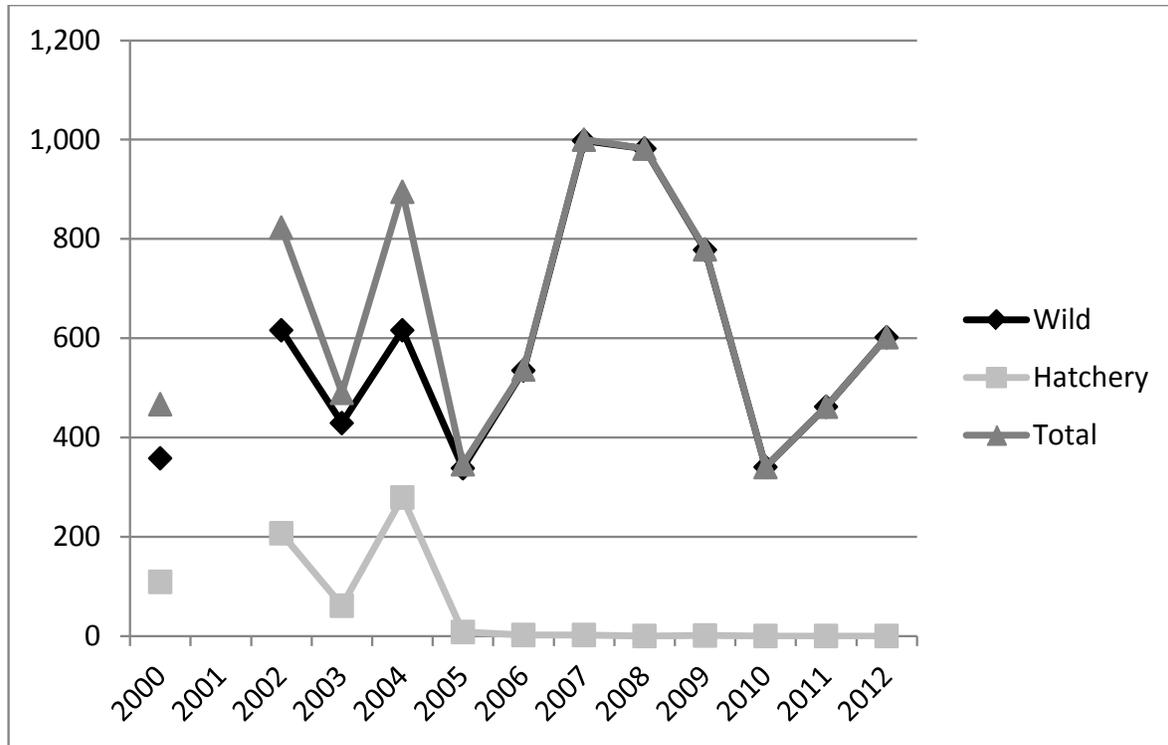


Figure 1. Population estimates of Finespotted Snake River Cutthroat Trout per mile in the Hoback River from 2000 to 2012.

Trout abundance estimates varied from year to year and were mostly a reflection of fluctuating numbers of younger Cutthroat Trout. The bimodal distribution of length classes indicates that, unlike the hatchery Cutthroat Trout fishery in the Hoback River, the wild Cutthroat Trout fishery is able to overwinter within the Hoback River and can sustain current angling pressure.

Fisheries management in the USA has made substantial changes over time. Those changes are reflected in the management of the Hoback River throughout its documented history. Early widespread stocking was very common, even before managers understood how wild populations may or may not have been able to handle angling pressure. As managers came to understand the winter habitat conditions in the river, and began using new sampling techniques, specifically electrofishing, they began to understand the differences in how hatchery and wild fish survived in their environment. In addition, changes in the attitudes and mindsets of the public as it relates to consumptive vs. non-consumptive recreational angling changed the dynamics of fish populations in the

Hoback River and the need to provide hatchery fish for consumptive anglers.

Only time will tell what changes we will see tomorrow in the realm of fisheries management in the USA and how those changes will be reflected in the rivers and lakes that we manage.

## ACKNOWLEDGEMENTS

A huge thanks goes out to all those who have helped manage the Hoback River through time. There are too many people to mention here, but they know who they are and I hope they know that all of their work is very much appreciated.

## REFERENCES

- Mesa, M.G. 1991. Variation in feeding, aggression, and position choice between hatchery and wild cutthroat trout in an artificial stream. *Transactions of the American Fisheries Society* 120: 723-727.
- Metsker, H. 1967. Hoback Canyon forest highway fisheries problems addendum report. U.S. Forest Service, Jackson, Wyoming. 10pp.

- Miller, R.B. 1954. Comparative survival of wild and hatchery-reared cutthroat trout in a stream. *Transactions of the American Fisheries Society* 83: 120-130.
- Nielsen, L. A. 1976. The evaluation of fisheries management philosophy. *U.S. National Marine Fisheries Service Marine Fisheries Review* 38(12): 15-23.
- Nielsen, L. A. 1999. History of Inland Fisheries Management in North America. Pages 3-28 in C. C. Kohler and W. A. Hubert, editors. *Inland fisheries management in North America*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- WGFD. 1998. Annual fisheries progress report on the 1998 work schedule. Fish Division, Wyoming Game and Fish Department, Cheyenne, Wyoming.
- WGFD. 1999. Annual fisheries progress report on the 1999 work schedule. Fish Division, Wyoming Game and Fish Department, Cheyenne, Wyoming.

## PHENOTYPE PREDICTS GENOTYPE FOR LINEAGES OF NATIVE CUTTHROAT TROUT IN THE SOUTHERN ROCKY MOUNTAINS

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**Extended Abstract**—Recent genetic investigations questioned traditionally accepted taxonomic and systematic relationships of Cutthroat Trout *Oncorhynchus clarkii* in the Southern Rocky Mountains (see Bestgen et al. for a review <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/2013CutthroatTroutMeristics.pdf>). Those studies suggested evidence of six lineages, but only the Blue Lineage (presumptive Colorado River Cutthroat Trout *O. c. pleuriticus*, Green Lineage (undetermined subspecies designation), South Platte River basin native Cutthroat Trout (represented by Bear Creek fish, presumptive Greenback Cutthroat Trout *O. c. stomias*, and Rio Grande Cutthroat Trout *O. c. virginalis* were believed extant. The Molecular Model was more successful identifying groups (subspecies or lineages) of Cutthroat Trout based on within-lineage or taxa similarities in morphological traits than the traditional Geographic Model. This was true whether comparisons among groups were for individual meristic traits, groupings in the principal component analysis scatter plots using four or eight variables, or the discriminant function classification analysis. Further, individual traits and discriminant function analysis also showed substantial structuring within lineages, organized by geographic management unit. As the Cutthroat Trout taxonomic literature suggests, the Geographic Model using a limited suite of morphological traits showed only moderate structuring of populations examined in this study and East and Western Slope populations of Cutthroat Trout were similar in meristic traits (e.g., lateral series scale, gill rakers counts, spotting patterns). Bear Creek fish were distinct under each classification because of differences in several traits, as were Rio Grande Cutthroat Trout populations. Blue Lineage populations were distinct in the Molecular Model (100% classification success), unlike the same populations in the Geographic Model, of which 44% were misclassified. Inconsistencies in classification of Green Lineage fish (individuals and populations) under the Molecular Model using discriminant analysis were due mostly to four Green Lineage populations found on the East Slope that showed distinct morphological and subtle genetic differences in traits relative to West Slope Green Lineage populations and Bear Creek fish. We discuss nuances uncovered in this analysis using traditional taxonomic traits, clarify where data do and do not support the Molecular Model, and describe existence of four discrete taxonomic groups of Cutthroat Trout, including Bear Creek, Green and Blue Lineages, and Rio Grande Cutthroat Trout, across our study area. How results presented and recent molecular studies on Cutthroat Trout of the Southern Rocky Mountains will shape future management is not evident. A logical first step would be to determine if the four lineages studied here constitute recognizable and definable groups at a level of taxonomic organization such as subspecies. We recommend agencies conduct additional stream surveys to better understand distribution of various lineages of Cutthroat Trout on the landscape. Further studies are also needed to resolve taxonomic status of all lineages, particularly, East Slope Green Lineage populations. Until that time, populations of East Slope Green Lineage Cutthroat Trout, as well as other rare morphological and genetic types in all lineages, should be protected. Population structuring at the drainage basin level, as recognized with morphological techniques in this study, supports the long-held notion that population management and restoration activities should emphasize preservation of the unique genotypes that likely evolved in concert with the environment. Preservation of that genetic diversity, regardless of where it resides on the landscape, should be a guiding principle for future management.

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Figure 1: Top to bottom: South Platte River drainage (Bear Creek), Blue Lineage, Green Lineage, and Rio Grande Cutthroat trouts

## IN MEMORIAM (1929-2013)



We recognize Dr. Robert J. Behnke as the driving force behind understanding the distribution, taxonomy, and conservation of salmonids in North America over the last half century. His work was particularly focused on description of taxa and conservation of the amazing diversity contained in the native trout of the Rocky Mountain west. We wonder what little

might be left of that native diversity had “Doc” not dedicated his professional life to studying these fishes. His teachings and writings stimulated our interest in continuing to explore the taxonomy of Cutthroat Trout in the American West, and further his long-standing commitment to conserve these beautiful native fishes.

## USING GENETIC DIVERSITY TO INFORM CONSERVATION EFFORTS FOR NATIVE CUTTHROAT TROUT OF THE SOUTHERN ROCKY MOUNTAINS

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**Abstract**—Recent research on native Cutthroat Trout *Oncorhynchus clarkii* of the southern Rocky Mountains suggests a convoluted taxonomy confused by stocking in the early 1900s that obscured the native distributions of these fish. DNA recovered from the few museum specimens collected 150 years ago shed light on the historical diversity and native ranges of lineages in Colorado. This study aims to characterize what remains of that diversity across the entire southern Rockies using a stratified random sampling design across the range of putative Colorado River Cutthroat Trout *O. c. pleuriticus*, Greenback Cutthroat Trout *O. c. stomias*, and Rio Grande Cutthroat Trout *O. c. virginialis*. Twenty-four biologists from four states collected 801 fish from 49 randomly selected conservation populations across Colorado, New Mexico, Utah, and Wyoming. Whole specimens were used to explore phenotypic differences in lineages suggested by molecular studies. Here, we used tissue samples collected prior to specimen preservation to describe mitochondrial haplotype diversity. These diversity patterns are critical to inform managers tasked with listing decisions for rare Cutthroat Trout lineages. Consistent with previous studies, four distinct lineages were recovered from sequence data on 648 base pairs of the ND2 mitochondrial gene. Substantial diversity was recovered in Rio Grande Cutthroat Trout (12 haplotypes), while only a single haplotype could be found in native Cutthroat Trout of the South Platte River basin. Within Colorado River Cutthroat Trout, nine haplotypes were recovered from 14 populations putatively native to the Upper Colorado, Gunnison, and Dolores basins (Green Lineage), but only six were found in 21 populations native to the Lower Colorado, Green, and Yampa basins (Blue Lineage). This was unexpected given the broad range of the Blue Lineage, and may suggest more recent ancestry of Green River basin fish. Rare haplotypes may indicate pockets of historical diversity. To avoid inadvertently “throwing away the pieces”, these conservation populations should be targeted for replication and protection to ensure their continued persistence.

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### INTRODUCTION

As the official state fish of seven western states and a prized game fish, Cutthroat Trout *Oncorhynchus clarkii* have long held the interest of anglers and managers alike. That interest in the taxonomy of native Cutthroat Trout was reignited several years ago by a study published in the journal *Molecular Ecology* suggesting there was a genetic basis for separating our native trout, and that earlier efforts to identify genetic markers for this purpose were hampered by a historical distribution patterns that were largely occluded by extensive stocking of native trout in the early part of the 20th century (Metcalf et al. 2007). That assertion was supported by more recent work that examined 150 year-old specimens housed in our nation’s most

prestigious museums (Metcalf et al. 2012). That study also suggested a richer diversity than is currently present on the landscape – at least than we are aware of, with six different lineages of Cutthroat Trout once calling Colorado home (Metcalf et al. 2012). The same colors used to describe the four extant lineages in that paper are also used here for consistency (Figure 1; see Bestgen et al. 2013 for color rendition), with blue representing Cutthroat Trout native to the Yampa, White, and Green River basins, green representing those native to the Colorado, Gunnison, and Dolores basins, orange for the Rio Grande Cutthroat Trout *O. c. virginialis*, and purple for the putative South Platte basin native.

Given that our native Cutthroat Trout occupy roughly just a tenth of their historic range (Alves et al. 2008, Hirsch et al. 2013), a loss of genetic diversity is not unexpected. It does however illustrate the importance of cataloging what remains, so that conservation efforts can target those populations that harbor remnant diversity, rather than ones that are already well replicated through historical stocking efforts.

New molecular methods have already been integrated in the routine management of Cutthroat Trout in the southern Rocky Mountains, with general tests of purity being used to evaluate which populations deserve “Conservation Population” status as outlined in conservation agreements and their associated strategies (UDWR 2000; CRCT Coordination Team 2006; Rogers 2008; Rogers 2012a; RGCT Conservation Team 2013). However, the United States Court of Appeals has affirmed that the U.S. Fish and Wildlife Service should continue to rely on morphology for identifying native trout in listing decisions (Campton and Kaeding 2005). While the primary focus of this large-scale cataloging effort was indeed to determine if differences implied by the DNA lineages described in Metcalf et al. (2012) are reflected in the physical characteristics of the populations they represent (Bestgen et al. 2013), it also provided an opportunity to characterize mitochondrial sequence diversity across the range of Cutthroat Trout in the southern Rocky Mountains at the same time. While the meristic work represents a critical step toward resolving the taxonomic uncertainty that will allow repatriation and restoration of these native trout to aboriginal habitats to resume, the molecular work described here can be used to inform conservation efforts that seek to determine which populations are most appropriate for those restoration activities.

## METHODS

### Tissue Collection

Both characterizing genetic diversity, and subsequent morpho-meristic treatments required an unbiased sampling of extant populations of Cutthroat Trout in the southern Rocky Mountains. This was achieved by randomly selecting Core Conservation Populations (sensu UDWR 2000) from Cutthroat Trout databases maintained by the Colorado River Cutthroat

Trout Conservation Team (Hirsch et al. 2013), Rio Grande Cutthroat Trout Conservation Team (Alves et al. 2008), and Greenback Cutthroat Trout Recovery Team (unpublished data). The sampling design was stratified across U. S. Geological Survey 4-digit Hydrologic Unit Code (HUCs) units that also serve as geographic Management Units (GMUs) by the conservation teams charged with securing the future of these three subspecies (Alves et al. 2008, Hirsch et al. 2013). Since genetic structuring if present, should contain a spatial element reflecting isolation by distance (Wright 1943, Whiteley et al. 2006, Pritchard et al. 2009), three candidate populations from each GMU were selected at random to ensure that both morphological and genetic diversity was well represented. Geographic bounds of trout lineages were based on the findings of Metcalf et al. (2007) with modifications from Metcalf et al. (2012) and supplementary information from unpublished data and Rogers (2010). Essentially, what was once termed the Colorado River Cutthroat Trout, *O. c. pleuriticus*, and formerly thought to occupy all Colorado drainages west of the Continental Divide, is now classified, in part, by Metcalf et al. (2012) as the Blue Lineage and is believed native only in the White, Yampa, Green and lower Colorado River drainages in northwestern Colorado, southwestern Wyoming, and eastern Utah. Remaining native trout in the Dolores, Gunnison, and upper Colorado basins are referred to as the Green Lineage. In HUCs where both blue and green lineages are present, up to three populations of each were selected. One exception to the protocol was in the upper Colorado River GMU where what was assumed to be a Blue Lineage population (Abrams Creek, Stream 25) was later determined to be a Green Lineage population. Thus, two Blue Lineage and four Green Lineage upper Colorado GMU populations were analyzed. In other drainages, limited numbers of populations of a certain lineage restricted the number of study streams (e.g., only one Blue Lineage population in each of the San Juan or Dolores River basins).

Inclusion of a stream in the study was also granted only for those meeting three additional criteria: (1) that a population from the same 8-digit HUC was not already selected, (2) molecular data was available to make a determination on the lineage present (Rogers 2008), and (3) estimated population size exceeded 150 adult Cutthroat Trout per mile to minimize

negative consequences of removing 12 or 24 fish from the population. Thus, the stream selection protocol generated a relatively unbiased sample of populations for inclusion in the study while minimally impacting relatively small populations of trout.

Twenty-four fish were collected from the first population selected for each GMU to characterize within population variability of morphometric and meristic characteristics (Bestgen et al. 2013). If that stream could not support removal of 24 fish because of small population size, only 12 fish were taken and another population was substituted for the larger sample. In several instances, sufficient numbers of fish could not be obtained from a stream and a substitute was identified, again based on a random draw from the remaining populations in that GMU. In one case, the only alternative was a lentic population, Henderson Horseshoe Pond, and was selected as an alternative to Steelman Creek. Only 12 fish were collected from subsequent populations within each GMU to characterize among-population variation. A small number of wild specimens and a larger number of hatchery fish were also available from Bear Creek in the Arkansas drainage, Colorado, which was noteworthy for its distinct genetic fingerprint (Proebstel et al. 1996; Evans and Shiozawa 2002; Metcalf et al. 2007; Metcalf et al. 2012).

Specimens were captured by electrofishing or hook and line. Tissue samples were obtained by clipping a 1-cm<sup>2</sup> piece of the right pelvic or upper caudal fin, which was then stored in 3.5-ml cryo-storage vials (Perfector Scientific, Atascadero, California) containing 80% ethanol. The blind nature of the study was maintained by labeling each vial with a unique code that was not shared with the molecular lab until after the study was complete.

### DNA Isolation and Evaluation

Tissue samples were delivered to Pisces Molecular (Boulder, Colorado) for DNA isolation and sequencing. A proteinase K tissue lysis and spin-column purification protocol following manufacturer specifications (Qiagen DNeasy Kit) was used to isolate DNA from the fin clip samples. Sample DNA was amplified using primers specific to a region of the NADH dehydrogenase subunit 2 (ND2) mitochondrial gene, generating a 648 bp fragment that falls within the fragment cited in previous studies (Metcalf et al. 2007, Loxterman and Keeley 2012), which allowed

us to confirm lineage assignments as well as identify unique haplotypes. Samples were run on a capillary sequencer (Applied Biosystems 3130 Genetic Analyzer, Foster City, California). Sequence reads were assembled using the Contig Express program (Vector NTI 11, Invitrogen, Carlsbad, California). The assembled contiguous sequence chromatograms were examined for sequence quality and accuracy, and the primer sequences removed from the ends of the fragments. Sequences were aligned in ClustalW (Thompson et al. 1994) and the evolutionary history was inferred using the Minimum Evolution method (Rzhetsky and Nei 1992) in MEGA4 (Tamura et al. 2007). The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (500 replicates) was calculated (Felsenstein 1985). The evolutionary distances were computed using the Maximum Composite Likelihood method (Tamura et al. 2004). The tree was searched using the Close-Neighbor-Interchange algorithm (Nei and Kumar 2000) at a search level of one. The Neighbor-joining algorithm (Saitou and Nei 1987) was used to generate the initial tree. Aligned sequence data was exported from MEGA to Arlequin using PGDSpider (Lischer and Excoffier 2012) where pairwise distances between haplotypes were calculated (Excoffier 2005). That table was then imported into HapStar (Teacher and Griffiths 2011) to generate a minimum spanning network.

## RESULTS

The stream selection protocol resulted in a relatively even representation of populations from throughout the ranges and GMUs of the respective lineages and recognized subspecies (Table 1, Figure 1). In some instances, we could not select three populations of each lineage for a given GMU, usually because insufficient numbers of available Core Conservation Populations existed from which to draw from. This was true for Blue Lineage Cutthroat Trout in the San Juan and Dolores GMU's where only one population was drawn from each, and Green Lineage populations in the South Platte and Arkansas River GMU's, where only two populations were drawn from each. One of the sobering results from this effort was just how few Core Conservation Populations of Cutthroat Trout are present east of the Continental Divide in the South Platte and Arkansas River basins (Figure 1), when compared to basins west of the Continental Divide or in the Rio Grande drainage.

**Table 1: Sample location information for the 49 populations of Cutthroat Trout used in this study. Geographic Management Units (GMU) reflect 4-digit USGS Hydrologic Unit Codes as portrayed in the study area map (Figure 1.)**

Drainage	GMU	Stream	Number	Coordinates	
				Latitude	Longitude
Arkansas	Arkansas	South Apache Creek	6	37.85	-104.94
Arkansas	Arkansas	North Taylor Creek	26	38.11	-105.62
Arkansas	Arkansas	Graneros Creek	43	37.89	-104.95
Arkansas	Arkansas	Hayden Creek, S. Prong	3	38.30	-105.81
Arkansas	Arkansas	Severy Creek	19	38.89	-104.99
Arkansas	Arkansas	Bear Creek	49	38.80	-104.90
Colorado River	Upper Colorado	Little Green Creek	29	40.30	-106.63
Colorado River	Upper Colorado	Mitchell Creek	42	39.57	-107.37
Colorado River	Upper Colorado	Abrams Creek	25	39.59	-106.85
Colorado River	Upper Colorado	Cunningham Creek	31	39.33	-106.55
Colorado River	Upper Colorado	Horseshoe Pond	34	39.83	-106.08
Colorado River	Upper Colorado	Brush Creek, W. Fk	46	39.34	-107.84
Colorado River	Dolores	Tabeguache Creek	12	38.45	-108.47
Colorado River	Dolores	Little Taylor Creek	18	37.58	-108.20
Colorado River	Dolores	Big Red Canyon Creek	21	38.26	-108.20
Colorado River	Dolores	Deep Creek, E. Fk	24	37.97	-107.90
Colorado River	Gunnison	Nate Creek	8	38.18	-107.60
Colorado River	Gunnison	Deep Creek	11	38.97	-107.30
Colorado River	Gunnison	Doug Creek	47	38.65	-107.53
Colorado River	Upper Green	Steel Creek	7	40.95	-110.48
Colorado River	Upper Green	South Beaver Creek	41	42.44	-110.38
Colorado River	Upper Green	Irish Canyon Creek	2	42.66	-109.36
Colorado River	Lower Green	Little West Fk	16	40.44	-111.09
Colorado River	Lower Green	South Brownie Creek	38	40.69	-109.77
Colorado River	Lower Green	Johnson Fk	44	39.93	-111.01
Colorado River	Yampa	Milk Creek	23	40.15	-107.62
Colorado River	Yampa	Snell Creek	30	40.07	-107.34
Colorado River	Yampa	Deep Creek	35	41.21	-107.17
Colorado River	Lower Colorado	Pine Creek	5	37.97	-111.65
Colorado River	Lower Colorado	Right Fk U M Creek	40	38.68	-111.59
Colorado River	Lower Colorado	West Fk Boulder Creek	45	38.04	-111.49
Colorado River	San Juan	East Fk Piedra River	28	37.49	-107.08
Rio Grande	Canadian	West Fk Luna Creek	22	36.21	-105.36
Rio Grande	Canadian	McCrystal Creek	36	36.78	-105.13
Rio Grande	Canadian	Leandro Creek	39	36.88	-105.19
Rio Grande	Pecos	Rio Valdez	9	35.93	-105.53
Rio Grande	Pecos	Dalton Creek	10	35.68	-105.76
Rio Grande	Pecos	Macho Creek	14	35.69	-105.72
Rio Grande	Upper Rio Grande	West Indian Creek	1	37.43	-105.21
Rio Grande	Upper Rio Grande	Osier Creek	15	37.02	-106.33

Table 1: Continued

Drainage	GMU	Stream	Number	Coordinates	
				Latitude	Longitude
Rio Grande	Upper Rio Grande	Carnero Creek, M	27	37.98	-106.42
Rio Grande	Lower Rio Grande	El Rito	4	36.53	-106.27
Rio Grande	Lower Rio Grande	Columbine Creek	20	36.65	-105.51
Rio Grande	Lower Rio Grande	Policarpio Creek	33	36.14	-105.45
South Platte	South Platte	S Fk Cache la Poudre	13	40.54	-105.60
South Platte	South Platte	Roaring Creek	32	40.75	-105.76
South Platte	South Platte	Hunters Creek	48	40.21	-105.58
South Platte	South Platte	Como Creek	17	40.02	-105.51
South Platte	South Platte	Fern Creek	37	40.34	-105.67

Absence of Core Conservation Populations in the southern portion of the South Platte River basin is notable and few exist in the western portion of the Arkansas River basin. Anthropogenic influences are not entirely responsible for the paucity of conservation populations east of the Continental Divide. The density of coldwater streams is simply higher on the West Slope and upper Rio Grande basin.

All specimens were screened with molecular methods to confirm that they fit within their anticipated clades using mitochondrial sequence data (Figure 2). We recovered 32 unique ND2 mitochondrial haplotypes in the 801 fish sampled from 49 populations that were distributed among five distinct clades consistent with those identified in earlier studies (Loxterman and Keeley 2012; Metcalf et al. 2012). Twenty-six haplotypes occurred in more than one individual, and 15 were shared among two or more populations. In addition to four haplotypes commonly found in Yellowstone Cutthroat Trout *O. c. bouvieri* that represent instances of admixture, we recovered 12 Rio Grande haplotypes, nine Green Lineage haplotypes and six Blue Lineage haplotypes (Figure 2). The ND2 sequence data suggested that 47 of 49 populations were assigned to their anticipated lineages (Figure 2). One of the two exceptions was Abrams Creek, where ND2 sequence data suggested it was a Green rather than Blue Lineage population. The other was Irish Canyon (Stream 2, SW Wyoming, Upper Green River GMU) where all fish had a pair of common Yellowstone Cutthroat Trout haplotypes, a finding corroborated by AFLP data which also indicated this population was Yellowstone Cutthroat Trout (Bestgen et al. 2013).

## DISCUSSION

Critical to the integrity of this study was to adequately represent the genetic diversity of the various taxonomic entities of Cutthroat Trout across the southern Rocky Mountains. We were largely successful to that end, as representatives from each of the groups were selected at random from each of the 14 GMUs that collectively encompass the range of these Cutthroat Trout. This coordinated sampling effort across a four-state area ensured that basic spatial sampling design considerations were fulfilled, which was different from historical efforts that used opportunistically obtained samples, and also ensured that bias associated with over or under representation of one or more groups was minimized. The blind data acquisition protocol ensured that investigators were not influenced by knowing location or heritage of samples or specimens. This was guaranteed by a coding system for streams and specimens that was not revealed until after data collection was complete.

Four putatively native distinct lineages were recovered from ND2 sequence data after those that fell into the Yellowstone Cutthroat Trout clade were discounted. These lineages are consistent with those described in earlier studies (Metcalf et al. 2007, Loxterman and Keeley 2012, Metcalf et al. 2012). Substantial diversity was recovered in Rio Grande Cutthroat Trout (12 haplotypes), while only a single haplotype could be found in native Cutthroat Trout of the South Platte River basin. Within Colorado River Cutthroat Trout, nine haplotypes were recovered from 14 populations presumed to be native to the Upper Colorado, Gunnison, and Dolores basins

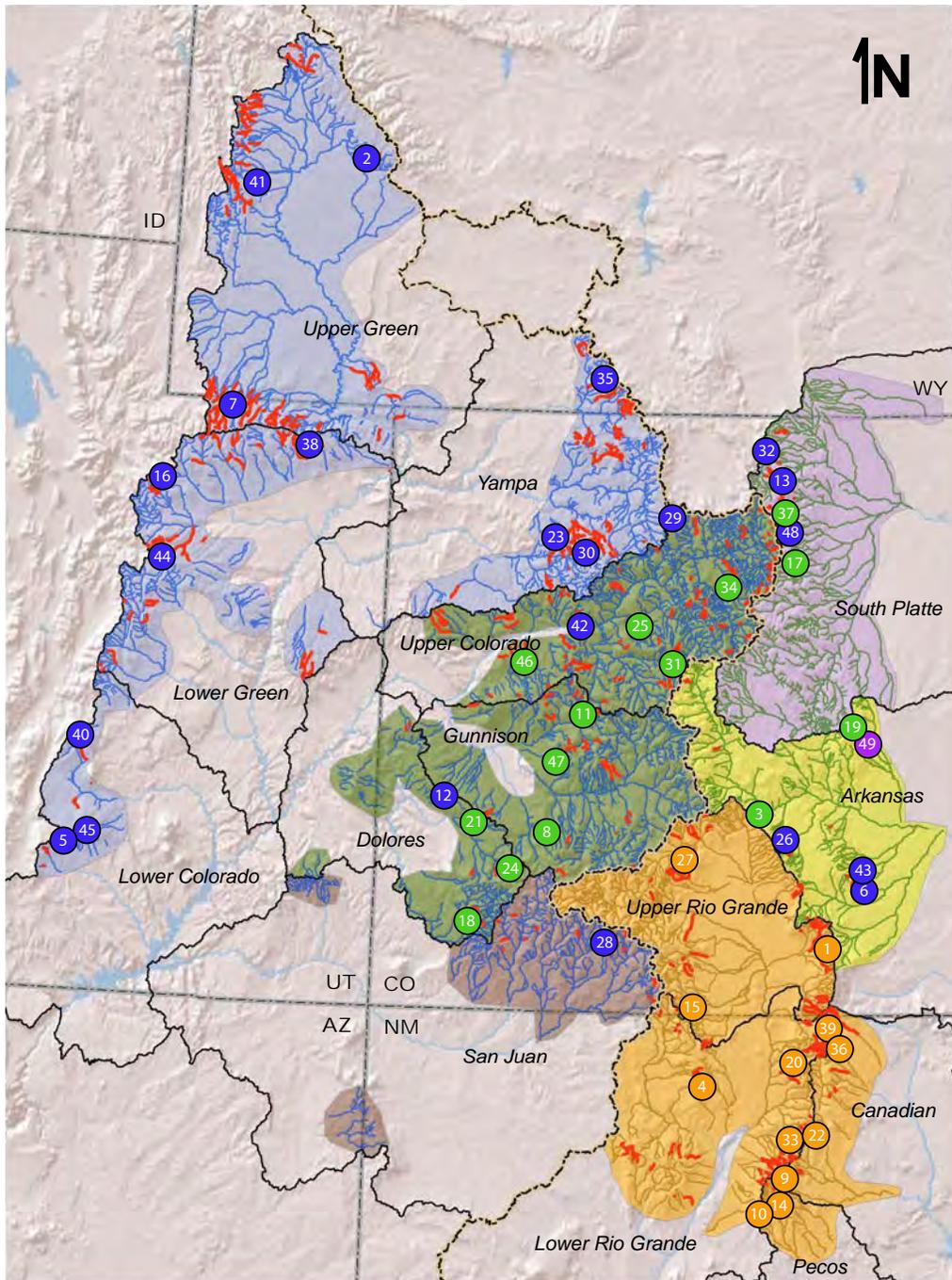
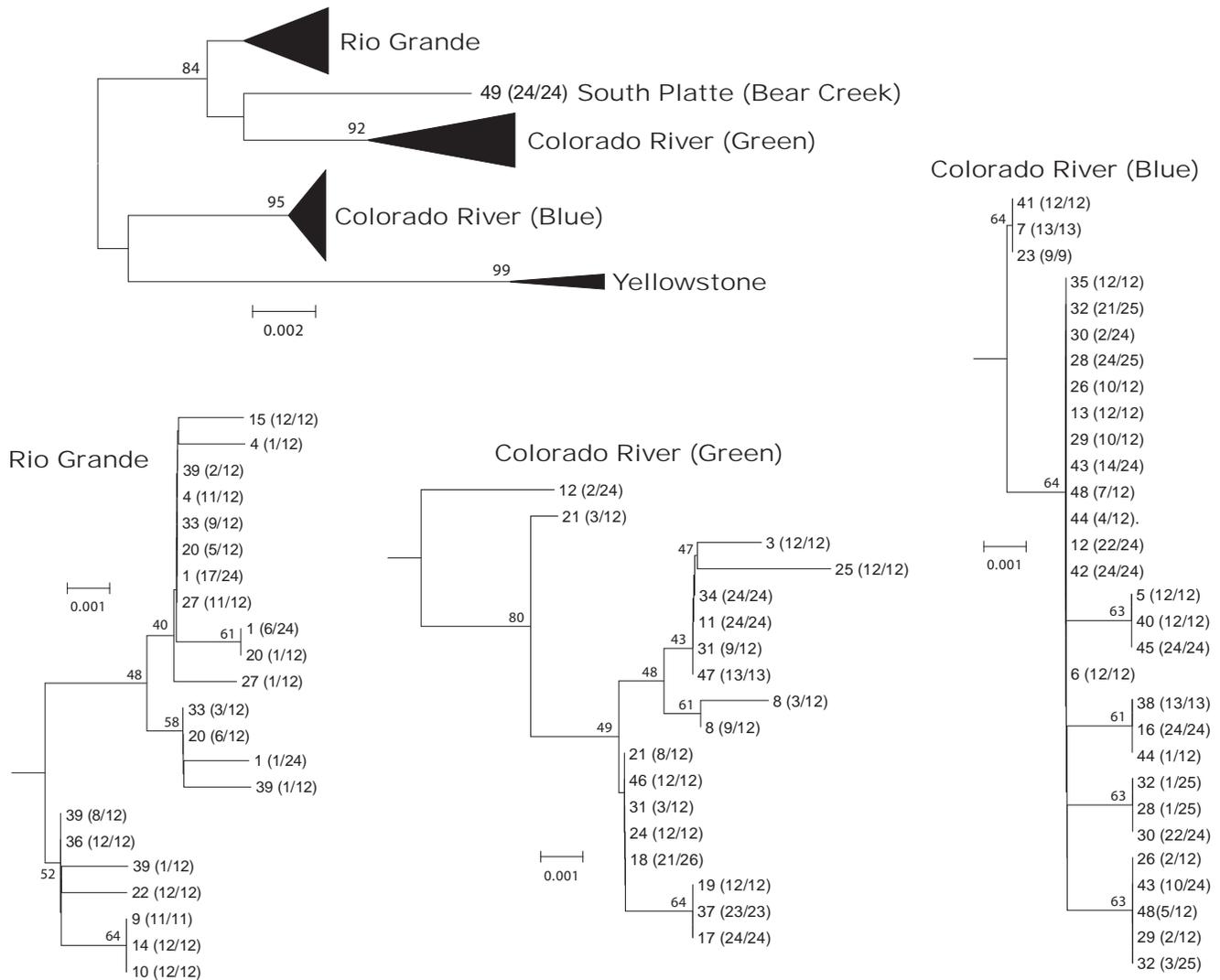


Figure 1: Fourteen hydrologic units from five western states that comprise the accepted historical range of Colorado River Cutthroat Trout (blue labeled streams), Greenback Cutthroat Trout (green streams), and Rio Grande Cutthroat Trout (orange streams) are named in italics. Core Conservation Populations from which our study populations were randomly drawn are highlighted in red. The presumed historical ranges of lineages described in Metcalf et al. (2012) are represented by shading: the Blue Lineage (Yampa River, upper and lower Green River, and lower Colorado River GMU's) is shaded blue, the Green Lineage (upper Colorado River, Gunnison River, and Dolores River drainage GMU's) is shaded green, San Juan River drainage (and GMU) is shaded brown, Rio Grande Cutthroat Trout (upper and lower Rio Grande, Pecos River and Canadian River GMU's) are shaded orange, yellowfin Cutthroat Trout (Arkansas River GMU) is shaded yellow, and South Platte native cutthroat lineage (South Platte River GMU) lineage is shaded purple. Dots represent the populations sampled in this study and are colored as per the lineage defined by the ND2 clade using the same color scheme above. The numbers within each dot indicate the stream sampled.

(Green Lineage), but only six were found in 21 populations native to the Lower Colorado, Green, and Yampa basins (Blue Lineage) despite covering a much broader geographical area. Perhaps this is a reflection of a more recent evolutionary past, or greater connectedness in the stream systems they inhabit. Presence of Blue Lineage Cutthroat Trout in the lower Colorado River basin GMU was unexpected, given presence of presumably native Green Lineage fish in Dolores and upper Colorado River basin GMUs

upstream. Headwater dispersal from proximate lower Green River basin GMU Blue Lineage stocks may explain presence of Blue Lineage fish in the lower Colorado River GMU. The unique haplotypes found in these populations (Streams 5, 40, and 45) and nowhere else (Figure 2) might suggest that these populations were not founded by stocking, but rather represent aboriginal genetic diversity.

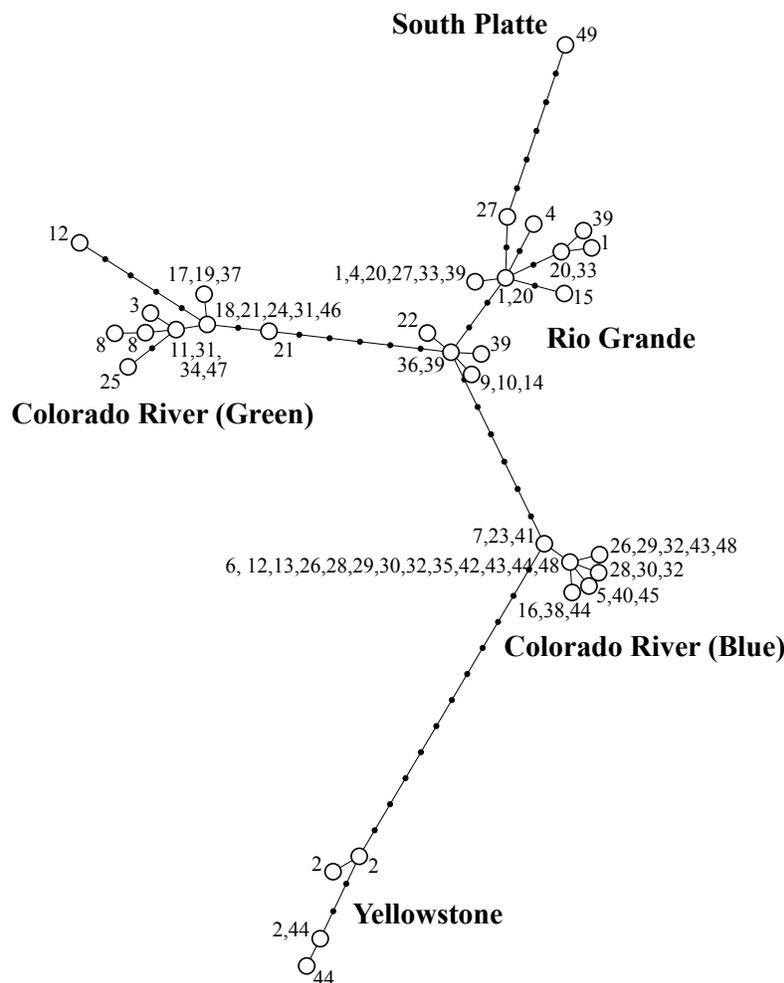
Invasion of West Slope Colorado River basin streams south of the presumed native distribution



**Figure 2: Phylogenetic relationships inferred from 648 base pairs of the mitochondrial ND2 gene for Cutthroat Trout from the Southern Rocky Mountains. The evolutionary history was developed with the Minimum Evolution method. Percent branching support was evaluated with 500 bootstrap replicates with values exceeding 40% indicated above the tree branches. Major clades relevant for this study are broken into separate sub-trees. Stream numbers are listed first, followed by (in parentheses) the number of fish with a given haplotype out of the total number sampled in each population. A Rainbow Trout haplotype was detected in a single fish in Stream 21, and from five fish in Stream 18 – these were not included in the tree. Four Yellowstone Cutthroat Trout haplotypes were also detected in two populations (Stream 2 and 44). Phylogenetic analyses were conducted in MEGA4 with evolutionary distance units representing the number of base substitutions per site.**

of Blue Lineage fish may have occurred at multiple times during their evolutionary history, resulting in apparently closely related Cutthroat Trout on both sides of the Continental Divide, with perhaps Green Lineage trout radiating into the Rio Grande basin to give rise to the Rio Grande Cutthroat Trout before invading streams to the north in the Arkansas and South Platte basins. The haplotype tree (Figure 2) does hint at a common ancestor for Rio Grande, Green Lineage, and South Platte native, which is supported by a minimum spanning haplotype network (Figure 3). This implies that these fish made it across the Divide at some point in their evolutionary history. There is no compelling reason to believe that would have been an isolated incident.

Haplotypes representing Rio Grande Cutthroat Trout were recovered from all of the putative Rio Grande Core Conservation Populations sampled but not anywhere else outside of their native range. Substantial structure was indicated among these populations (Figure 2) consistent with earlier work on the subspecies (Behnke 1992; Behnke 2002; Pritchard and Cowley 2006; Pritchard et al. 2009) that showed significant differentiation between fish in the Pecos and Canadian drainages compared to those from the upper and lower Rio Grande basins. Our data are consistent with those findings, with a unique endemic haplotype found in the Pecos drainage (Streams 9, 10, and 14). Populations from the Canadian River drainage (Streams 22 and 36) also harbor some unique



**Figure 3: A minimum spanning network generated for haplotypes recovered (open circles) from a 648 bp variable region of the ND2 mitochondrial gene. Line segments represent a single mutation and black dots represent unsampled haplotypes. Numbers identify the population from which a given haplotype was detected.**

haplotypes that appear to align with the Pecos drainage clade. Two of twelve trout collected from Leandro Creek (Stream 39, NE New Mexico, Canadian River GMU) displayed a more common “main basin” Rio Grande haplotype. This population was founded from Ricardo Creek stock (not part of this study), that also showed similar haplotypic diversity that Pritchard et al. (2009) suggested might reflect past anthropogenic transplants.

Of particular interest were the haplotypes recovered among Green Lineage fish. While clearly members of the same clade, it is interesting to note that those recovered East of the Divide were not the same as those recovered on the West Slope. This was unexpected since the current paradigm suggests that those Green Lineage fish found east of the Divide were founded from early stocking efforts in the very early 1900s that derived their fish from West Slope sources (Metcalf et al. 2012). As such, we should expect them to share haplotypes with other West Slope populations, which they do not. In fact, the only trout that share the haplotype found in the South Prong of Hayden Creek (Stream 3, SE Colorado, Arkansas River GMU) are a pair of specimens collected by David Starr Jordan in 1889 from Twin Lakes in the headwaters of the Arkansas basin, now housed at the Smithsonian (Metcalf et al. 2012). Although numerous species of nonnative salmonids had already been stocked into Twin Lakes by 1889, it does suggest the possibility at least, that Green Lineage fish may have again found their way across the Divide, into the Arkansas basin during the recent Pleistocene and begun to differentiate.

While sequence divergence among the different lineages of Cutthroat Trout is perhaps more subtle compared to other recognized coldwater fish species of the Rocky Mountains (Whiteley et al. 2006, Young et al. 2013), it is clear that enough structure exists to begin to suggest phylogenetic relationships in addition to identifying where remnants of past diversity might remain. Rare haplotypes (those found in only a single population) were recovered from three of the four lineages. Like earlier studies (Metcalf et al. 2012), the haplotype that matched those historically found in the South Platte basin were only recovered from Bear Creek (Stream 49, SE Colorado, Arkansas River GMU) on the eastern flanks of Pikes Peak, reconfirming the value of this population for

conservation efforts. Rare haplotypes recovered in both Rio Grande Cutthroat Trout and Green Lineage populations tended to occur around the periphery of their respective ranges or in marginal habitats lacking headwater lakes that may have attracted the attention of early fish culturists.

Only Green Lineage fish seem to be largely unaccounted for in terms of assignment to a recognized taxonomic group in the southern Rocky Mountains. Regardless of whether formal designation as a subspecies is warranted or if Green Lineage fish simply come to be known as an evolutionary significant unit or distinct population segment within Colorado River Cutthroat Trout, it is critical that we seek to preserve the substantial diversity contained in this lineage. With only 60 conservation populations identified to date (Rogers 2012b), these fish clearly deserve our attention if we are to preserve that diversity for future generations. Our hope is that management efforts will focus less on what trout from a given location are called, and more on preserving the native genetic diversity contained in them, regardless of where it is found on the landscape.

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## LITERATURE CITED

- Alves, J. E., K. A. Patten, D. E. Brauch, and P. M. Jones. 2008. Range-wide status of Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*): 2008. Colorado Division of Wildlife, Fort Collins. Available: <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/RGCTStatusAssessment2008.pdf>. Available: (August 2014).
- Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6, Bethesda, Maryland.
- Behnke, R. J. 2002. Trout and salmon of North America. The Free Press. New York, New York.
- Bestgen, K. R., K. B. Rogers, and R. Granger. 2013. Phenotype predicts genotype for lineages of native cutthroat trout in the Southern Rocky Mountains. Final Report to U. S. Fish and Wildlife Service, Colorado Field Office, Denver Federal Center (MS 65412), Denver, CO. Larval Fish Laboratory Contribution 177.
- Campton, D. E., and L. R. Kaeding. 2005. Westslope cutthroat trout, hybridization, and the U. S. Endangered Species Act. *Conservation Biology* 19:1323-1325.
- CRCT Conservation Team. 2006. Conservation agreement for Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) in the States of Colorado, Utah, and Wyoming. Colorado Division of Wildlife, Fort Collins. 10 p. Available: [http://cpw.state.co.us/Documents/Research/Aquatic/pdf/CRCT\\_Conservation\\_Agreement\\_Final\\_Dec06.pdf](http://cpw.state.co.us/Documents/Research/Aquatic/pdf/CRCT_Conservation_Agreement_Final_Dec06.pdf) (August 2014.)
- Evans, R. P. and D. K. Shiozawa. 2000. The genetic status of selected cutthroat trout populations in Colorado. May 1, 2000. Brigham Young University, Provo, Utah.
- Excoffier, L. G. Laval, and S. Schneider. 2005. Arlequin ver. 3.0: An integrated software package for population genetics data analysis. *Evolutionary Bioinformatics Online* 1:47- 50.
- Felsenstein, J. 1985. Confidence limits on phylogenies: an approach using the bootstrap. *Evolution* 39:783-791.
- Hirsch, C. L., M. R. Dare, and S. E. Albeke. 2013. Range-wide status of Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*): 2010. Colorado River Cutthroat Trout Conservation Team Report. Colorado Parks and Wildlife, Fort Collins. Available: <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/CRCTRangewideAssessment-08.04.2013.pdf>
- Lischer H. E. L. and L. Excoffier. 2012. PGDSpider: An automated data conversion tool for connecting population genetics and genomics programs. *Bioinformatics* 28: 298-299.
- Loxterman, J. L. and E. R. Keeley. 2012. Watershed boundaries and geographic isolation: patterns of diversification in cutthroat trout from western North America. *BMC Evolutionary Biology* 12:38 (<http://www.biomedcentral.com/1471-2148/12/38>)
- Metcalfe, J. L., V. L. Pritchard, S. M. Silvestri, J. B. Jenkins, J. S. Wood, D. E. Cowley, R. P. Evans, D. K. Shiozawa, and A. P. Martin. 2007. Across the great divide: genetic forensics reveals misidentification of endangered cutthroat trout populations. *Molecular Ecology* 16:4445-4454.
- Metcalfe, J. L., S. L. Stowell, C. M. Kennedy, K. B. Rogers, D. McDonald, J. Epp, K. Keepers, A. Cooper, J. J. Austin, and A. P. Martin. 2012. Historical stocking data and 19th century DNA reveal human-induced changes to native diversity and distribution of cutthroat trout. *Molecular Ecology* 21:5194-5207.
- Nei, M., and S. Kumar. 2000. *Molecular Evolution and Phylogenetics*. Oxford University Press, New York.
- Pritchard, V.L., and D.E. Cowley. 2006. Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available: <http://www.fs.fed.us/r2/projects/scp/assessments/riograndecutthroattrout.pdf>
- Pritchard, V. L., J. L. Metcalfe, K. Jones, A. Martin, and D. E. Cowley. 2009. Population structure and genetic management of Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis*). *Conservation Genetics* 10:1209–1221.
- Proebstel, D. S., A. M. Martinez, and R. P. Ellis. 1996. Taxonomic status of cutthroat trout, Rio Grande suckers, and Arkansas darters determined through morphometric, meristic, and mitochondrial DNA analysis, unpublished report, Colorado State University, Fort Collins.
- RGCT Conservation Team. 2013. Conservation Agreement for Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis*) in the states of Colorado and New Mexico. Colorado Division of Parks and Wildlife, Denver. 29p. <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/2013RGCTConservationAgreement.pdf> (August 2014.)
- Rogers, K. B. 2008. Using amplified fragment length polymorphisms to characterize purity of cutthroat trout in Colorado: results from 2007. Colorado Division of Wildlife, Fort Collins. Available: <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/2007AFLPSummary.pdf> (August 2014).
- Rogers, K. B. 2010. Cutthroat trout taxonomy: exploring the heritage of Colorado's state fish. Pages 152-157 in R. F. Carline and C. LoSapio, editors. *Wild Trout X: Sustaining wild trout in a changing world*. Wild Trout Symposium, Bozeman, Montana. Available: <http://www.wildtroutsymposium.com/proceedings.php>

- Rogers, K. B. 2012a. Genetic purity assessment of select Colorado River cutthroat trout populations in northwest Colorado. Wildlife Conservation Grant final report. Colorado Parks and Wildlife, Fort Collins. Available: <http://cpw.state.co.us/Documents/Research/Aquatic/CutthroatTrout/2011WCGrantReport.pdf>. (August 2014).
- Rogers, K. B. 2012b. Characterizing genetic diversity in Colorado River cutthroat trout: identifying Lineage GB populations. Colorado Division of Wildlife, Fort Collins.
- Rzhetsky, A., and M. Nei. 1992. A simple method for estimating and testing minimum evolution trees. *Molecular Biology and Evolution* 9:945-967.
- Saitou, N., and M. Nei. 1987. The neighbor-joining method: a new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution* 4:406-425.
- Tamura, K., M. Nei, and S. Kumar. 2004. Prospects for inferring very large phylogenies by using the neighbor-joining method. *Proceedings of the National Academy of Sciences (USA)* 101:11030-11035.
- Tamura K., J. Dudley, M. Nei, and S. Kumar. 2007. MEGA4: Molecular Evolutionary Genetics Analysis (MEGA) software Version 4.0. *Molecular Biology and Evolution* 24:1596- 1599.
- Teacher, A. G. F. and D. J. Griffiths. 2011. HapStar: Automated haplotype network layout and visualisation. *Molecular Ecology Resources* 11: 151-153
- Thompson, J. D., D. G. Higgins, and T. J. Gibson. 1994. ClustalW-improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. *Nucleic Acids Research* 22:4673-4680.
- UDWR. 2000. Genetic considerations associated with cutthroat trout management: a position paper. Publication Number 00-26, Utah Division of Wildlife Resources, Salt Lake City, Utah. Available: <http://cpw.state.co.us/learn/Pages/ResearchColoradoRiverCutthroatTrout.aspx>. (July 2014).
- Whiteley, A. R., P. Spruell, and F. W. Allendorf. 2006. Can common species provide valuable information for conservation. *Molecular Ecology* 15:2767-2786.
- Wright, S. 1943. Isolation by distance. *Genetics* 28:114-138.

## WHITewater BALDY FIRE: WHAT DOES IT MEAN FOR GILA TROUT RECOVERY?

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**Abstract**—The 2012 Whitewater Baldy Fire was the largest recorded wildfire in New Mexico, burning over 120,000 ha of the Gila National Forest and encompassing much of the current range of the Gila Trout *Oncorhynchus gilae*, a federally- and state-protected species. Nine of 17 recovery populations were impacted, including three remnant populations. During and immediately after the fire, individuals from remnant populations were evacuated and taken to Mora National Fish Hatchery (NFH) and stocked in available habitats. Fish raised at Mora NFH will be used to establish populations as streams again become capable of supporting Gila Trout. Given the location and severity of the burn, it is likely that rainfall events will continue to impact streams and diminish habitat quality. Although the fire was a serious setback for Gila Trout recovery, it also presents opportunities to increase the number of Gila Trout populations. The fire eliminated or greatly reduced nonnative trout populations in several streams identified as suitable for Gila Trout restoration. Assessments of fire-affected streams are being conducted. Results of these efforts will guide future Gila Trout conservation activities, especially in stream selection and timing of stocking activities.

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### INTRODUCTION

Much progress in understanding wildfire effects on western trout and aquatic ecosystems has been made in the past two decades (e.g., Propst et al. 1992; Rinne 1996, 2004; Rieman and Clayton 1997; Gresswell 1999; Dunham et al. 2003). The effects on southwestern native trout appear to be particularly deleterious (Propst et al. 1992; Rinne 1996, 2004). Because of isolation due to altered hydrology and introduction of nonnative fishes, native trout of the American Southwest occur mainly as disconnected, small populations (Minckley and Marsh 2009). Population fragmentation coupled with over a century of fire suppression has made southwestern native trout especially vulnerable to wildfire (Gresswell 1999). In the southwest, the spring and early summer fire season is immediately followed by the late summer monsoon season. In many cases, fires are extinguished by monsoon rains that wash ash and associated high levels of trace elements into streams (Gresswell 1999). The continuing drought cycle in the southwest has potentially made wildfire the ultimate limiting factor to the persistence of native fishes that occupy upper elevation aquatic habitats (Brown et al. 2001; Rinne 2004).

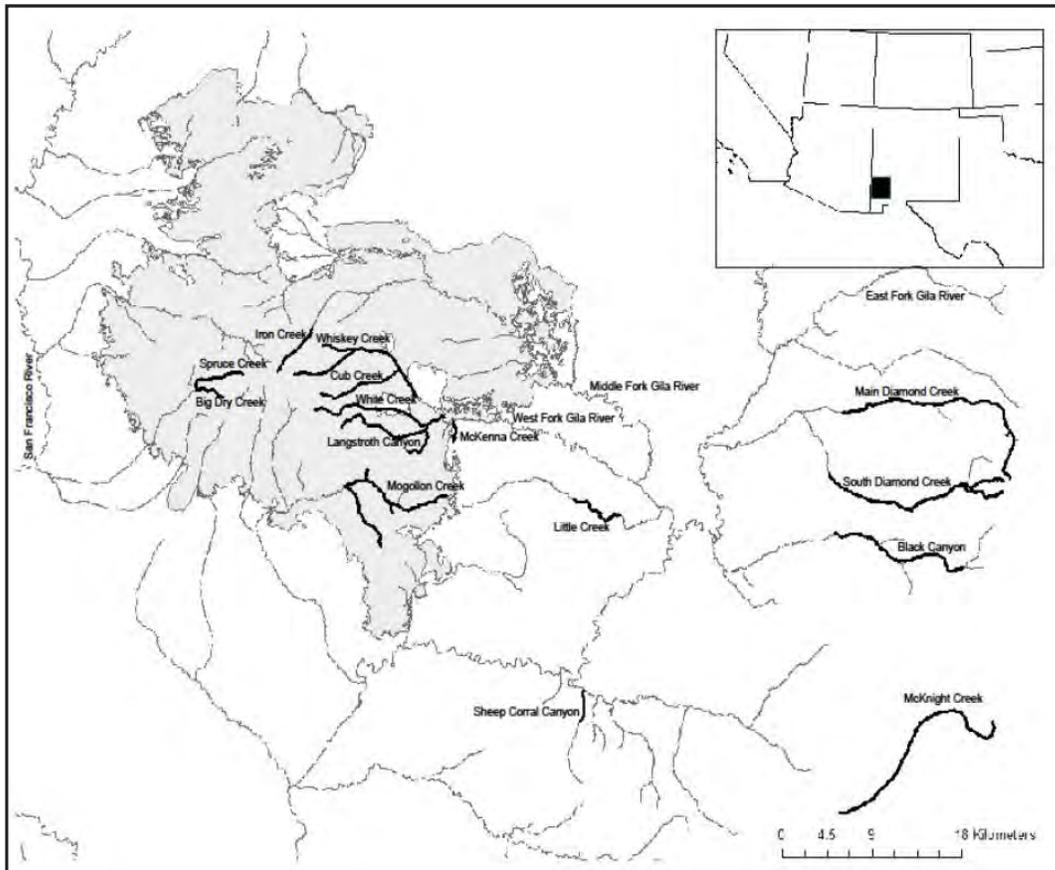
Wildfire has been a realized threat to Gila Trout *Oncorhynchus gilae* recovery since the 1989 Divide

Fire eliminated one remnant population and reduced another (Propst et al. 1992). Brown et al. (2001) suggested that wildfire was the most important risk factor for Gila Trout. Gila Trout occupy streams in an arid and harsh environment that is characterized more by environmental stochasticity than constancy (Propst and Stefferud 1997). The species' small range and limited dispersal capabilities and opportunities make it especially susceptible to wildfire (Rinne 1982, Propst et al. 1992, Propst and Stefferud 1997, Brown et al. 2001).

The objective of this paper is to provide an overview of how the Gila Trout recovery effort has evolved in response to wildfire effects on extant Gila Trout populations and to explore opportunities created by wildfire. The 2012 Whitewater Baldy Fire starkly illustrates the challenges Gila Trout will face in the future.

### History of Gila Trout Conservation

Gila Trout are now restricted to small first- to third-order streams in the Gila-San Francisco drainage of southwest New Mexico and southeast Arizona (Figure 1). Habitats are highly variable and few occupied streams have continuous surface flow, particularly during early summer. Most extant Gila Trout populations are in federally designated



**Figure 1. Gila Trout populations in the Gila-San Francisco River drainage of southwest New Mexico. Grey indicates area burned by Whitewater Baldy Fire. Arizona populations of Gila Trout (Grapevine, Frye, and Ash creeks) are not indicated.**

wilderness areas within the Gila National Forest where human visitation and disturbances are minimal.

Within the range of Gila Trout, wildfires historically consisted of cool-burning understory fires with return intervals of 3-7 years in ponderosa pine forests and 75-100 years in mixed-conifer forests at higher elevations (Swetnam and Dieterich 1985). In the early 1900s, however, fuel loads began to increase as a result of fire suppression by the U.S. Forest Service (Swetnam and Dieterich 1985). The resultant increase in woody debris on the forest floor and increased sapling density increased the potential for catastrophic crown fires (Rieman and Clayton 1997).

Efforts to conserve Gila Trout began in 1923 with the establishment of Jenks Cabin Hatchery by the New Mexico Department of Game and Fish and the agency followed a policy of not stocking nonnative salmonids into streams known to support Gila Trout (Miller 1950). Despite these and other efforts, Gila Trout was listed as endangered under the Endangered Species

Preservation Act of 1966, the Endangered Species Act of 1973, and the New Mexico Wildlife Conservation Act of 1974. At the time of its listing, five remnant populations persisted. The initial Gila Trout Recovery Plan (1979) focused on establishing additional populations of each remnant lineage using donor fish from the population being replicated. By 2006, sufficient progress had been made to enable down-listing of Gila Trout from ‘endangered’ to ‘threatened’ (USOFR 2006).

The first fire to impact Gila Trout since the recovery program began was the 1989 Divide Fire, which burned much of the watershed of Main and South Diamond creeks. Despite having little knowledge of fire effects on fish, a decision was made to evacuate trout from Main Diamond Creek. Post fire ash flow eliminated fish from Main Diamond Creek and significantly reduced numbers in South Diamond Creek. The experience of the Divide Fire prompted a practice of evacuating fish from fire-imperiled remnant

**Table 1. History of fire impacts to Gila Trout populations from the time each population was established to 2014.**\* *Evacuated fish died in captivity.*

STREAM	YEAR ESTABLISHED	FIRE, YEAR	EFFECT/RESULT
Main Diamond	remnant	Divide, 1989	evacuated, eliminated, restored 1994
McKnight	1970	McKnight, 1955	reduced pop as a result of flood in 1988
		Silver, 2013	eliminated
Sheep Corral	1972	Shelley, 1989	survived
Black	1998	Bonner, 1995	eliminated Brown Trout
		Aspen, 2007	survived
		Silver, 2013	unknown
Little	2000	Bloodgood, 2000	reduced population
		Dry Lakes, 2003	reduced population
		Miller, 2011	reduced population
White	2000	LL Complex, 1996	eliminated below fire, survived above fire
		Whitewater Baldy, 2012	eliminated
West Fork Gila	2010	Whitewater Baldy, 2012	significantly reduced population
<b>South Diamond</b>	remnant	Divide, 1989	reduced population
		Bonner, 1995	eliminated, restored 1997
		Silver, 2013	evacuated, survived
Mogollon	1987-1989, 1998	Sprite, 1995	evacuated, reduced population
		LL Complex, 1996	evacuated, eliminated
		Dry Lakes, 2003	evacuated, reduced population
		Whitewater Baldy, 2012	survived
Grapevine	2009		
Frye	2009		
Cub	2010	Whitewater Baldy, 2012	eliminated
<b>Whiskey</b>	remnant	Cub, 2002	evacuated*, reduced population
		Bear Wallow, 2006	evacuated*, survived
		Whitewater Baldy, 2012	evacuated, eliminated
Langstroth	2006	Whitewater Baldy, 2012	evacuated, eliminated
McKenna	2012		
Iron	remnant	Whitewater Baldy, 2012	evacuated. unknown
<b>Spruce</b>	remnant	Spruce, 1994	evacuated*, remaining fish survived
		Whitewater Baldy, 2012	evacuated*, eliminated
Big Dry	1985	Whitewater Baldy, 2012	unknown
Raspberry	2000	Wallow, 2011	eliminated
Ash	2011		
Dude	2000	Dude, 1989	failed to establish due to post fire stream recovery

populations. Since the Divide Fire, 14 wildfires have burned in watersheds occupied by Gila Trout, affecting all but three populations. Collectively, these fires eliminated 10 Gila Trout populations and significantly

impacted nine others (Table 1). Nine streams having Gila Trout, including three remnant populations, and eight potential recovery streams were within the perimeter of the 120,627-ha Whitewater Baldy Fire.

## METHODS

On 7 June 2012, an aerial assessment of Gila Trout streams affected by the Whitewater Baldy Fire was made. The assessment focused on determining extent and severity of the burn, occupied stream reaches relative to burned areas, and extent of riparian burn with the aim of estimating the likelihood of catastrophic flows during subsequent rain events. A numerical system was used to qualitatively assess fire impacts and assign a rank based on observations. For extent and severity of the fire within a stream, a 1-10 scale was used to rate fire extent and severity (1 = none and 10 = all [extent] or high [severity]). Fish location relative to fire was ‘above’ = 1 and ‘within’ or ‘below’ = 3. Burned stream banks equaled 1 and unburned was 0. Summed values greater than 15 indicated major impacts to habitat and fish population were likely and values greater than 20 indicated catastrophic impacts and extended time ( $\geq 5$  years) for watershed recovery were probable. This assessment was used to determine priority of streams to be sampled, with the most severely impacted being the highest priority for evaluation.

Post-fire assessments of occupied and potential recovery streams consisted of on-site visual surveys that characterized burn severity, burn extent, riparian area burn, estimates of bank stability and remaining canopy, determining dominant channel substrate and habitats, and evidence of debris flows. Following visual assessment, the stream was electrofished to determine if fish were present. Mass and length were obtained for all captured fish, and native specimens were returned alive to stream at capture point. The purpose of this effort was to obtain empirical information upon which future restorations might be planned and scheduled.

## RESULTS

The aerial assessment, although a rough evaluation, indicated that most, if not all, Gila Trout streams within Whitewater Baldy perimeter likely had suffered major impacts (Table 2). Because of the relative insecurity of their lineages and the potential for fire-impacts, Whiskey and Spruce creeks were identified as the highest priority populations for evacuation.

Whiskey Creek is a small tributary to West Fork Gila River and supported a remnant population of Gila Trout that was not held at Mora National Fish Hatchery (NFH) at time of the fire, but was replicated in Langstroth Canyon. Unfortunately, Langstroth Canyon watershed was severely burned during the Whitewater Baldy Fire. Consequently, it was critical that the Whiskey Creek population be evacuated, and in mid June 340 Gila Trout were captured and transported by helicopter to a hatchery truck and then Mora NFH, where they are currently held.

Spruce Creek supports the only remnant population in the San Francisco River drainage and was only replicated in Big Dry Creek, into which Spruce Creek flows. Previously, the 2011 Wallow Fire had eliminated a replicate Spruce population in Raspberry Creek and its replicate in Dude Creek had failed. In late June, 306 Gila Trout were collected, taken by helicopter to Glenwood, New Mexico where the lot was split with 250 being stocked in Ash Creek and the remaining transferred to Mora NFH.

The third post-Whitewater Baldy Fire rescue effort involved collecting Gila Trout from Langstroth Canyon in early July 2012, after ash flows had diminished the population, and stocking them ( $n = 69$ ) in the recently renovated McKenna Creek. Evacuation of Gila Trout from Iron Creek (May 2013) was the

**Table 2. Burn impact assessment of Gila Trout occupied and potential recovery streams immediately following the Whitewater Baldy Fire, 2012. Fish location: 3 = above or within burn, 0 = below burn; Riparian burned: 1=yes, 0=no.**

STREAM	BURN EXTENT	BURN SEVERITY	FISH LOCATION	RIPARIAN BURNED	TOTAL
Iron	4	9	3	1	17
Whiskey	10	10	3	1	24
White	7	8	3	1	19
Cub	6	6	3	1	16
Langstroth	5	8	3	1	17
Big Dry	6	6	3	1	16
Spruce	4	6	3	1	14

final evacuation in response to the Whitewater Baldy Fire.

During April 2013 to July 2014, 14 affected streams were surveyed. Of eight streams occupied by Gila Trout prior to the fire, trout were present in only three after the fire (Table 3).

When surveyed in May 2013, trout were found in upper-most Iron Creek only where fire intensity was low along the stream; elsewhere fish were absent. Multiple age classes were found, and electrofishing catch rates were 0.52 trout/min. Numerous debris piles were present, but little ash or fine sediment was observed. Above the reach occupied by trout, fire severity was high and scouring flows associated

with intense summer storms were deemed likely to adversely affect this population.

Surveys of the entire upper West Fork Gila River drainage during May 2013 yielded two Gila Trout. Both were collected in the West Fork Gila River just upstream of a barrier waterfall (i.e., the downstream terminus of pre-fire Gila Trout occupied habitat). Impacts to the drainage were progressively more severe from the barrier waterfall upstream. Ash, fine sediment, and sand accumulations were observed in much of the drainage and were especially pronounced in pools. Debris piles were present in all streams. In portions of Langstroth Canyon and Whiskey and upper White creeks, channels were scoured to bedrock.

**Table 3. Status of extant Gila Trout populations and potential recovery streams, 2014.**

STREAM	LINEAGE	STATUS	km
<b><u>Dedicated Gila Trout Streams</u></b>			
<b>Main Diamond</b>	Remnant	stable	6.1
McKnight	Main Diamond	eliminated	8.5
Sheep Corral	Main Diamond	stocked, not sustaining	1.3
Black	Main Diamond	new population	18.2
Little	Main Diamond	stable	6.0
Upper White	Main Diamond	eliminated	8.8
West Fork Gila	Main Diamond	hybridized	4.5
<b>South Diamond</b>	Remnant	stable	6.7
Mogollon	South Diamond	stable	27.1
Grapevine	South Diamond	stable	2.4
Frye	South Diamond	stable	8.0
Cub	South Diamond	eliminated	25.2
<b>Whiskey</b>	Remnant	eliminated	2.6
Langstroth	Whiskey	eliminated	4.3
McKenna	Whiskey	new population	1.8
<b>Iron</b>	Remnant	survived as of May 2013	3.2
<b>Spruce</b>	Remnant	eliminated	3.7
Big Dry	Spruce	unknown	1.9
Ash	Spruce	new population	2.0
<b><u>Potential Gila Trout Streams</u></b>			
Willow		brown trout	5.6
Turkey		rainbow trout	26.1
Rain		rainbow trout	11.3
WF Mogollon		rainbow trout	10.0
Whitewater		unknown	14.4
SF Whitewater		brook trout	6.8
Mineral		No Fish	2.9
Lower Big Dry		unknown	12.0

Where the adjacent slopes were not intensely burned, channel scouring was less and accumulation of fine sediment was not great.

Of the streams within the perimeter of Whitewater Baldy Fire sampled to date, Mogollon Creek was least affected. Gila Trout were present in all sampled portions; electrofishing catch rates were 1.94 trout/min. Aquatic habitats were only slightly affected by the fire as little ash or fine sediments were noted, and the fire did not burn in the immediate vicinity of the stream.

Nonnative salmonids were eliminated from at least one potential recovery stream. Large debris flows in Mineral Creek diminished habitat quality throughout much of the stream and only a 1.5-km reach appeared suitable for immediate Gila Trout restoration. Nonnative fish populations were significantly reduced in two streams, Willow Creek and South Fork Whitewater Creek. Four Brown Trout *Salmo trutta* and three Brook Trout *Salvelinus fontinalis*, respectively, were collected in these streams. Two streams supporting nonnative trout prior to the Whitewater Baldy Fire and within its perimeter remain to be surveyed.

## DISCUSSION

The effects of wildfire on aquatic ecosystems may be direct and immediate or indirect and occur over an extended period (Gresswell 1999). Multiple fires within the range of Gila Trout (Divide, Bonner, LL Complex, Wallow, Whitewater Baldy) have had the direct and immediate effect of eliminating fish. These and other fires have had long-term impacts to Gila Trout populations by the slow return of habitats to pre-fire quality. The 1955 McKnight Fire had consequences for a Gila Trout population 33 years later when catastrophic flooding in the still recovering watershed scoured the stream and significantly reduced the Gila Trout population (Propst et al. 1992). Multiple scouring flows after the 1989 Dude Fire prevented successful establishment of Gila Trout in Dude Creek. In addition, streams that experienced multiple fires have little chance to recover and sustain fish populations. Little Creek has burned three times within the past 13 years and although none of these fires eliminated fish, abundance of Gila Trout there has been suppressed compared to nonnative trout numbers prior to renovation.

Dunham et al. (2003) suggested that fires are patchy in their burn severity and that in larger habitats it is less likely that a patchy fire will affect all occupied habitats with the same intensity. This was seen on Iron Creek, where fish were eliminated in stretches where the Whitewater Baldy Fire burned with great intensity and trout survived where the burn was less severe. However, in a small watershed such as Iron Creek, this is likely a short-term condition, as runoff from burned slopes upstream of the unburned reaches will likely eliminate surviving fish.

The Whitewater Baldy Fire may present opportunities for establishing new recovery populations where the fire eliminated nonnative salmonids, especially in streams such as Whitewater Creek where chemical renovation would be unlikely because its lower-most reaches flow through residential areas. Past fires presented opportunities for expanding Gila Trout populations and these were taken. Gila Trout was restored to Black Canyon after the 1995 Bonner fire eliminated Brown Trout. The 2011 Miller Fire reduced Rainbow Trout *Oncorhynchus mykiss* sufficiently in McKenna Creek that mechanical removal could be used to eliminate them.

The 1989 Divide Fire and its impact on Gila Trout populations, prompted, in part, the withdrawal of a proposal to down-list the species from ‘endangered’ to ‘threatened’ and forced managers to reevaluate recovery strategies (Propst et al. 1992). Recovery efforts to this point had focused on reclaiming individual, isolated headwaters. However, the fires as well as flooding, genetic contamination, and drought, demonstrated that this approach was inadequate. Consequently the revised recovery plan identified restoring large and hydrologically complex drainages as essential to implementing a meta-population approach to recovery (USFWS 2003). Doing so would not only yield numerically larger populations, but would increase the likelihood that a single event would not eliminate an entire population. Rather, fish in unaffected portions of the drainage would colonize affected reaches as they recovered from natural catastrophic events. In addition, a genetic brood-stock management plan was developed to ensure genetic viability of all captive hatchery stocks (Kincaid and Reisenbichler 2002). To provide for orderly execution of evacuations prompted by fire, an emergency evacuation plan was adopted (Brooks 2004). Finally,

Mora NFH was enlisted to provide captive rearing and holding facilities for Gila Trout.

The importance of a watershed approach to recovery and management has been long recognized, and recent investigations into wildfire effects on native fishes suggest that the key to resiliency lies in maximizing the size and connectivity of occupied habitats and populations (Gresswell 1999, Brown et al. 2001, Dunham et al. 2003, Rinne 2004). Within its six streams, the upper West Fork Gila River drainage had almost 50 km of habitat, making it the largest catchment suitable for Gila Trout restoration. It was hoped, if not believed, that it was sufficiently large and complex that no single natural event would eliminate its meta-population. The Whitewater Baldy Fire disproved that notion. It eliminated all Gila Trout from the upper West Fork Gila River and impacted four populations in adjacent catchments. All previous fires affected only one or two streams. Since 2011, three fires (Wallow, Whitewater Baldy, and Silver) exceeding 40,000 ha have burned in Gila Trout occupied watersheds, and climate scientists are predicting that wildfires of this size are the new 'normal' (Westerling et al. 2006). For species such as Gila Trout that have small ranges and limited opportunities to expand their distribution, this becomes an especially vexing problem. Survival will require maintenance of captive stocks for replenishment of lost populations and reclaiming the few large and hydrologically complex drainages available for Gila Trout.

## REFERENCES

- Brooks, J.E. 2004. Emergency evacuation procedures for Gila Trout. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.
- Brown, D.K., A. A. Echelle, D. L. Propst, J. E. Brooks, and W. L. Fisher. 2001. Catastrophic wildfire and number of populations as factors influencing risk of extinction for Gila trout (*Oncorhynchus gilae*). *Western North American Naturalist* 61:139-148.
- Dunham, J.B., M.K. Young, R.E. Gresswell, and B.E. Rieman. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. *Forest Ecology and Management* 178: 183-196.
- Gresswell, R.E. 1999. Fire and aquatic ecosystems in forested biomes of North America. *Transactions of the American Fisheries Society* 128: 193-221.
- Kincaid, H.L., and R. Reisenbichler. 2002. Gila Trout – genetic broodstock management plan. U.S., Fish and Wildlife Service, Region 2, Albuquerque, New Mexico.
- Miller, R.R. 1950. Notes on the cutthroat and rainbow trouts with the description of a new species from the Gila River, New Mexico. *Occasional Papers of Museum of Zoology, University of Michigan*, 529:1-42.
- Minckley, W.L., and P.C. Marsh. 2009. *Inland Fishes of the Greater Southwest; Chronicle of a Vanishing Biota*. The University of Arizona Press, Tucson.
- Propst, D.L., J.A. Stefferud, and P.R. Turner. 1992. Conservation and status of Gila trout, *Oncorhynchus gilae*. *The Southwest Naturalist* 37: 117-125.
- Propst, D.L., and J.A. Stefferud. 1997. Population dynamics of Gila trout in the Gila River drainage of the southwestern United States. *Journal of Fish Biology* 51: 1137-1154.
- Rieman, B.E., and J. Clayton. 1997. Wildfire and native fish: Issues of forest health and conservation of sensitive species. *Fisheries* 22: 6-15
- Rinne, J.N. 1982. Movement, home range, and growth of a rare Southwestern trout in improved and unimproved habitats. *North American Journal of Fisheries Management* 2: 150-157.
- Rinne, J.N. 1996. Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the southwestern United States. *North American Journal of Fisheries Management* 16: 653-658.
- Rinne, J.N. 2004. Forests, fish and fire: Relationships and management implications for fishes in the southwest USA. Pages 151-156 in G.J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins and M. Monita, Editors. *Forest Land-Fish Conference II – Ecosystem Stewardship through Collaboration*. Proc. Forest-Land-Fish Conf II, April 26-28, Edmonton, Alberta.
- Swetnam, T.W., and J.H. Dieterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. Pages 390-397 in J.E. Lotan et al., technical coordinators, *Proceedings: symposium and workshop on wilderness fire*. USDA Forest Service General Technical Report INT 182.
- Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase in western U.S. forest wildfire activity. *Science* 313: 940-943
- USFWS (U.S. Fish and Wildlife Service). 2003. Gila trout (*Oncorhynchus gilae*) recovery plan. U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico.
- USOFR (U.S. Office of the Federal Register). 2006. Reclassification of the Gila Trout (*Oncorhynchus gilae*) from endangered to threatened; special rule for Gila Trout in New Mexico and Arizona, final rule. *Federal Register* 71:173 (18 July 2006): 40657 -40673



Photo courtesy of Eric Stark.

# Session 6

## Regulations and Stocking





## CONTEMPORARY ROLE OF SPECIAL REGULATIONS IN WILD TROUT MANAGEMENT: ASSESSMENT OF BIOLOGIST VIEWS IN THE EASTERN AND MIDWESTERN U.S.

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**Abstract**—We evaluated the current and future role of special regulations in wild trout management by surveying 18 trout biologists representing 16 states and two national parks throughout the Eastern and Midwestern U.S. Each biologist was provided a written survey that contained 25 questions. For this project, special regulations were defined as angling regulations that impose tackle or harvest restrictions well beyond general statewide (or park-wide) trout angling regulations. Survey results indicated that special regulations are most commonly applied to headwater and moderate-size streams that are productive or receive high angler use. Brook Trout *Salvelinus fontinalis* were the most common species managed under special regulations. The proportion of waters managed for Brook Trout under special regulations in each state ranged from <1% to 50% (median = 6%). Shenandoah National Park has park-wide special regulations for Brook Trout and Great Smoky Mountains National Park has special regulations on about one-third of its trout waters. Biological and social motivations were equally important in implementing special regulations. Most (61%) biologists responded that the use of special regulations in wild trout management is warranted based solely on social preferences. Nearly one-half (44%) of respondents indicated there has been significant negative public reaction to special regulations that restricted harvest or gear type. Biologists favored maintaining (44%) or increasing (11%) the number of specially regulated waters in their state; 22% favored a reduction. Biologists were evenly divided as to whether or not their agency's view of special regulations was consistent (50%) or at odds (44%) with that of organized angling groups. Respondents were divided on whether or not their agency's special regulations were unduly restrictive. All respondents agreed that special regulations affected participation by certain sectors all of the time (44%) or at least some of the time (56%). One-half (50%) of respondents felt special regulations resulted in increased fishing pressure, while 22% said no change, 11% said it decreased, and 17% were uncertain or indicated it may increase or decrease based on the individual fishery. Most (89%) biologists felt that use of bait can be compatible with special regulations, and 56% stated that bait was allowed in at least some of their waters managed under special regulations. Respondents indicated that their biggest challenges were conducting rigorous biological evaluations of special regulations and helping the public understand what special regulations can and cannot do. Whether implemented for social or biological reasons, we conclude that special regulations are and will continue to be an important tool for managing wild trout in the Eastern and Midwestern U.S. Nonetheless, considerable work is still needed to better understand and communicate the role of special regulations.

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### INTRODUCTION

Fisheries management is a complex, dynamic activity that involves biological, social, political, and economic factors that are continuously interacting (Wydoski 1977). Special regulations (e.g., catch-and-release, elevated minimum size limits, maximum size limits, slot limits, reduced creel limits, and tackle restrictions) are a common tool used in wild trout management. Special regulations gained in popularity from the late 1960s through the 1980s in response

to increased angling pressure, a harvest-oriented angling public, social influences, and decreasing wild trout stocks. During the Wild Trout I Symposium in 1974, a technical session titled, “*Regulations, Political Realities, and the Angler Panel*” included three presentations that discussed angling regulations. Presentations by Whitney (1974) and Hunt (1974) outlined some of the initial attempts at using special regulations in wild trout management along with the challenges and in some cases controversy associated with them, while Abele (1974) discussed politics

in wild trout management. Presentations or entire technical sessions have discussed angling regulations in each of the subsequent Wild Trout Symposia, including Wild Trout XI. The frequency and continued recurrence of these presentations and discussions outlines the ongoing importance of special regulations in wild trout management, but may also indicate that fishery managers continue to struggle with similar issues over time.

While there was a prevalent biological need for increased conservation and more restrictive angling regulations in the 1960-1980 era, angler sentiment began shifting in the late 1980s and early 1990s to higher levels of voluntary catch-and-release. Graff (1987) surveyed fishery managers across the U.S. and reported that the concept of catch-and-release grew substantially in popularity as both a wild trout management tool and personal philosophy during the prior decade. The shift in angler sentiment was further outlined by Kellert (1980) and Duda et al. (1999). In a nationwide telephone survey, Kellert (1980) reported that the top three reasons people fish were to catch food to eat, fishing for sport, and being with friends and family. Two decades later, Duda et al. (1999) conducted a similar survey and reported that the top three reasons people fish shifted to relaxation, being with family and friends, and being close to nature. Numerous additional state-specific angler surveys during the 2000s suggest the trend in angler sentiment is continuing (Duda et al. 2004a; 2004b; 2007; 2008) and creel surveys conducted by Reeser and Mohn (2004) documented 99% catch-and-release in Virginia wild trout streams, and Greene et al. (2005) documented 93% catch-and-release in Pennsylvania wild trout streams.

Even as angler sentiment was shifting, in a survey of Eastern state management agencies presented at the Wild Trout V Symposium, Graff (1994) reported that regulations on harvest were perceived as the most powerful tools for managing individual wild trout populations. Graff (1994) also noted that conflicting angler preferences and attitudes is a problem in wild trout management, and social preferences for regulations that are restrictive beyond what is necessary to achieve a biological objective can create problems when trying to build as broad a base as possible in support of wild trout. While numerous broad-scale surveys suggest that the angling public has shifted its focus over the past four decades to



**Figure 1. Map of the 16 states and two national parks in which biologists participated in the special regulations survey.**

the overall experience, rather than catching and harvesting large numbers of fish, these surveys may not capture local trends. As such, maintaining up-to-date fishery, angler use, and harvest data remains critically important to facilitating management at a stream-specific scale. So, as we approach the mid-2010s, what is the contemporary role of special regulations and what are the biggest challenges facing biologists with the use of special regulations in wild trout management? As part of the Wild Trout XI Symposium “*Looking Back and Moving Forward*”, we attempt to answer this question by offering a regional perspective of biologist views regarding the current and future role of special regulations in wild trout management in the Eastern and Midwestern U.S.

## METHODS

We sent a written survey to the primary trout biologist or coldwater unit leader in 14 Eastern states, three Midwestern states, and two national parks

during December 2012 (Figure 1). For this project, we defined special regulations as angling regulations that impose tackle or harvest restrictions well beyond general statewide (or park-wide) trout angling regulations. The survey contained 25 questions and was divided into seven general areas: (1) Participant characterization (n = 2), (2) Type of waters and to what extent special regulations are being used (n = 4), (3) Reasons for using special regulations (n = 5), (4) Attitudes toward special regulations (n = 5), (5) Effect of special regulations on angler participation (n = 3), (6) Use of bait in special regulation waters (n = 3), and (7) Future of special regulations (n = 3). Questions focused on Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, Rainbow Trout *Oncorhynchus mykiss*, or mixed-species (some combination these species) wild trout fisheries as these species comprise the wild trout fisheries in the Eastern and Midwestern U.S. For each question, all responses were tallied and pooled to provide the overall view of biologists. All responses in which a percentage is reported represents the number of responses per 18 total possible responses; however, not all biologists answered all 25 questions; thus, results may not add up to 100% for every question.

## RESULTS

### Participant Characterization

Surveys were completed by 18 of 19 biologists contacted, including 16 of 17 states (with the exception of Massachusetts) and both Shenandoah National Park and Great Smoky Mountains National Park (Figure 1). Results indicated that the biologists who participated in the survey are trout anglers with 89% stating that they fish for wild trout mostly using a combination of tackle types (61%), and the remainder using flies (22%), lures (11%), or bait (6%).

### Type of Waters and to What Extent Special Regulations are Being Used

Biologists indicated that special regulations are most commonly applied to headwater (78%) and medium-large (78%) streams and to a lesser degree on rivers (39%), tailwaters (39%), and lakes (28%; Table 1). Productive or high angler-use waters were identified as the most common type of water to receive special angling regulations (61%). Brook Trout were

the most common species managed under special regulations. The proportion of waters managed for Brook Trout under special regulations in each state ranged from <1% to 50% (median = 6%). Shenandoah National Park has park-wide special regulations for Brook Trout and Great Smoky Mountains National Park has special regulations on about one-third of its trout waters (Table 1). All biologists indicated that their respective state or park has special regulations for at least one trout species, with special regulations most commonly applying to Brook Trout (83%), followed by mixed trout species fisheries (78%), Brown Trout (61%), and Rainbow Trout (50%).

### Reasons for Using Special Regulations

Biologists indicated that the primary motivation for applying special regulations to Brook Trout, Brown Trout, Rainbow Trout, and mixed trout fisheries was fishery enhancement. Conservation of native species was also important to Brook Trout with social reasons ranking last. However, a follow-up question regarding the primary role of special regulations in wild trout management indicated that biologists were divided between whether the current role of special regulations are primarily biologically or socially based. Most (61%) biologists indicated that the use of special regulations in wild trout management is warranted based solely on social preferences. When asked to rank the importance of various factors on regulating wild trout populations, all biologists indicated that habitat and environmental conditions were more important than angling mortality, predation, or disease. When asked about their agency's view of special regulations, more biologists responded that it is biologically (47%) rather than socially (35%) based.

### Attitudes Toward Special Regulations

When asked if there has been a change in public attitude towards special regulations in recent years, equal percentages (44%) of biologists said there were no changes or there were requests for more. Only 11% of respondents indicated a request for fewer special regulations. However, a relatively large number of respondents (44%) indicated there has been significant negative public reaction to special regulations that restricted harvest or gear type in recent years, while the remainder (56%) indicated no significant reaction. When asked about their attitudes toward the number of waters managed under special regulations in their

Table 1. Summary of the wild trout resources managed under special regulations in the 16 states and two National Parks (NP) in the Eastern and Midwestern U.S. that participated in the survey.

State/National Park	Approximate number of waters with special regulations by trout species (approximate % of state or park-wide resource)				Primary type(s) of resource managed for wild trout under special regulations					Bait allowed with some special regulations	
	Brook Trout	Rainbow Trout	Brown Trout	Mixed trout species fisheries	Combined trout species (not reported separately)	Headwater streams	Medium -large streams	Rivers	Tail-waters		Lakes
Georgia	--	--	--	11 (10%)	--	X	X			X	
Maine	405 (34%)	3 (100%)	2 (67%)	--	--		X	X	X	X	
Maryland	12 (8%)	2 (<1%)	5 (<1%)	3 (<1%)	--	X	X	X			
Michigan	3 (0.1%)	--	9 (0.5%)	4 (0.2%)	--		X				
Minnesota	3 (<1%)	7 (36%)	--	23 (4%)	--	X	X				X
New Hampshire	16 (<1%)	--	--	--	--	X		X		X	X
New Jersey	9 (<5%)	2 (<5%)	11 (5%)	15 (7%)	--	X					
New York	--	--	--	--	293 (8%)	X	X	X	X	X	X
North Carolina	--	--	--	--	45 (3%)	X			X		X
Pennsylvania	10 (<1%)	1 (4%)	30 (<1%)	7 (<1%)	--		X				X
South Carolina	1 (6%)	6 (20%)	1(2%)	3 (4%)	--	X	X	X			X
Tennessee	30 (18%)	1 (<1%)	4 (4%)	11 (7%)	--	X	X		X		X
Vermont	3 (50%)*	--	--	7 (<5%)	--		X	X			X
Virginia	30 (50%)	10 (50%)	10 (60%)	5 (80%)	--	X	X		X		
West Virginia	6 (1%)	1 (<1%)	--	--	--	X	X	X			
Wisconsin	--	--	--	--	314 (13.5%)	X	X			X	X
Great Smoky Mountains NP	168 (24%)	149 (38%)	--	139 (38%)	--	X				X	
Shenandoah NP	60 (100%)	--	--	--	--	X					

\*Vermont reported to have 3 ponds containing Brook Trout managed under special regulations, but no streams.

respective state or park, 44% favored maintaining the current number in their state, 11% favored an increase, and 22% favored a reduction in specially regulated waters. Similarly, biologists reported that their agency favored maintaining (39%) or increasing (11%) the number of specially regulated waters in their state; 22% favored a reduction. Biologists were divided as to whether or not their agency's view of special regulations was consistent (50%) or at odds (44%) with that of organized angling groups.

### Effect of Special Regulations on Participation

All respondents agreed that special regulations affected participation by certain sectors all of the time (44%) or at least some of the time (56%), while respondents were divided on whether or not their agency's special regulations were unduly restrictive (11% indicated yes, 36% indicated no, and 29% indicated somewhat). One-half (50%) of respondents felt special regulations resulted in increased fishing pressure, while 22% said no change, 11% said it decreased, and 17% were uncertain or indicated it may increase or decrease based on the individual fishery.

### Use of Bait in Special Regulation Waters

Most (89%) biologists indicated that the use of bait can be compatible with special regulations. Over one-half (56%) of biologists stated that bait was allowed in at least some waters managed under special regulations while the remainder (44%) noted that bait was not allowed in any special regulation waters (Table 1). When asked if banning bait was important in preventing the spread of aquatic invasive species, only 6% replied it was very important, 22% said somewhat important, while 50% noted low importance and 22% said it was not important at all.

### Future of Special Regulations

Respondents indicated that the biggest challenges facing fisheries biologists with the use of special regulations in the future are lack of public understanding of what special regulations can and cannot do and limited rigorous biological evaluation of special regulations. Most (89%) respondents indicated that biologists can do a better job communicating with the public, including explaining decisions and educating them on the variables that impact trout

populations. When asked what the primary role of special regulations in wild trout management will be in the future, biologists were divided between whether the future role will be primarily biologically or socially based. Most (83%) biologists indicated special regulations are difficult to remove once established due to social pressures and public perception. Several biologists also mentioned that multiple steps are required to remove regulations, which makes it a complex process.

## DISCUSSION

The trout biologists that participated in our survey are almost all active trout anglers and thus tied to the fishery both professionally and recreationally, perhaps helping to give them a unique perspective of both biologist and angler. All participants indicated that their respective state or park has special regulations for at least one trout species, illustrating the continued popularity of special regulations in wild trout management. Generally, a small percentage of a states' wild trout resources are managed under special regulations, but the regulations are most often used on productive or high angler-use streams, which may mean that a disproportionate number of these resources are being managed under special regulations.

Biologists and their respective agencies strongly felt that special regulations should be used to enhance fisheries, while acknowledging that habitat and environmental factors had more influence on wild trout populations than did fishing mortality. Yet, despite emphasizing biological reasons for implementing special regulations, one-half of the respondents said that the main motivation for instituting special regulations was social pressure. And furthermore, two-thirds of the respondents reported that implementation of special regulations could be justified on strictly social issues. From these responses, we infer that opinions of organized angling groups and perhaps individual anglers can and do have substantial influence on implementation of restrictive regulations, and that biological considerations are often of secondary concern.

Among the questions relating to biologists' attitudes towards special regulations, we fail to see any obvious consensus either advocating for more special regulations or less. One possible reason for the balanced response is that there is a roughly even distribution of

anglers who use bait and may favor harvest versus those who use flies or artificial lures and may favor little or no harvest as documented in state angler opinion and creel surveys (e.g., Reeser and Mohn 2004; Greene et al. 2005; Duda et al. 2007, 2008).

All biologists indicated that special regulations affect participation and respondents were divided when asked if special regulations affected fishing pressure. Several biologists noted that changes in fishing pressure were site specific, i.e., depended upon type of regulations and location of water. Those who suggested an increase in pressure attributed the response to the expectation of higher fishing quality owing to the regulation. The most frequent comment was that states had not attempted to measure fishing pressure before and after new regulations were implemented. While there was agreement that special regulations affect participation by some sectors, reduced fishing pressure by some groups may be offset by increases from anglers anticipating improved fishing.

While most biologists felt that bait can be compatible with special regulations, nearly one-half indicated that bait was not allowed in any special regulations in their respective state or park. This may represent an opportunity for some states to consider establishing or expanding the use of bait with some special regulations, especially given that trout anglers often prefer to fish with bait. For example, Duda et al. (2007, 2008) showed that 54% of trout anglers in North Carolina and 65% of trout anglers in Pennsylvania prefer to use bait or a combination of bait, flies, and lures. Similarly, Reeser and Mohn (2004) showed that 40% of wild trout anglers used bait in Virginia streams where bait was permitted. The opportunity for using bait with special regulations may be especially applicable for nonnative salmonids or species that are less vulnerable to angling (e.g., Brown Trout) even on high angler-use waters, and may be able to be further expanded when combined with gear restrictions. Gear restrictions, such as circle hooks, may help to substantially reduce hooking mortality (Sullivan et al. 2013) while providing for the opportunity to use bait and maximize angling opportunities for all sectors. Prohibition of bait in special regulation waters did not seem to be motivated by the desire to minimize the spread of invasive species as only one biologist replied it was very important. Presumably, the major motivation for

banning bait fishing was related to reportedly higher levels of hooking mortality associated with baited hooks. Use of live fish in any water is prohibited in at least one state (Georgia) and all bait is banned in the two National Parks, where the primary motivation is to minimize the spread of invasive species.

When asked if there has been a change in public attitude towards the number of special regulations in recent years, equal percentages (44%) said there were no changes or there were requests for more and only 11% of respondents indicated a request for fewer special regulations. These data suggest that there continues to be reasonably strong public support for special regulations and is further supported by trout angler surveys in Pennsylvania and West Virginia, that documented relatively strong support for special regulations (78 and 73%, respectively; Duda et al. 2005, 2008).

Nearly one-half of respondents indicated there has been significant negative public reaction in recent years to special regulations that restricted harvest or gear type. These data seem to be somewhat inconsistent with the relatively strong support for maintaining or increasing the number of special regulation waters. Comments from several states indicated that the negative reactions were coming from bait anglers who opposed gear restrictions and in some instances harvest restrictions. Opposition by landowners to proposed gear and tackle restrictions influenced several states to withdraw proposed special regulations. Perhaps these data simply reflect a dichotomy in the trout angling public. Anglers who support catch-and-release or restricted harvest along with gear restrictions more often belong to organized groups who can influence state agencies and even legislators. Unaffiliated anglers make up the majority of the angling population (Duda et al. 2005, 2007, 2008), including most bait anglers, and generally favor at least some harvest and often oppose restrictive regulations, but often have less political influence.

Barnhart (1989) summarized the 1987 symposium "*Catch and Release – A Decade of Experience*" at which several criteria were suggested for the selection of waters for catch-and-release management: (1) waters should be productive enough to elicit a response by the trout population, (2) waters should be easy to fish with flies and artificial lures, and angler access should be assured, (3) fish longevity is important; fish should live long enough to respond to reduced fishing

mortality, (4) can be used to protect a unique species or a species especially vulnerable to overharvest, and (5) there should be good public support for the catch-and-release fishery. While these criteria might not be applicable to all situations, they do suggest a standard approach that could be implemented to more consistently apply special regulations. Respondents in our survey indicated that the biggest challenges facing fisheries biologists with the use of special regulations in the future are lack of public understanding of what special regulations can and cannot do and limited rigorous biological evaluation of special regulations. The various rationales for implementing special regulations, and limited biological need in some cases, may be a primary contributing factor to the public's perception and lack of understanding of special regulations. Perhaps biologists are sending mixed signals when regulations are implemented for biological reasons on one water and social reasons on the next, resulting in a continued misunderstanding of what special regulations can and cannot do.

Most respondents indicated that biologists can do a better job communicating with the public. Stalling (2004) and Turner (2004) provided suggestions to biologists regarding improved communications with the public as part of Wild Trout VIII Symposium. Similarly, Stange (1981) outlined four suggestions for improved communication and education between biologists and anglers. While articles such as these that specifically focus on communication are uncommon in the fisheries literature, they point to communication and education as the linchpin that makes or breaks management programs. This especially holds true for angling regulations and improved communications may help to increase public knowledge and potentially resolve the reoccurring cycle of confusion surrounding special regulations. While biologists are increasingly busy, if time is not made to communicate with the public, it is likely that biologists will continue to see the same issues continuing to surface in the future.

In this survey we treated special regulations as those that restrict harvest, gear type, or both. As a result, we infer that we have two general types of anglers – those who use artificial lures or flies and favor little or no harvest versus those who use bait and favor harvest. In the future, a better approach may be to ask separate questions about harvest restrictions and about gear restrictions. Questions about special regulations that include only harvest restrictions or

only gear restrictions in addition to including both categories may reveal three or more angler groups. Having to deal with a more diversified angling public may influence how agencies go about proposing and instituting special regulations.

In summary, biologists' views on the future role of special regulations are relatively similar to their current attitudes - a combination of biological and social roles. Graff and Hollender (1977) noted that there is no universal approach to trout management and that catch-and-release affects trout populations but not always in a predictable manner nor in the way often anticipated by advocates of "quality" angling. This continues to be the case 36 years later and as we consider the future of Eastern and Midwestern wild trout fisheries, many will continue to be limited by habitat and environmental factors rather than angling mortality, as pointed out by biologists in this survey. Nonetheless, there is a continued biological need for special regulations in some situations. However, angling regulations are often focused on by the public regardless of biological need, because they can be changed in the short term and are often perceived to result in improved angling in all situations. We must continue to improve communications with the public regarding what special regulations can and cannot do and when their implementation is appropriate, as well as conduct rigorous evaluations to determine if regulations are meeting their objectives. Additionally, when biologists consider implementing special regulations in the future, we need to carefully consider their need and ensure that the regulation does not further alienate angling groups at a time when we need a strong, concerted voice for wild trout.

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## REFERENCE

- Abele, R. W. 1974. Wild trout – the political area. Pages 74-76 in W. King, editor. Proceedings of Wild Trout I symposium. Yellowstone National Park, Wyoming.
- Barnhart, R. A. 1989. Symposium review: catch-and-release fishing, a decade of experience. *North American Journal of Fisheries Management* 9:74-80.
- Duda, M. D., M. Jones, T. Beppler, S. J. Bissell, A. Criscione, B. Hepler, J. B. Hepler, A. Richie, C. L. Schilli, T. Winegord, and A. Lanier. 2008. Pennsylvania trout fishing survey. Responsive Management, Harrisonburg, Virginia.
- Duda, M. D., M. Jones, C. Craun, T. Beppler, A. Criscione, B. Hepler, T. Winegord, A. Lanier, S. Bissell, and J. Herrick. 2007. North Carolina trout anglers' participation in and satisfaction with trout fishing and their opinions on specific regulations. Responsive Management, Harrisonburg, Virginia.
- Duda, M. D., P. De Michele, M. Jones, A. Criscione, C. Craun, T. Winegord, A. Lanier, S. Bissell, and J. Herrick. 2005. West Virginia resident's attitudes toward wildlife, their participation in wildlife-related recreation, and their consumption of fish caught in West Virginia. Responsive Management, Harrisonburg, Virginia.
- Duda, M. D., P. De Michele, C. Zurawski, M. Jones, J. Yoder, W. Testerman, J. Marshall, A. Lanier, S. Bissell, P. Wang, and J. Herrick. 2004a. South Carolina fishing license holders' opinions on and attitudes toward freshwater fisheries management and the South Carolina Department of Natural Resources. Responsive Management, Harrisonburg, Virginia.
- Duda, M. D., P. De Michele, M. Jones, C. Zurawski, W. Testerman, J. Marshall, A. Lanier, S. Bissell, P. Wang, and J. Herrick. 2004b. New Hampshire angler survey: resident anglers' participation in and satisfaction with fishing and their opinions on fishing issues. Responsive Management, Harrisonburg, Virginia.
- Duda, M. D., V. L. Wise, W. Testerman, A. Lanier, S. J. Bissell, and P. Wang. 1999. The future of fishing in the United States: assessment of needs to increase sport fishing participation. Final report, recommendations and strategies to the International Association of Fish and Wildlife Agencies. Responsive Management, Harrisonburg, Virginia.
- Graff, D. R. 1994. Wild trout in North America – an Eastern perspective. Pages 37-43 in R. Barnhart, B. Shake, R. H. Hamre, editors. Proceedings of Wild Trout V symposium. Yellowstone National Park, Wyoming.
- Graff, D. R. 1987. Catch-and-release fishing – where it's hot and where it's not. Pages 5-15 in R. Barnhart and T. Roelofs, editors. Catch and-release fishing – a decade of experience. Proceedings of a National Sport Fishing Symposium. California Cooperative Fishery Research Unit, Arcata.
- Graff, D. R., and B. A. Hollender. 1977. Catch and release fishing – the Pennsylvania experience. Pages 137 – 149 in R. Barnhart and T. Roelofs, editors. Catch and-release fishing as a management tool. Proceedings of a National Sport Fishing Symposium. California Cooperative Fishery Research Unit, Arcata.
- Greene, R., R. Weber, R. Carline, D. Diefenbach, M. Shieds, M. Kaufmann, R. Moase, and B. Hollender. 2005. Angler use, harvest and economic assessment on wild trout streams in Pennsylvania. Pennsylvania Fish and Boat Commission, Harrisburg.
- Hunt, R. L. 1974. Angling regulations in relation to wild trout management. Pages 66-74 in W. King, editor. Proceedings of Wild Trout I symposium. Yellowstone National Park, Wyoming.
- Kellert, S. R. 1980. Activities of the American public relating to animals. Phase II of U.S. Fish and Wildlife Service Study, Government Printing Office 024-010-00-624-2, Washington D.C.
- Reeser, S. J., and L. O. Mohn. 2004. An analysis of wild trout anglers in Virginia. Pages 214-221 in R. F. Carline and C. LoSapio, editors. Sustaining wild trout in a changing world. Proceedings of Wild Trout VIII symposium. West Yellowstone, Montana.
- Stalling, D. 2004. Reaching the angling public: turning good science into good policy. Pages 103-107 in R. F. Carline and C. LoSapio, editors. Sustaining wild trout in a changing world. Proceedings of Wild Trout VIII symposium. Yellowstone National Park, Wyoming.
- Stange, D. 1981. An open letter to anglers and fisheries professionals. *North American Journal of Fisheries Management* 1:193-199.
- Sullivan, C. L., K. A. Meyer, and D. J. Schill. 2013. Deep hooking and angling success when passively and actively fishing for stream-dwelling trout with baited J and circle hooks. *North American Journal of Fisheries Management* 33:1-6.
- Turner, S. E. 2004. Becoming a better communicator. Pages 108-111 in R. F. Carline and C. LoSapio, editors. Sustaining wild trout in a changing world. Proceedings of Wild Trout VIII symposium. Yellowstone National Park, Wyoming.
- Whitney, A. N. 1974. Creel, size, seasons, and angling methods – the manager's viewpoint. Pages 64-66 in W. King, editor. Proceedings of Wild Trout I symposium. Yellowstone National Park, Wyoming.
- Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43-87 in R. Barnhart and T. Roelofs, editors. Catch-and-release fishing as a management tool. Proceedings of a National Sport Fishing Symposium. California Cooperative Fishery Research Unit, Arcata.

## PERFORMANCE OF CIRCLE HOOKS WHEN BAIT FISHING FOR STREAM-DWELLING TROUT

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**Abstract**—Although the use of circle hooks in some settings demonstrably reduces deep hooking of fish, little information exists for circle hooks when bait-fishing for stream-dwelling trout. We used a series of studies to compare hooking mortality and deep hooking with circle hooks to more conventional hook types (baited J hooks, J hook dry flies, and treble hook spinners), and assessed the attributes of circle hooks that produced the largest reductions in deep hooking. We landed over 2,000 trout using a variety of baited circle hooks and J hooks noting hooking location, number of strikes, hook-ups, and landings. Deep hooking with circle hooks was much lower than for J hooks, and for both hooks, active fishing nearly always reduced deep hooking compared to passive fishing (i.e., no traditional hook set); a combined estimate of deep hooking for circle hooks was 11% and 17% for active and passive fishing, respectively, compared to 20% and 26% for actively and passively fished J hooks. Capture efficiencies (the number of landings per number of strikes) for circle hooks were 43% and 36% for actively and passively fished baited circle hooks, respectively, compared to 54% and 42% for actively and passively fished baited J hooks. We found no difference in deep hooking or capture efficiency by anglers between in-line and 4° offset circle hooks. In a another study, we caught and released trout in a 1-km enclosed section of stream, and estimated relative hooking mortality 69 days later. Relative mortality was higher for trout caught with spinners (29%) and baited J hooks fished actively (25%) than for trout caught with baited circle hooks fished passively (7%) and dry flies (4%). We conclude that circle hooks successfully reduced deep hooking and hooking mortality when bait fishing for stream-dwelling trout compared to more conventional bait hooks.

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### INTRODUCTION

Increasing angler effort on popular wild trout fisheries has often led to implementation of “special regulations” such as creel limits, slot limits, size limits, and tackle restrictions designed to reduce mortality rates. Thus, post-release hooking mortality must be negligible for restrictive regulations to be effective (Wydoski 1977). Numerous studies have shown that bait fishing for trout results in mortality rates 3 to 6 times higher than other gear types such as flies or spinners (e.g., Shetter and Allison 1955; Hunsaker et al. 1970; Mongillo 1984). Hooking mortality for trout using conventional bait fishing gear is significantly higher than for other gear types, because mortality of caught-and-released fish is strongly dependent on the anatomical site of hooking and resultant injury to vital organs due to deep-hooking and bleeding (Mason and Hunt 1967; Schill 1996). While artificial flies and spinners are not immune to hooking fish in critical areas such as the esophagus, stomach, or gills (areas generally referred to as “deep hooking”),

they generally penetrate these critical areas less than 10% of the time, compared to a much higher rate (up to 50%) when bait is used with conventional J hooks (Mongillo 1984). Therefore, it is often assumed that bait fishing is incompatible with special regulation fisheries, even though several studies have demonstrated that bait fishing can be compatible with special regulations for salmonids in some situations (e.g., Carline et al. 1991).

Although circle hooks have been used for centuries, and major hook manufacturers have been producing circle hooks for decades (Bowerman 1984), they have only recently gained a reputation as a potentially more benign bait hook that often reduces hooking mortality relative to conventional J hooks (reviewed in Cooke and Suski 2004). On a circle hook, the point of the hook is oriented perpendicular to the shank, rather than being more parallel as on a J hook (Figure 1). It is generally assumed that for circle hooks to perform properly, anglers must not set the hook, but rather should lift lightly on the rod and

slowly retrieve the fish (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). This has been termed “passive fishing” (Prince et al. 2002; Alós 2009). Because of the paucity of information on the use of baited circle hooks for trout in riverine settings, we undertook a series of studies to compare deep hooking and hooking mortality with circle hooks to more conventional hook types and fishing methods (i.e., baited J hook, J hook dry fly, and treble hook spinner), and evaluated what hook designs and angling methods influenced deep hooking rates for stream-dwelling trout.

## METHODS

### Hooking Location and Capture Efficiency

To assess deep hooking with baited hooks, angling was conducted on a number of streams in southern Idaho using a variety of barbed hooks (Table 1; Figure 1). Anglers fished from late June to early October between 2006 and 2011 where wild Rainbow Trout *Oncorhynchus mykiss*, Cutthroat Trout *O. clarkii*, and Rainbow x Cutthroat hybrids dominated species compositions.

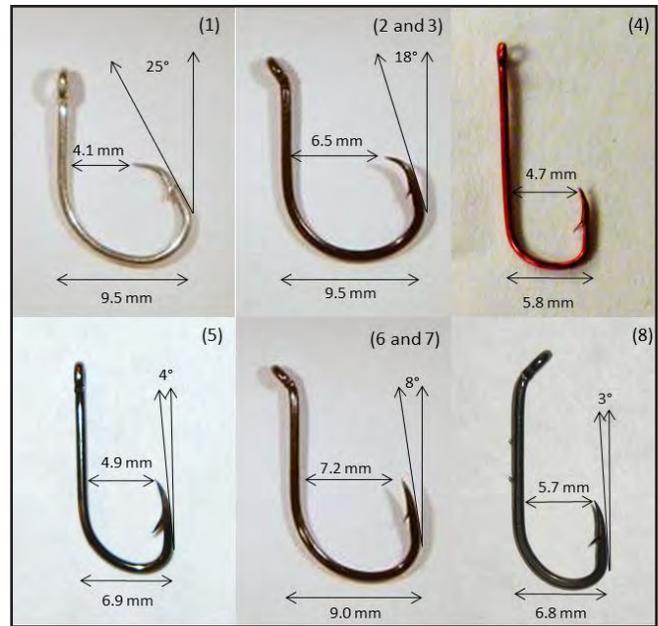


Figure 1. Hook gap, hook width, and front angle (°) for J and circle hooks used to bait fish for stream-dwelling trout in Idaho. Hook numbers (in parentheses) correspond to Table 1. Hook number 4 has a 0° front angle.

Table 1. Hook characteristics and rates of deep hooking and hooking and landing success for the various barbed hooks involved in our study.

Hook number	Hook	Offset	Fishing method	Brand	Hook size	Front angle (°)	Hook gap (mm)	Hook width (mm)	Number of landed fish	Deep hooking	Hooking success	Landing success	Capture efficiency
1	Circle	0	Active	Eagle Claw	8	25	4.1	9.5	97	0.10 ± 0.05	0.61 ± 0.07	0.78 ± 0.08	0.48 ± 0.07
1	Circle	0	Active	Eagle Claw	8	25	4.1	9.5	106	0.03 ± 0.06	0.40 ± 0.07	0.74 ± 0.07	0.30 ± 0.05
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	100	0.19 ± 0.08	0.45 ± 0.06	0.77 ± 0.08	0.35 ± 0.06
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	100	0.10 ± 0.06	0.37 ± 0.05	0.68 ± 0.08	0.25 ± 0.04
1	Circle	0	Passive	Eagle Claw	8	25	4.1	9.5	75	0.04 ± 0.04	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>
2	Circle	0	Active	Gamakatsu Octopus	8	18	6.5	9.5	45	0.13 ± 0.07	0.66 ± 0.10	0.80 ± 0.11	0.53 ± 0.11
2	Circle	0	Passive	Gamakatsu Octopus	8	18	6.5	9.5	65	0.25 ± 0.09	0.70 ± 0.08	0.77 ± 0.09	0.54 ± 0.09
3	Circle	4	Active	Gamakatsu Octopus	8	18	6.5	9.5	96	0.19 ± 0.06	0.69 ± 0.07	0.91 ± 0.06	0.63 ± 0.08
3	Circle	4	Passive	Gamakatsu Octopus	8	18	6.5	9.5	80	0.31 ± 0.08	0.69 ± 0.08	0.78 ± 0.08	0.54 ± 0.08
4	J	0	Active	Eagle Claw	8	0	4.7	5.8	92	0.28 ± 0.09	0.75 ± 0.07	0.84 ± 0.07	0.63 ± 0.08
4	J	0	Passive	Eagle Claw	8	0	4.7	5.8	99	0.24 ± 0.08	0.66 ± 0.08	0.76 ± 0.09	0.50 ± 0.07
5	J	4	Active	Eagle Claw	8	4	4.9	6.9	94	0.09 ± 0.05	0.61 ± 0.07	0.80 ± 0.07	0.49 ± 0.07
5	J	4	Passive	Eagle Claw	8	4	4.9	6.9	101	0.28 ± 0.08	0.48 ± 0.08	0.86 ± 0.07	0.41 ± 0.06
6	J	0	Active	Gamakatsu Octopus	6	8	7.2	9	87	0.23 ± 0.08	0.65 ± 0.08	0.84 ± 0.07	0.55 ± 0.08
6	J	0	Passive	Gamakatsu Octopus	6	8	7.2	9	87	0.29 ± 0.08	0.66 ± 0.08	0.85 ± 0.07	0.56 ± 0.08
7	J	4	Active	Gamakatsu Octopus	6	8	7.2	9	75	0.20 ± 0.07	0.64 ± 0.08	0.84 ± 0.08	0.54 ± 0.08
7	J	4	Passive	Gamakatsu Octopus	6	8	7.2	9	90	0.32 ± 0.08	0.68 ± 0.07	0.83 ± 0.07	0.56 ± 0.08
8	J	4	Active	Renegade	8	3	5.7	6.8	100	0.19 ± 0.08	0.63 ± 0.05	0.82 ± 0.08	0.52 ± 0.07
8	J	4	Active	Renegade	8	3	5.7	6.8	76	0.21 ± 0.09	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>
8	J	4	Passive	Renegade	8	3	5.7	6.8	100	0.20 ± 0.08	0.38 ± 0.05	0.69 ± 0.07	0.26 ± 0.04
9	Fly	-	Active	-	4-14	-	-	-	100	0 ± 0	0.56 ± 0.07	0.87 ± 0.06	0.49 ± 0.07
9	Fly	-	Active	-	4-14	-	-	-	74	0.01 ± 0.03	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>
10	Spinner	-	Active	Panther Martin	3.5 g	-	-	-	100	0.01 ± 0.05	0.65 ± 0.07	0.73 ± 0.08	0.47 ± 0.07
10	Spinner	-	Active	Panther Martin	3.5 g	-	-	-	75	0.05 ± 0.05	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>

<sup>a</sup>Fish were part of hooking mortality study, and hooking and landing success data were not collected.

Anglers fished hooks baited with night crawlers both actively and passively. Spinners and flies were fished actively using standard angling techniques. All anglers fished all hook types, and periodically switched from one hook to another to collectively accumulate sample size for each hook. Landed fish were identified to species, measured to the nearest millimeter in total length, and assigned a hook location of esophagus, gills, upper jaw or mouth, lower jaw or mouth, or foul hooked (i.e., head, back, fin, etc.). The number of strikes, hook-ups, and landings were recorded to estimate hooking success and capture efficiency.

### Hooking Mortality

We conducted a hooking mortality experiment in 2006 in Badger Creek, a tributary of the Teton River in eastern Idaho within a 1-km section isolated by weirs. Anglers fished within the enclosed section of stream using baited in-line circle hooks (hook number 1 in Table 1), baited 4° off-set J hooks (hook number 8), J hook dry flies (hook number 9), and treble hook spinners (hook number 10). All anglers fished all hook types, and periodically switched from one hook to another until the desired sample size ( $n = 75$  fish for each hook type) was achieved. Hooking location was noted for captured trout, and all fish were measured and received a PIT tag and an adipose clip prior to release.

After a 69-d holding period, a mark-recapture (M-R) electrofishing survey was conducted within the study reach. The Lincoln-Petersen M-R model as modified by Chapman (1951) was used to estimate abundance for all trout in the study reach as well as the remaining abundance of test fish for each hook type as identified by PIT tags. Some test fish shed PIT tags during the holding period and could not be traced back to hook type. We estimated how many fish shed PIT tags by calculating a M-R population estimate for this group. We assumed no differences in PIT tag shedding rates among fish caught with different hook types, and distributed the estimate of test fish that lost PIT tags and the corresponding variance back into the four hook types. We weighted this adjustment based on the proportion of the total sample size estimated to remain after the holding period for each hook type.

We calculated a relative mortality rate over the test period for each hook type as follows:

$$M_n = (A_n - B_n)/A_n$$

where  $M_n$  is the relative mortality rate for fish of hook type  $n$ ,  $A_n$  is the number of fish of hook type  $n$  initially tagged while angling, and  $B_n$  is the estimate of the abundance of fish captured with hook type  $n$  at the end of the study. Confidence intervals (CIs) for the relative mortality rates were derived by using the lower and upper bound values of the  $B_n$  estimate in the above formula for each hook type, respectively. In all deep hooking and hooking mortality analyses, we used  $\alpha = 0.10$  or non-overlapping 90% CIs to indicate statistical significance.

## RESULTS

### Deep Hooking

A total of 2,114 fish were landed by anglers with all hooks combined to determine deep hooking rates and capture efficiency (Table 1). Fish averaged about 300 mm total length and ranged from 130 to 520 mm.

Use of baited circle hooks resulted in significantly less deep hooking compared to baited J hooks, and for both circle and J hooks, we found that active fishing nearly always resulted in less deep hooking compared to passive fishing (Table 1; Figure 2). For circle hooks (pooled across all hooks used), deep hooking rate was  $11\% \pm 3\%$  and  $17\% \pm 4\%$  for active and passive fishing, respectively, compared to  $20\% \pm 3\%$  and  $26\% \pm 3\%$  for actively and passively fished J hooks, respectively. In comparison, deep hooking averaged 1% when using dry flies and 3% when using spinners (Table 1).

Despite the fact that use of circle hooks generally resulted in less deep hooking, rates of deep hooking varied widely among hook designs for circle hooks (3-31%) and J hooks (9-32%; Table 1). Because we only used two different circle hooks in our study, deep hooking rate for circle hooks was correlated equally to (1) hook gap, (2) the front angle of the point shank, and (3) the proportion of the entire hook width that the hook gap comprised ( $r = 0.72$ ). In contrast, none of these hook characteristics were correlated to deep hooking rates for J hooks ( $r$  varied from 0.17 to 0.28; Figure 3).

There were only four direct comparisons of in-line and offset hooks (i.e., hooks 2 vs. 3 and 6 vs. 7, each fished actively and passively; Table 1). In these four direct comparisons, there was no difference in deep hooking for in-line hooks ( $24\% \pm 5\%$ ) compared to offset hooks ( $26\% \pm 5\%$ ).

Capture efficiency (which combined hooking success and landing success) was generally lower for circle hooks than for J hooks, and passively fishing either hook type reduced capture efficiency compared to actively fishing the hook (Figure 2). Across all experiments, capture efficiency for circle hooks was  $43\% \pm 3\%$  and  $36\% \pm 3\%$  for active and passive fishing, respectively, compared to  $54\% \pm 3\%$  and  $42\% \pm 2\%$  for actively and passively fished J hooks. Thus, capture efficiency was reduced by about 17% when using circle hooks compared to J hooks, and by about 20% when passively fishing compared to actively fishing. For dry flies and spinners, capture efficiency was 49% and 47%, respectively (Table 1). Capture efficiency was virtually identical between directly comparable in-line hooks ( $55\% \pm 4\%$ ) and offset hooks ( $57\% \pm 4\%$ ).

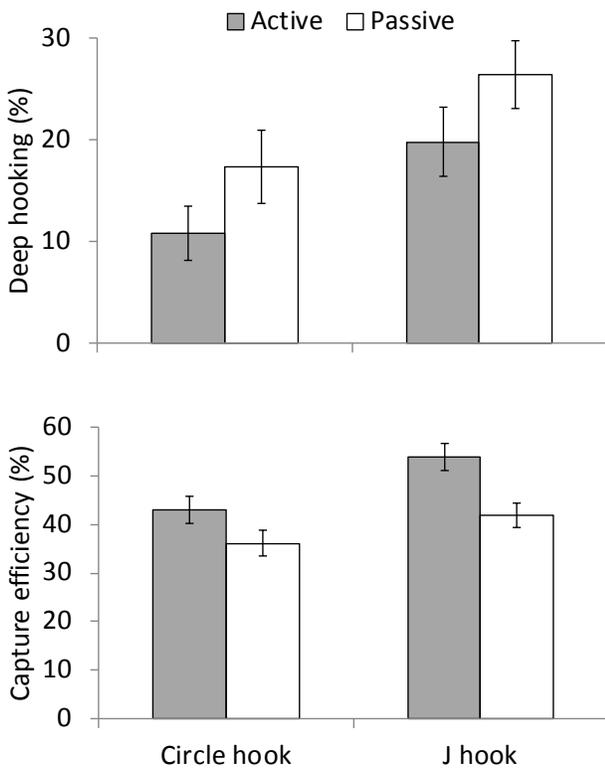


Figure 2. Rates of deep hooking and capture efficiency for circle and J hooks fish actively and passively, pooled across all hook designs. Error bars are 90% confidence intervals.

For circle hooks, capture efficiency decreased as deep hooking decreased (correlation coefficient  $r = 0.59$ ). For J hooks, the relationship between capture efficiency and deep hooking was much less pronounced ( $r = 0.25$ ). Most of the reduction in capture efficiency for circle hooks compared to J hooks, and for passive fishing compared to active fishing, was in reduced hooking success (Table 1). Once fish were successfully hooked, there was little difference in landing success between hook types or angling methods.

### Hooking Mortality

The majority (72%) of the 300 trout caught by anglers were hooked in the upper or lower jaw, followed by the roof and floor of the mouth (13%). Eight percent were deep-hooked, most (67%) of which

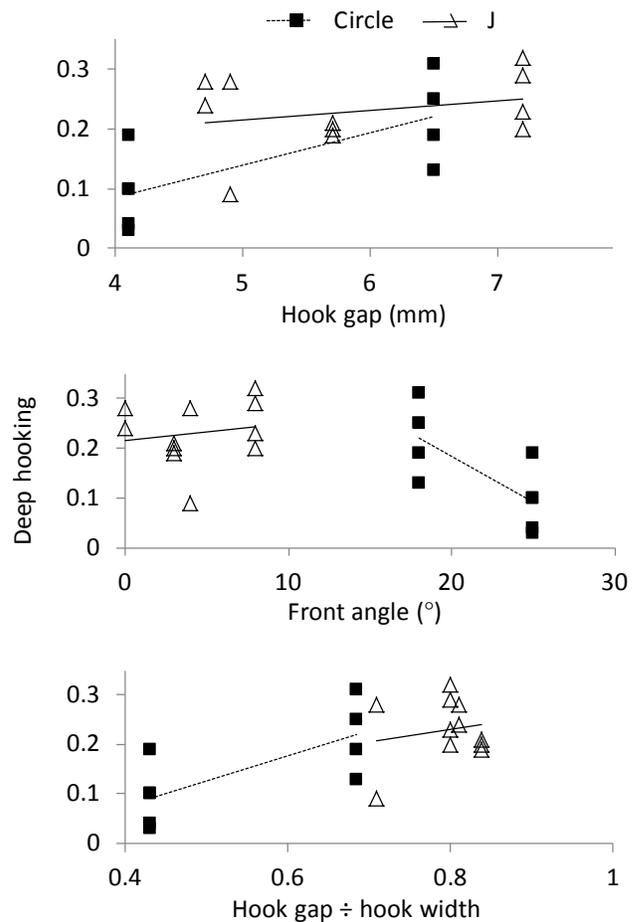


Figure 3. Relationship between deep hooking rates and three hook characteristics: (1) hook gap; (2) front angle; and (3) proportion of the entire hook width that the hook gap comprises. Lines represent trends through the data.

occurred with baited J hooks. Only one immediate mortality was observed, occurring after the release of a fish caught in the esophagus on a baited J hook. Deep-hooking was significantly higher for baited J hooks fished actively ( $21\% \pm 9\%$ ) than for treble hook spinners ( $5\% \pm 5\%$ ), baited circle hooks fished passively ( $4\% \pm 4\%$ ), and J hook dry flies ( $1\% \pm 3\%$ ; Table 1).

Relative mortality over the 69-d holding period was significantly higher for fish caught with spinners (29%; 90% CI = 24-35) and baited J hooks fished actively (25%; 90% CI = 19-28) than for fish caught with baited circle hooks fished passively (7%; 90% CI = 1-11) and dry flies (4%; 90% CI = 1-12). For baited J hooked fish, relative mortality was 54% (90% CI = 41-67%) for deep-hooked fish compared to only 14% (9-20%) for those that were not deep-hooked. For circle hooks, flies, and spinners, there were not enough deep-hooked fish to make similar comparisons.

## DISCUSSION

### Deep Hooking

All of the hook types we tested produced the lowest deep hooking rates when they were actively fished, which for circle hooks contradicts manufacturers' recommendations and conventional wisdom (Montrey 1999; ASMFC 2003; Cooke and Suski 2004). Our results suggest that, for stream-dwelling trout, fishery managers should encourage anglers to actively set the hook when bait fishing, regardless of whether they are using J hooks or circle hooks.

Actively setting the hook in our study may have resulted in less deep hooking (for both circle and J hooks), because our studies were conducted in flowing water, and hooks drifting laterally through flowing water may perform differently than in lentic environments where bait is usually fished vertically (e.g., longline marine fisheries; Zimmerman and Bochenek 2002).

For some hook comparisons in our study, the only difference between hooks was whether they were in-line or slightly offset (by  $4^\circ$ ), but in-line and offset angles did not influence deep hooking rates in our study. Previous studies that have documented higher deep hooking rates for offset hooks have typically used severely offset hooks of  $10^\circ$  or more (Malchoff et al. 2002; Prince et al. 2002), whereas studies using minor offset hooks ( $\sim 4^\circ$ ) have generally demonstrated no

difference in deep hooking compared to in-line hooks (Hand 2001; Graves and Horodysky 2008). Our results concur with these latter findings.

We found that the better a circle hook was at reducing deep hooking, the worse it was at effectively catching fish, which may limit circle hook acceptance among anglers (Jordan 1999). Interestingly, anglers actively fishing circle hooks had capture efficiencies similar to anglers fishing J hooks passively in our study. Thus, for those anglers who fish passively, transitioning to circle hook use would result in virtually no change in angling success, if the angler also switched to active hook setting.

### Hooking Mortality

Our results indicate that passively-fished baited circle hooks caused minimal hooking-related mortality, similar to J hook dry flies but much lower than for treble hook spinners and actively-fished baited J hooks. These results corroborate results of previous studies using baited circle hooks on hatchery Rainbow Trout, which reported 9% mortality after 26 d in a net pen (Jenkins 2003) and 10% mortality after 28 d in a hatchery setting (Parmenter 2000). The higher mortality rate we observed when actively fishing baited J hooks relative to other hook types was likely caused by the higher rate of deep-hooking with baited J hooks and associated tissue and organ damage (Mason and Hunt 1967; Schill 1996).

Our hooking mortality study used only one circle hook and one J hook, that were fished differently (passive for circle, active for J), thus our hooking mortality results should be considered preliminary. However, as high rates of hooking mortality for hooks with high rates of deep hooking were correlated, as were lower rates of mortality for hooks with lower rates of deep hooking, it is likely that any hook that reduces deep hooking reduces hooking mortality.

A limitation of our hooking mortality study was that fish handling (including PIT-tagging), angler harvest, and natural mortality may have caused some mortality during the study period which we could not account for, resulting in an overestimation of actual hooking mortality rates. However, the fact that relative mortality for fish caught with dry flies in our study was very low (4%) over the 69-d experiment, and in general agreement with other hooking mortality estimates involving trout caught with artificial flies (Shetter and Allison 1955, Hunsaker et al. 1970,

Mongillo 1984, Schisler and Bergerson 1996), suggests that our estimate of mortality for fish caught with dry flies was not substantially biased by a lack of control fish.

## CONCLUSION

Fishery managers often must balance social preferences for fishing regulations with the biological constraints of individual fish populations. Special regulations are typically put in place to limit annual mortality rates of fish populations by reducing angling mortality. Unfortunately, special regulations restricting bait have a tendency to alienate those constituents, sometimes with legal consequences (Gigliotti and Peyton 1993; Thurow and Schill 1994). The current study demonstrates that circle hooks may be fished with bait for wild trout in streams with resultant deep hooking and hooking mortality rates much lower than baited J hooks and in some cases not appreciably different than dry flies. Thus, allowing bait fishing in the development of future restrictive special regulation waters may be possible, if additional studies confirm the present findings and subsequent use of properly designed circle hooks is mandated.

Our results highlight the conclusion by Serafy et al. (2012) that not all circle hooks are alike (also see Smith 2006), and some designs do not appear to reduce deep hooking as much as others. The relationship between deep hooking and hook configuration, such as hook size, the degree of offset, the front angle, the gap width compared to hook width, and other features of circle hooks are only beginning to be understood, and clearly require further research before definitive conclusions can be drawn regarding the use of circle hooks in freshwater fisheries. Nevertheless, the consistency with which active fishing results in less deep hooking than passive fishing suggests that hook manufacturers, management agencies, and outdoor media need to modify their hook set recommendations for circle hooks used to bait fish for stream-dwelling trout.

## LITERATURE CITED

- Alós, J., 2009. Mortality impact of recreational angling techniques and hook types on *Trachynotus ovatus* (Linnaeus, 1758) following catch-and-release. *Fisheries Research* 95:365-369.
- Atlantic State Marine Fisheries Commission (ASMFC). 2003. Circle hook definition and research issues. Special Report no. 77. 29 p.
- Bowerman, M. 1984. The ancient circle hook rediscovered. *Australian Fisheries* 43:34-35.
- Carline, R. F., T. Beard, Jr., and B. A. Hollender. 1991. Response of wild brown trout to elimination of stocking and no-harvest regulations. *North American Journal of Fisheries Management* 11:253-266.
- Chapman, D. G. 1951. Some properties of the hypergeometric distribution, with applications to zoological sample censuses. *University of California Publications in Statistics* 1:131-160.
- Cooke, S. J., and C. D. Suski. 2004. Are circle hooks and effective tool for conserving marine and freshwater recreational catch-and-release fisheries? *Aquatic Conservation: Marine and Freshwater Ecosystems* 14:299-326.
- Gigliotti, L. M., and R. B. Peyton. 1993. Values and behaviors of trout anglers, and their attitudes toward fishery management, relative to membership in fishing organizations: a Michigan case study. *North American Journal of Fisheries Management* 13:492-501.
- Graves, J. E., and A. Z. Horodysky. 2008. Does hook choice matter? Effects of three circle hooks on postrelease survival of white marlin. *North American Journal of Fisheries Management* 28:271-480.
- Hand, R. G. 2001. Evaluation of circle hooks as a means of reducing catch and release mortality of Roanoke River striped bass. *North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Federal Aid in Fish Restoration Project F-22, Raleigh, North Carolina.*
- Hunsaker, D., L. F. Marnell, and F. P. Sharpe. 1970. Hooking mortality of Yellowstone cutthroat trout. *Progressive Fish-Culturist* 32:231-235.
- Jenkins, T. M. 2003. Evaluating recent innovations in bait fishing tackle and technique for catch and release of rainbow trout. *North American Journal of Fisheries Management* 23:1098-1107.
- Jordan, J. 1999. Going full circle. *Big Game Fishing Journal* 12(3): 52-62.
- Malchoff, M. H., J. Gearhart, J. Lucy, and P. J. Sullivan. 2002. The influence of hook type, hook wound location, and other variables associated with post catch-and-release mortality in the U.S. summer flounder recreational fishery. *American Fisheries Society Symposium* 30:101-105.
- Mason, J. W., and R. L. Hunt. 1967. Mortality rates of deeply hooked rainbow trout. *Progressive Fish-Culturist* 29:87-91.
- Mongillo, P. E. 1984. A summary of salmonid hooking mortality. *Washington Department of Game*, 110 pages.

- Montrey, N. 1999. Circle hooks ready to boom- design pierces fish through jaw, promotes conservation. *American Sportfishing: The official publication of the American Sportfishing Association* (2) 6-7.
- Parmenter, S. 2000. Circle hooks: Remedy for bait angling mortality? Pages 61-65 in D. A. Schill, S. Moore, AP. Byorth, and B. Harne (editors), *Management in the new millennium: are we ready? Wild trout VII. Yellowstone National Park, Old Faithful, Wyoming.*
- Prince, E. D., M. Ortiz, and A. Venizelos. 2002. A comparison of circle hook and 'J' hook performance in recreational catch-and-release fisheries for billfish. *American Fisheries Society Symposium* 30:66-79.
- Schill, D. J. 1996. Hooking mortality of bait-caught rainbow trout in an Idaho trout stream and a hatchery: implications for special-regulation management. *North American Journal of Fisheries Management* 16:348-356.
- Schisler, G. J., and E. P. Bergersen. 1996. Post release hooking mortality of rainbow trout caught on scented artificial baits. *North American Journal of Fisheries Management* 16:570-578.
- Serafy, J. E., S. J. Cooke, G. A. Diaz, J. E. Graves, M. Hall, M. Shivji, and Y. Swimmer. 2012. Circle hooks in commercial, recreational, and artisanal fisheries: research status and needs for improved conservation and management. *Bulletin of Marine Science* 88:371-391.
- Shetter, D. S., and L. N. Allison. 1955. Comparison of mortality between fly-hooked and worm-hooked trout in Michigan streams. Michigan Department of Conservation, Institute of Fish Research, Publication No. 9. 44 pages.
- Siewert, H. F., and J. B. Cave. 1990. Survival of released bluegill, *Lepomis macrochirus*, caught on artificial flies, worms, and spinner lures. *Journal of Freshwater Ecology* 5:407-411.
- Smith, S. 2006. Disconnected government circles: which hooks will meet the non-offset circle hook requirement for Atlantic billfish tournaments? *Billfish Magazine* 3:26-27.
- Thurow, R. F., and D. J. Schill. 1994. Conflicts in allocation of wild trout resources: an Idaho case history. Pages 132-140 in R. Barnhart, B. Shake, and R. H. Hamre, editors. *Wild Trout V. Trout Unlimited, Arlington, Virginia.*
- Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quantify fishery management. Pages 43-87 in R.A. Barnhart and T.D. Roelofs, editors. *A national symposium on catch-and-release fishing. Humboldt State University, Arcata, California.*
- Zimmerman S. R., and E. A. Bochenek. 2002. Evaluation of the effectiveness of circle hooks in New Jersey's recreational summer flounder fishery. *American Fisheries Society Symposium* 30: 106-109.

## EVALUATING POTENTIAL IMPACT OF ANGLER BYCATCH ON THREATENED BULL TROUT IN WESTERN MONTANA

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**Abstract**—The primary objective of this study was to conduct a preliminary survey of readily available groups of anglers fishing waters occupied by Bull Trout *Salvelinus confluentus*, with the intent of examining whether unintentional bycatch and hooking mortality is potentially a significant factor affecting Bull Trout recovery. An anonymous post hoc survey of 51 prolific anglers accounted for approximately 2,839 rod days expended during 2012 on nine rivers containing Bull Trout in western Montana. Despite intentional angling for Bull Trout being illegal in eight of the nine waters, the trip reports resulted in incidental catch of an estimated 294 Bull Trout (a rate of 0.10 per angler per day). Nearly half of all Bull Trout caught were estimated to exceed 16 inches in length and were presumptively adult-sized fish. Of that adult-sized portion of the catch, anglers reported that about 5% were lethally hooked. Extrapolation of these data for eight officially designated Bull Trout recovery core areas of the Clark Fork (n = 5) and Flathead River (n = 3) watersheds to include year-around fishing pressure indicated that incidental bycatch of Bull Trout, by anglers ostensibly pursuing other species, may exceed 30,000 fish per year; thus, potentially translating to a high proportion of the adult Bull Trout in some populations being lost annually to angling mortality. Where adult Bull Trout numbers are already low, incidental mortality from angler bycatch could be a significant threat and an obstacle to Bull Trout recovery. Despite its shortcomings, this survey suggests that a better understanding of angling bycatch impacts and better evaluation of the levels of potentially sustainable angling mortality are important and necessary components of an overall Bull Trout recovery strategy and more rigorous study may be warranted.

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### INTRODUCTION

Bull Trout *Salvelinus confluentus* are large (commonly 5 to 15 pounds), often migratory, and native in the U.S., mostly to coldwater portions of the river systems and lakes of Pacific Northwest. Bull Trout also range north into British Columbia and Alberta, Canada, along the continental divide and certain coastal river systems. Bull Trout were listed in 1998 under the U.S. Endangered Species Act (ESA) as a Threatened Species (USFWS 2002). The ESA listing was brought about by declines in distribution and abundance, primarily due to habitat degradation and fragmentation, blockage of migratory corridors, poor water quality, past fisheries management practices, and the introduction of nonnative species (Al-Chokhachy et al. 2008). Susceptibility of Bull Trout to sport angling and harvest is well documented (Johnston et al. 2007), occurs both legally and illegally, and is often complicated by angler misidentification (Schmetterling and Long 1999). These factors combined to result

in well-intended proactive fisheries management measures in the early 1990's to close most Bull Trout waters to intentional fishing for the species and to eliminate nearly all legal sport harvest across the U.S. portion of the range.

Western Montana fishing regulations were changed in the early 1990's and currently read "All waters are closed to angling for Bull Trout and all fish must be immediately released unless otherwise authorized in the Western District Exceptions" (MFWP 2014). Those few exceptions allow for a regulated experimental Bull Trout angling season (catch and release only) on only one stream; seasonal angling is permitted on a portion of the South Fork Flathead River upstream of Hungry Horse Reservoir.

Many western Montana streams and lakes receive moderate to heavy annual angling pressure (MFWP 2012), and while anglers are not allowed under the regulations to intentionally fish for Bull Trout, anecdotal evidence (e.g., this study and other unquantified sources such as casual conversations and

postings on the internet) indicates that Bull Trout catch on Montana rivers is nonetheless quite common.

The demographic recovery of ESA Threatened Bull Trout is primarily dependent on alleviating threats (USFWS 2014). Due to their known vulnerability, the loss of juvenile and adult Bull Trout to angling is one of the potentially important threats to population viability, especially in heavily-fished waters. Mortality may occur either as a result of illegal harvest (poaching or misidentification; see e.g. Schmetterling and Long 1999) or as delayed mortality due to catch and release (incidental hooking mortality). Timing (especially warm water conditions), physiological condition of the fish (especially pre- or post-spawn), hook type and location of the hook in the fish, methods of playing and releasing fish, and other elements are all factors in determining the rate of incidental hooking mortality in non-anadromous trout (Taylor and White 1992).

The objectives of this study were to design and implement a post hoc angling survey to gather information from anglers on the relative rate of Bull Trout bycatch in western Montana rivers, most of which function as migratory corridors and foraging, migrating and overwintering habitat (U.S. Fish and Wildlife Service 2002, 2010) for larger juvenile, subadult, and adult Bull Trout. Then, survey results were related to Bull Trout population levels, potentially gaining insight into whether or not legal angling might be problematic, especially in core areas where Bull Trout numbers are low. Finally, because very little is known from empirical studies about the rate of hooking mortality in Bull Trout (see e.g., Andrusak and Thorley 2013), some survey questions were designed specifically to probe the potential concerns over bycatch-related hooking mortality. The survey was designed to have broad coverage across western Montana, with the idea that potential hotspots identified through this coarse filter approach could be followed up in the future with more in-depth analysis.

## METHODS

In spring 2013, I requested leaders of several organized angling forums to solicit their members to fill out a voluntary survey. In most cases, anglers were given basic background information about the status of Bull Trout and the concern over potential hooking mortality issues. Anglers were asked to fill out a questionnaire with a retrospective survey of

their angling observations over the course of the 2012 fishing season. In general, those filling out the survey were either avid anglers or commercial fishing guides, often both. Most were primarily fly fishermen, though tackle preference was not identified on the survey. Anglers were asked to pick from a list of watersheds, and then record how many rod days they were involved in (as either an angler or observer of other anglers fishing from the boat they captained). Next, they were asked to report how many Bull Trout they caught (or directly observed caught in the rod days they reported on), how many of those caught exceeded 16 inches in total length (roughly the minimum size for migratory adult Bull Trout), and of those fish over 16 inches how many (in their opinion) “were physically harmed by hooking and playing to the point where they suspect the fish had a less than 50% chance of survival upon release.”

Four basic groups of Montana anglers were surveyed, which resulted in 51 useable interviews. These groups were (a) a non-affiliated group of mostly river guides who attended a spring fishing forum in Missoula (18 useable interviews); (b) members of the Bitterroot Chapter of Trout Unlimited in Hamilton (10); (c) members of the Flathead Valley Chapter of Trout Unlimited in Kalispell (21); and (d) participants in Flathead Lake Mack Days fishing contest sponsored by the Confederated Salish and Kootenai Tribes in Polson (4). Useable interviews were considered to be those where anglers fished the specific waters of interest (Clark Fork River above and below Missoula, Rock Creek, Blackfoot River, Bitterroot River, Flathead River including North and Middle Forks, South Fork Flathead River, Swan River, or Kootenai River; Figure 1) and where the written questions were answered fully and legibly and the results were consistent with known Bull Trout demographics. Fewer than 10 interviews were rejected for incomplete results or because they pertained to waters outside the area of interest. No information was collected on species other than Bull Trout. Since intentional targeting of Bull Trout was legal only in the South Fork Flathead River, it was presumed other species (i.e., Rainbow Trout *Oncorhynchus mykiss*, Cutthroat Trout *O. clarkii*, or Brown Trout *Salmo trutta*) were the primary species that surveyed anglers pursued, although this was not specifically queried.

The angler interview data (i.e., Bull Trout catch rates separated for adult and smaller fish) were then

compared with the estimated angler-use data for those same streams, to arrive at extrapolated total Bull Trout catch. The angler-use data were obtained from Montana Fish, Wildlife and Parks mail-in survey (MFWP 2012), whereby a stratified random mail survey design is used to estimate total fishing pressure statewide, by water body. The mail survey occurs only on odd years (e.g., 2011), so that angler use data from 2011 were compared to Bull Trout survey results from 2012. Even though annual variation occurs, the general patterns of angler use from year to year are fairly consistent on major rivers, so that the values from 2011 were still considered representative for 2012.

Next, the self-reported proportion of adult Bull Trout in the catch for each core area from the survey

was applied to the estimated total numbers of Bull Trout caught to apportion the total catch of adult Bull Trout by core area. Using the self-reported mortality rate from the survey for adult Bull Trout in rivers of western Montana (roughly 5%), a further extrapolation was made to establish the potential loss of adult fish due to hooking mortality. Finally, estimated mortality totals were compared to the estimated adult population size, taken from USFWS Bull Trout core area templates (USFWS 2008). The range of adult population size for each Bull Trout core area in the watersheds surveyed was estimated within relatively broad bounds (USFWS 2008), based on consensus professional opinion derived by using known Bull Trout redd counts and expanding by a factor of 3.2

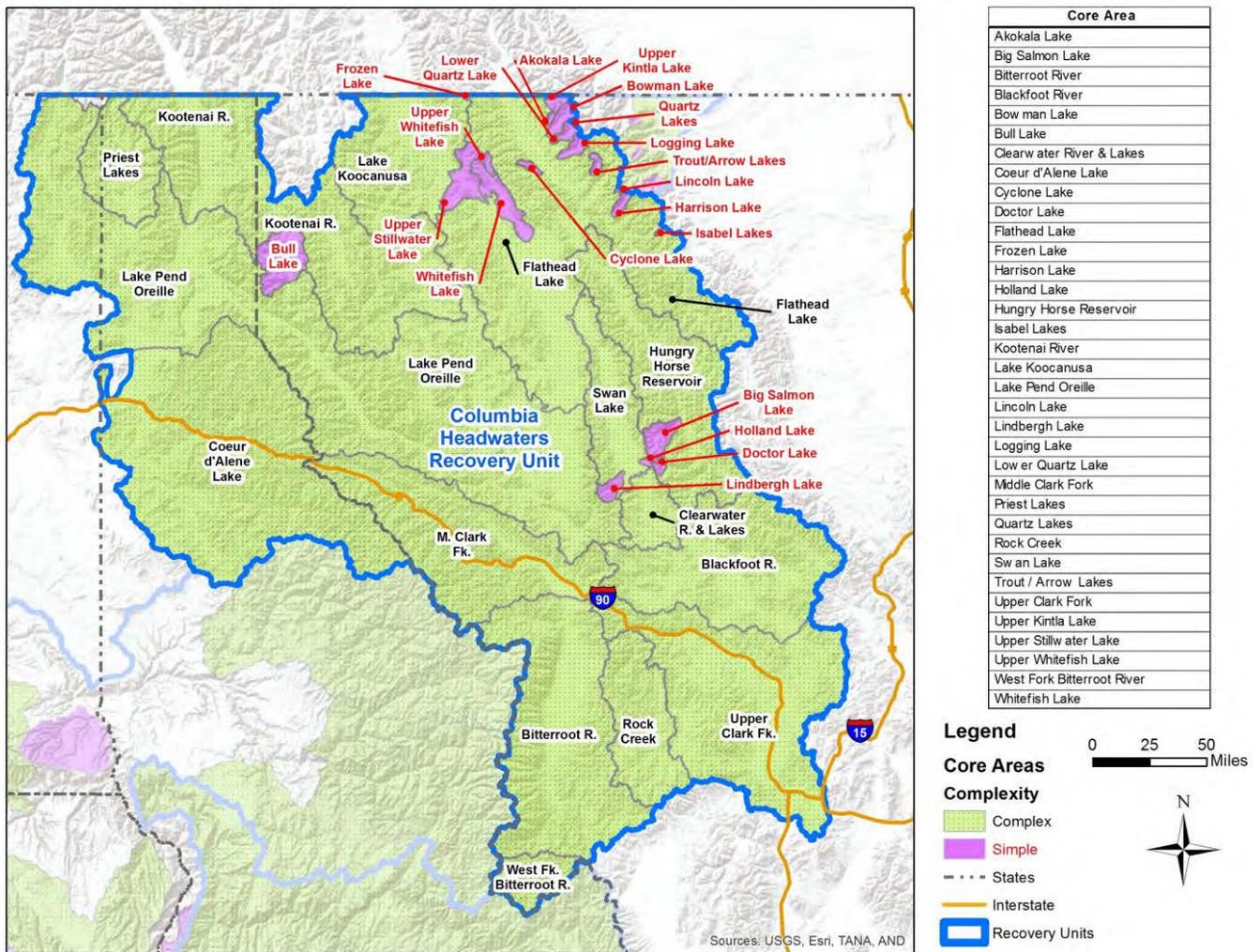


Figure 1. Bull Trout Core Areas in the Columbia Headwaters Recovery Unit, showing general location of the Clark Fork River, Rock Creek, Blackfoot River, Bitterroot River, Flathead River, South Fork Flathead River (upstream of Hungry Horse Reservoir), Swan River, and Kootenai River (from USFWS 2014).

adults per redd (Downs and Jakubowski 2006). For purposes of this exercise, the midpoint of that range was chosen as a point estimate.

### Data Limitations

Extrapolation of retrospective angler survey data to the level projected in this report is a coarse approximation, and there are multiple sources of uncertainty. The voluntary angler sample was not randomly chosen and may over- or under-represent catch rates. While the participants in this survey were believed to have been biased toward better anglers typically using fly fishing methods, potentially even higher catch rates for Bull Trout would have been observed if a broader cross-section of anglers including those using lures or bait as the primary capture method was surveyed. Any survey based on angler recall over a long timeframe with self-reporting has the potential to be flawed or biased. Angler observations of potentially lethal injury to fish, while likely erring on the conservative side, are not necessarily accurate. The methodology does not account for potential multiple recaptures of single uniquely vulnerable fish. The nature of this analysis is not statistically rigorous. Consequently, some estimates are open to challenge from a statistical perspective.

Further, this study was restricted to larger streams and rivers, which is only part of the habitat utilized by migratory Bull Trout. In addition, Bull Trout may be present only seasonally or sporadically in much of the habitat where the angling pressure occurs. Potential impacts to spawning Bull Trout were not accounted for where they might occur in (typically) much smaller tributaries where vulnerability of large staging or spawning trout may be even higher. Due to warmer water temperatures and dynamically flowing streams, mortality in fluvial systems may also be higher (e.g., Nuhfer and Alexander 1992; Boyd et al. 2010).

Finally, it is noted that the subject of this paper deals only with bycatch mortality of Bull Trout associated with otherwise legal angling. Additional, potentially severe consequences occur in some locations due to wanton and willful poaching of adult Bull Trout on spawning runs, especially in small tributary streams. Despite the shortcomings of this survey, it was successful in meeting the intended goal of gathering insight into patterns of angler Bull Trout bycatch. It covered a broad swath of main-stem

Bull Trout migratory habitat in western Montana and conclusions are presented as preliminary observations to illustrate the concern about vulnerability of Bull Trout to angling and the need for more rigorous studies.

## RESULTS

Surveyed anglers reported participating in or observing 2,839 rod days on rivers in nine different watersheds during 2012 (Table 1). They reported catching 294 Bull Trout (a rate of 0.10 per angler per day), of which nearly half (145/294) were estimated to exceed 16 inches in length (i.e., most likely mature adults).

Survey results were fairly well distributed amongst nine major western Montana drainages. Highest number of days were reported in the Bitterroot ( $n = 923$ ) and Blackfoot ( $n = 583$ ) rivers, collectively accounting for 53% of the total rod days sampled (Table 1). Lowest sample sizes were in the Kootenai River ( $n = 13$ ) and Swan River ( $n = 85$ ), with results for each of the other streams exceeding 100 rod days. Roughly half of the reported Bull Trout catch was adult sized fish (16 inches or larger). This varied by stream, with the highest proportions being in the Swan (75%), South Fork Flathead River (66%), and Blackfoot River (63%) and lowest in the Bitterroot River (23%), upper Clark Fork (21%), and Rock Creek (19%).

Bull Trout catch was reported in all watersheds except the Kootenai River, where, as noted, sample size was small and is not analyzed further. Highest catch rate was reported on the one stream where fishing for Bull Trout is legal, the South Fork Flathead River (0.22 Bull Trout per rod day). However, nearly as high catch rates were reported on the Blackfoot River (0.21 per rod day), Rock Creek (0.15 per rod day), and the Swan River (0.14 per rod day) where fishing for Bull Trout is not legal (Table 2). Lowest Bull Trout catch rates were reported on Clark Fork River downstream of Missoula (0.06 per rod day), and the Bitterroot River (0.03 per rod day).

Angler days, an estimate of overall year-long fishing pressure obtained from MFWP mail survey (MFWP 2012) for the year 2011, were compared to the 2012 estimate of Bull Trout catch rates (this survey). By simple multiplication, estimates were obtained for total Bull Trout catch, by watershed. Next, the self-reported proportion of adult Bull Trout in the catch for each core area (Table 1) was applied

to the estimated total caught (Table 2, column 4) to project the total catch of adult Bull Trout (Table 2, column 5), by drainage.

The proportion of the reported Bull Trout catch that exceeded 16 inches in length was generally highest in larger main-stem rivers, especially those which function primarily as migratory corridors for adfluvial populations (Swan River 75%, South Fork Flathead 66%, Blackfoot River 63%, lower Clark Fork 50%, Flathead River 41%) that sometimes migrate long distances to spawn. It was lower in headwater rivers that are more typically associated with fluvial populations that often have closely associated spawning and rearing habitat (Bitterroot River 23%, Upper Clark Fork 21%, Rock Creek 19%) and consequently shorter migrations (Table 2). In adfluvial systems, much of the maturation from juvenile to adult also typically occurs in the lakes.

Seriously injured Bull Trout (described in the survey question as: “physically harmed by hooking/playing to the point where chances of survival upon release were less than 50:50”) were reported by anglers only in two watersheds, four fish (5% of the catch) in the Blackfoot River and three fish (16% of the catch) in the South Fork Flathead River. Perhaps not coincidentally, these were also the two waters with the highest reported Bull Trout catch rates. Single fish were reported seriously injured by each of seven different survey respondents. Overall, 4.8% of large Bull Trout caught were reported to be seriously injured and considered by the anglers to be likely hooking mortalities.

## DISCUSSION

Bull Trout possess multiple attributes that make them highly vulnerable to angling. First, they are aggressive predators that will often strike non-selectively and repeatedly at nearly any large flies, baits, spoons, plugs, or even small fish that are being caught on another fly or lure (Onishuk 1959; Bates 1973; Thomas 2008). Bull Trout typically occupy clear streams (USFWS 2010), which increases ‘visibility’ to anglers. The allure of potentially catching a large trout, which many anglers may not be able to identify by species, is often irresistible to even the otherwise cautious and conscientious angler (Fralely 1994) who may not understand the intent or spirit of the regulations that prohibit “intentional” fishing for Bull Trout. Second, the migratory life history of Bull Trout and strong habitat preference for the cover provided by deep pools, especially in proximity to coldwater tributary inflows, predictably concentrates Bull Trout in well-known “fishing holes” (USFWS 2010). Third, in certain types of fisheries Bull Trout bycatch is almost impossible for anglers to avoid, due in large measure to similarity of fishing methods when targeting other predatory species such as Northern Pike *Esox lucius*, Lake Trout *Salvelinus namaycush*, Brown Trout, or even Smallmouth Bass *Micropterus dolomieu* or Largemouth Bass *M. salmoides*.

This survey found that Bull Trout catch was widely distributed across the range of western Montana, regardless of whether or not fishing regulations allow anglers to legally fish for Bull Trout

**Table 1. Survey results of 51 anglers and guides regarding angler use and Bull Trout catch during fishing activities conducted in 2012.**

Watershed	Total Rod Days	Total Bull Trout Caught	Bull Trout >16 Inches Caught
Upper Clark Fork (above Missoula)	202	24	5
Lower Clark Fork (below Missoula)	248	14	7
Rock Creek	175	26	5
Blackfoot River	583	124	78
Bitterroot River	923	26	6
Flathead R.(includes North& Middle Fork)	476	39	16
South Fork Flathead River	134	29	19
Swan River	85	12	9
Kootenai River	13	0	0
<b>TOTAL</b>	<b>2,839</b>	<b>294</b>	<b>145</b>



**Figure 2. Photo of a large Bull Trout, showing the wide gape capable of swallowing nearly any angler offering (photo credit: Joel Sartore with Wade Fredenberg).**

and regardless of apparent low densities of Bull Trout in some waters. Highest total angling pressure in 2011 (Table 2), was estimated in the Bitterroot River, lower Clark Fork River, Rock Creek, Flathead River, and Blackfoot River and estimated pressure is roughly correlated with the number of rod days included in the survey sample. The estimated total Bull Trout catch, by watershed (Table 2, column 4) reveals that

across the Montana Bull Trout range the total numbers of Bull Trout caught by anglers is potentially high (estimated total exceeding 30,000 fish), especially given the regulatory ban on “intentionally fishing for Bull Trout” in all but one of these watersheds. This finding supports the notion that relatively heavy fishing pressure over a naïve predator species (i.e., relatively susceptible to angling) such as Bull Trout could result in high inadvertent angler bycatch, despite low populations.

The reported catch and related degree of handling of adult Bull Trout on spawning runs is potentially more significant than the total catch. The extrapolated catch from the survey of potentially adult fish (i.e., >16 inches) adds up to nearly 10,000 fish in the Clark Fork River and its headwaters and potentially another 3,500 fish in the Flathead and Swan watersheds. We can also infer that some individual adult Bull Trout in heavily fished waters are subjected to multiple capture events. Inadvertent stress or rough handling of pre-spawn adult fish has the potential to injure fish and could affect current or future migratory capability and reproductive output, even if pre-spawn mortality does not occur (Johnston et al. 2007).

**Table 2. Extrapolation of estimated angler days and surveyed Bull Trout catch rate to project annual Bull Trout catch and adult Bull Trout catch in eight watersheds of western Montana during 2012.**

Watershed	2011 Estimated Angler Days <sup>1</sup>	2012 Bull Trout Catch Rate (Fish/Day) <sup>2</sup>	Extrapolated Total Bull Trout Catch <sup>3</sup>	Extrapolated Bull Trout Catch >16 inches <sup>4</sup>
Upper Clark Fork (above Missoula)	26,357	0.12	3,163	659
Lower Clark Fork (below Missoula)	56,289	0.06	3,377	1,689
Rock Creek	46,919	0.15	7,038	1,353
Blackfoot River	39,355	0.21	8,265	5,199
Bitterroot River	99,331	0.03	2,980	688
Flathead River (includes North & Middle Fork)	46,689	0.08	3,735	1,532
South Fork Flathead River	9,195	0.22	2,023	1,325
Swan River	7,005	0.14	981	736
<b>TOTAL</b>	<b>349,587</b>	<b>0.10</b>	<b>31,562</b>	<b>13,181</b>

<sup>1</sup> From MFWP angler mail survey for license year 2011 (March 1, 2011 through February 28, 2012).

<sup>2</sup> From Table 1, based on this survey

<sup>3</sup> Column 2 (Angler Days) X Column 3 (Bull Trout Catch Rate/Day)

<sup>4</sup> Apportioned per Table 1 results, by watershed

Within a realistic range of angling and population scenarios, estimated annual hooking mortality of adult Bull Trout could range as high as 100 or more fish in some watersheds (Figure 3). Therefore, comparison of estimated potential mortality to the estimated adult population size, taken from USFWS Bull Trout core area templates (USFWS 2008), is revealing (Figure 3). It should be noted that for Bull Trout core areas with adfluvial populations, potentially additive angling

mortality also occurs in the lake portion of the habitat where adfluvial adult Bull Trout spend more than half their life cycle. While not accounted for in this survey, lake mortality should also be factored into any determination of the overall extent of the angling bycatch threat.

Large salmonids that fight vigorously when hooked can be subject to high rates of both instantaneous and delayed hooking mortality. That

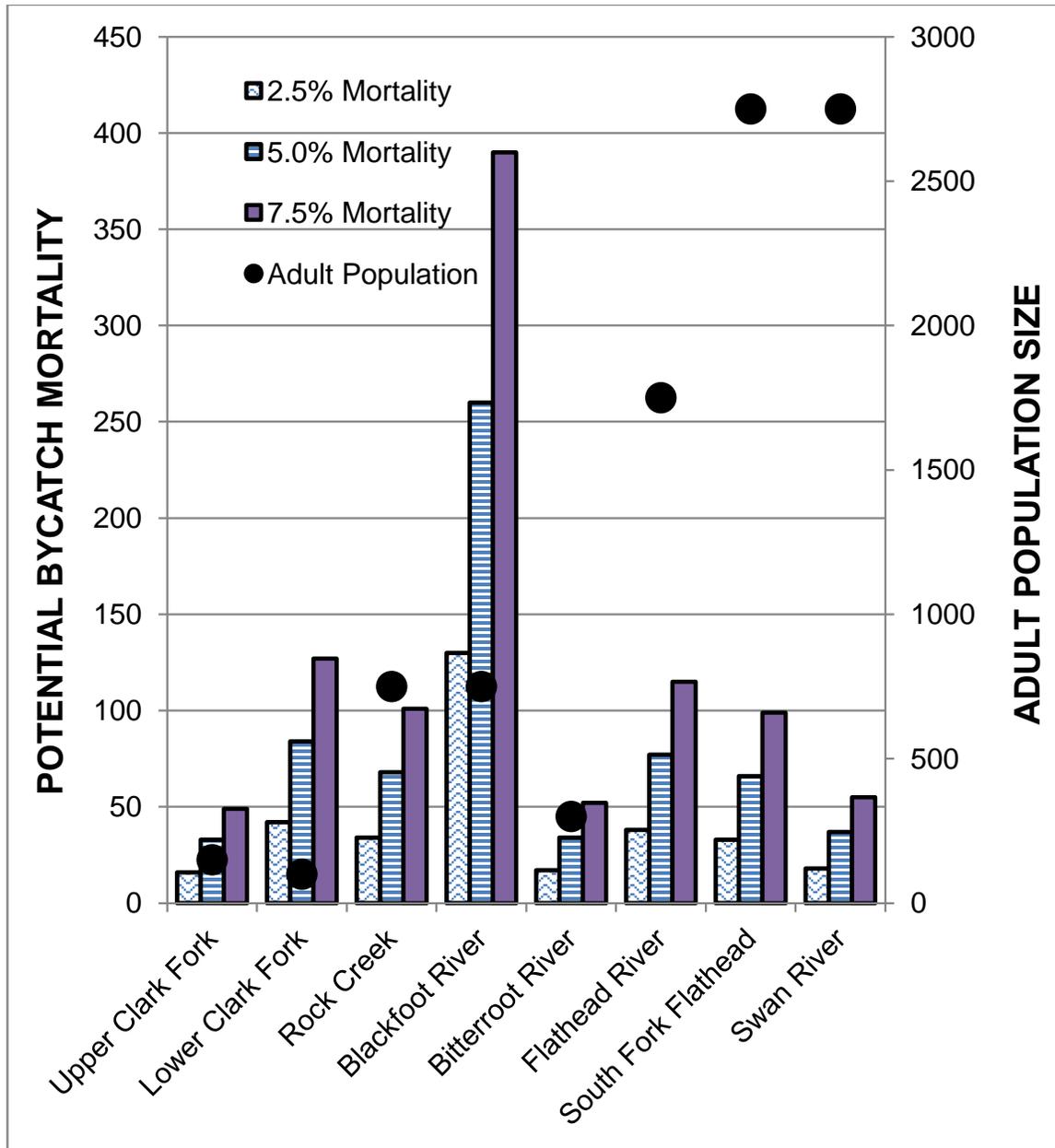


Figure 3. Point estimates (black dots) representative of adult Bull Trout population numbers by recovery core area (right vertical axis) compared to potential adult Bull Trout angling bycatch mortality (left vertical axis) for each watershed under scenarios with variable mortality rates (shaded bars).

mortality can vary greatly in scope and magnitude depending on the type of fishery, hooking location and wound severity, and ambient conditions during and after release. For example, Bendock and Alexandersottir (1993) found short-term (5-day) hooking mortality averaging 7.6% for Chinook Salmon released in the Kenai River, Alaska. Nuhfer and Alexander (1992) studied even shorter-term (48 hour) mortality in trophy-sized (381 mm and larger) Brook Trout *Salvelinus fontinalis* and found an overall hooking mortality rate of 4.3%, but hooking mortality rate increased with increasing size of fish and increasing water temperature.

There is evidence currently being developed in at least one study regarding hooking mortality specific to Bull Trout. Andrusak and Thorley (2013) working on an exploitation study of Gerrard Rainbow Trout and Bull Trout on Kootenay Lake, B.C. have used several years of sonic telemetry data and angler reward tags to develop an estimate of 29% total annual mortality (all sources) for large Bull Trout in this adfluvial population. Included in that total, is 11% (nearly one-third) apportioned to fishing mortality (limited Bull Trout harvest is legal in Kootenay Lake) and the authors estimate that post-release handling mortality (termed hooking mortality in this paper) is ~3% for large Bull Trout.

These and other studies corroborate many of the concerns raised in this paper about the potential threat angling may represent to Bull Trout recovery in Western Montana. Johnston et al. (2007) clearly documented the effect of angling in suppressing the Bull Trout population in Lake Kananaskis, Alberta. Knotek and Pierce (2005) noted through observation of fish followed in telemetry studies that the impact of angling mortality (illegal harvest and delayed mortality combined of 10-15%) was a concern for fluvial Bull Trout populations in the middle Clark Fork River system. They also noted that fish identification continued to be a problem and that accurate recognition of Bull Trout was particularly problematic, a factor corroborated by other studies (see, e.g., Schmetterling and Long 1999).

In 2008, biologists affiliated with the Western Division of the American Fisheries Society who work closely with Bull Trout across the Pacific Northwest were surveyed for their professional opinion regarding historical and current limiting factors for Bull Trout (Al-Chokhachy et al. 2008). A total of 235 respondents

indicated fish passage, forest management practices, and nonnative species interactions were the primary factors limiting Bull Trout populations, and these issues were also identified as the primary recovery challenges in the foreseeable future. Angling or harvest (both legal and illegal) was ranked next in order of importance, both historically and current.

There are no easy solutions to the potential problem of Bull Trout angling bycatch mortality. It would be neither easy, nor necessarily prudent to restrict legal angling for other species on most rivers, nor should we propose to do so without strong supporting evidence. This survey points toward angling as being a potentially important impediment to recovery of populations of fluvial Bull Trout in the main-stem Clark Fork River, Blackfoot River, and likely in Rock Creek and Bitterroot River core areas as well. Given other population stressors and low population sizes, the loss of 10% or more (sometimes much more, Fig. 3) of an adult Bull Trout population annually to incidental angler bycatch is potentially limiting population recovery. It should be noted, however, that angling mortality is also potentially compensatory, and if spawning tributaries are adequately stocked by existing runs, then the loss of a few individuals will not necessarily have direct population-level impacts.

In addition, this survey fails to take into account the less common, but also potentially serious losses that may occur due to willful or wanton poaching. The overall degree to which human angling has contributed to the depleted status of Bull Trout abundance across the range is well documented. However, on a positive note, if angling bycatch and poaching as limiting factors can be successfully mitigated, the beneficial effects of other habitat-based recovery measures may be amplified.

An important near-term action is to take stock of the current circumstances and determine whether angling-related bycatch mortality can be further mitigated by angler (or guide) education or further changes to fishing regulations. Building upon documentation of the angler impacts suggested in this survey would require the initiation of more focused research in one or more specific locations to refine this analysis and tease apart important variables of timing, location, gear type, etc. Given the combination of high angling pressure, significant Bull Trout populations, and high projected Bull Trout bycatch mortality, the

Blackfoot River core area might be a good place to conduct a more specific evaluation.

Ultimately, a better understanding of the extent to which angling mortality may be compensatory in Bull Trout populations and then refining estimates of the sustainable rates of angling bycatch as well as consequences of overharvest (even unintentional) are potentially very important components of an effective Bull Trout conservation and recovery strategy.

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## LITERATURE CITED

- Al-Chokhachy, R., W. Fredenberg, and S. Spalding. 2008. Surveying professional opinion to inform bull trout recovery and management decisions. *Fisheries* 33(1):28.
- Andrusak, G.F., and J.L. Thorley. 2013. Kootenay Lake exploitation study: fishing and natural mortality of large rainbow trout and bull trout. Poisson Consulting and Redfish Consulting Ltd. *Prepared for: Habitat Conservation Trust Foundation, British Columbia.*
- Bates, J.D., Jr. 1973. Fishing. An encyclopedic guide to tackle and tactics for fresh and salt water. *Outdoor Life / Sunrise Books. E.P. Dutton and Co., Inc. New York, NY.*
- Bendock, T., and M. Alexandersdottir. 1993. Hooking mortality of Chinook salmon released in the Kenai River, Alaska. *North American Journal of Fisheries Management* 13:540-549.
- Boyd, J.W., C.S. Guy, T.B. Horton, and S.A. Leathe. 2010. Effects of catch-and-release angling on salmonids at elevated water temperatures. *North American Journal of Fisheries Management* 30:898-907.
- Downs C., and R. Jakubowski. 2006. Lake Pend Oreille/ Clark Fork River fishery research and monitoring 2005 progress report; 2005 Johnson and Granite creeks bull trout trapping. IDFG 06-41. Report to Avista Corporation from the Idaho Department of Fish and Game. Boise.
- Fraley, J.J. 1994. Further Adventures of a Travelin' Fish. *Montana Outdoors, May/June 1994. Montana Fish, Wildlife and Parks, Helena.*
- Johnston, F.D., J.R. Post, C.J. Mushens, J.D. Stelfox, A.J. Paul, and B. Lajeunesse. 2007. The demography of recovery of an overexploited bull trout, *Salvelinus confluentus*, population. *Canadian Journal of Fisheries and Aquatic Science* 64:113-126.
- Knotek, L., and R. Pierce. 2005. Behavior and characteristics of anglers in bull trout recovery areas within the upper Clark Fork watershed. ABSTRACT presented at Montana Chapter AFS Meeting, Missoula, MT.
- Montana Fish, Wildlife and Parks. 2012. Montana Statewide Angling Pressure 2011. Annual Estimates. MFWP, Bozeman.
- Montana Fish, Wildlife and Parks. 2014. Montana Fishing Regulations. MFWP, Helena.
- Nuhfer, A.J., and G.R. Alexander. 1992. Hooking mortality of trophy-sized wild brook trout caught on artificial lures. *North American Journal of Fisheries Management* 12:634-644.
- Onishuk, M. 1959. Poor Man's Salmon. *Montana Sports Outdoors* 1:9-13.
- Schmetterling, D.A., and M.H. Long. 1999. Montana anglers' inability to identify bull trout and other salmonids. *Fisheries* 24(7):24-27.
- Taylor, M. J., and K. R. White. 1992. A meta-analysis of hooking mortality of non-anadromous trout. *North American Journal of Fisheries Management* 12:760-767.
- Thomas, G. 2008. In the Woods. Shady tributaries hide big fish in the northern backcountry of Idaho and Montana. *Big Sky Journal, Spring 2008.*
- U.S. Fish and Wildlife Service (USFWS). 2002. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan. Chapter 1 – Introduction. U.S. Fish and Wildlife Service, Portland, Oregon.
- U.S. Fish and Wildlife Service (USFWS) 2008. Bull Trout core area status assessment template. Core area by core area summary. U.S. Fish and Wildlife Service, Portland, Oregon.
- U.S. Fish and Wildlife Service (USFWS). 2010. Endangered and threatened wildlife and plants; Revised designation of Critical Habitat for bull trout in the coterminous United States; Proposed Rule. *Federal Register* 75(9)2270-2431.
- U.S. Fish and Wildlife Service (USFWS). 2014. Revised Draft Recovery Plan for the Coterminous United States Population of Bull Trout (*Salvelinus confluentus*). U.S. Fish and Wildlife Service, Portland, Oregon.

## COMPETITION BETWEEN WILD TROUT AND STOCKED “CATCHABLE” TROUT; A LITERATURE REVIEW AND THOUGHTS AN A LONG-STANDING DEBATE

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**Abstract**—Few issues in the wild trout management arena have proven more controversial or longstanding than the dialog regarding potential negative competitive effects of catchable trout stocking programs on lotic wild trout populations. Here, I define wild trout as fish that are progeny of adult trout spawned without human intervention, and catchable trout or “catchables” as stocked trout of sufficient size (about 230-275 mm total length) to be caught and harvested immediately after being released. I review the literature on competitive interactions between these two groups of fish in streams and discuss potential reasons for differing perspectives regarding results of past studies. There are few resident fish competition studies that incorporated manipulative designs. Two of the most influential catchable: wild competition studies in the literature were presented at Wild Trout III with the authors reaching opposite conclusions. Researchers directly evaluating competitive interactions between catchable trout and wild trout using “strong” manipulative treatment and control designs have not concluded that stocking catchables results in population-level impacts. The largest such competition study yet conducted found that the abundance, recruitment to age 1, survival, growth, and condition of wild Rainbow Trout *Oncorhynchus mykiss* were all unaffected by stocking catchable trout. Despite the lack of consistent empirical support confirming the existence of a competitive effect from stocking catchables on wild trout, professional dialog in the literature and certainly at professional meetings often appears to assume that the competition hypothesis has been rigorously supported. A possible reason for the dichotomy of views regarding interpretation of results from catchable: wild trout competition studies, lies in the sociology of science and our inability to remove humanity (and hence values) from ourselves as scientists. It is indeed possible that the next well designed manipulative study of the competition issue will show a meaningful, population-level effect. Until then, the wild trout community should rethink the widespread belief that stocking hatchery catchables results in meaningful competitive effects on wild trout.

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### INTRODUCTION

Few issues in the wild trout management arena have proven more durable than the dialog regarding negative competitive effects of catchable trout stocking on lotic wild trout populations. Here, I define wild trout as fish that are progeny of adult trout spawned without human intervention (Weber and Fausch 2003) and catchable trout or “catchables”, as stocked trout of sufficient size (about 200 mm total length) to be caught and harvested immediately after being released (Butler and Borgeson 1965; Mallet 1978; Petrosky and Bjornn 1984; Vincent 1987).

The hatchery catchable: wild trout competition debate has perhaps gone on longer in the four decade-long series of 11 Wild Trout Symposia than anywhere else. Beginning with the very first Symposia (WTI), several speakers (Butler 1975; Reed 1975; Vincent

1975) discussed the negative effects of hatchery trout stocking, including undesirable behavioral interactions with wild trout. By Wild Trout III, the discussion grew divergent (Petrosky and Bjornn 1984; Vincent 1984). In these two papers, biologists from the adjoining states of Montana and Idaho reached opposing conclusions regarding possible competitive effects of stocked trout on wild trout. At WTV, White et al. (1994) presented a paper regarding the negative consequences of stocked trout including competition with wild trout. Several other attendees concurred with that view at the conclusion of the session and offered additional supporting opinions from their own work (e.g., Bachman 1982). A spirited discussion between several meeting attendees and those speakers ensued at the break regarding the strength of evidence regarding hatchery: wild trout competition; clearly the

debate had not ended, nor has it since. As we attend the milestone 40th anniversary of the Wild Trout Symposium, it only seems fitting to summarize what is known about catchable: wild trout competition.

Given this context, the objectives of this paper are to (1) review the literature on competitive interactions between catchable-sized hatchery trout and resident wild trout in streams, (2) present a detailed summary of the most recent study on the subject (Meyer et al. 2012), and (3) discuss possible reasons for differing perspectives regarding the results from past studies. For reasons that will become apparent in the discussion section below, I note here that I work for an agency that stocks roughly one-half million sterile catchable Rainbow Trout *Oncorhynchus mykiss* per year in Idaho streams.

## LITERATURE REVIEW

A search for published studies specifically assessing direct competitive impacts of stocking catchable trout on wild trout populations in controlled studies reveals a scarcity of such investigations. Weber and Fausch (2003) published a thorough review of all possible hatchery: wild trout interactions including those arising from competition, concluding that, although often cited by authors as a known negative ecological interaction, hatchery: wild trout competition has seldom been tested rigorously. An earlier review (Marnell 1986) reached a similar conclusion noting the dearth of studies and general lack of experimental rigor in those few that existed at the time.

An indirect approach to the competition question, perhaps first advocated by Butler (1975), was to observe behavioral interactions between individual wild and stocked hatchery trout. McClaren (1979) reported that hatchery Brown Trout *Salmo trutta* in a semi-natural stream environment demonstrated more antagonistic behaviors than wild Brown Trout. However, the author subsequently concluded that “total losses of hatchery-reared trout were 1.5 to two times greater than for wild trout, so that regulation of population size was largely at the expense of introduced hatchery fish”. In a subsequent study, stocked Brown Trout reportedly disrupted the stable social structure that existed in the wild Brown Trout population of Spruce Creek, Pennsylvania (Bachman 1982); the author further suggested that “blotchy backs” on some wild trout were evidence of a negative competitive effect (Bachman 1984). Behavioral

observations made *via* snorkeling were used as part of a larger population-level study to evaluate effects of stocking hatchery Rainbow Trout on wild Cutthroat Trout *Oncorhynchus clarkii* (Petrosky and Bjornn 1984). Upon release, hatchery Rainbow Trout formed aggregations, typically in deeper, swifter water than that preferred by wild Cutthroat Trout in allopatry. Nonetheless, where hatchery Rainbow Trout and wild Cutthroat Trout occupied similar habitat, they interacted aggressively with size (length) determining the outcome of agonistic encounters in all instances (Petrosky and Bjornn 1988). Although such direct behavioral interactions have thus been reported for decades, competition cannot strictly be demonstrated using such approaches, because competitive impacts to the population such as reductions in population abundance, survival, growth, or reproduction must be demonstrated (Weber and Fausch 2003).

To provide sound evidence of competition, replicated, manipulative experiments that appropriately incorporate temporal or spatial controls are necessary (Underwood 1986). The ideal design for evaluating the effect of hatchery trout densities on wild trout has been termed an additive experiment (Weber and Fausch 2003). Only five existing studies have attempted to evaluate the stocking of catchables on wild trout at the population level in this manner. Weber and Fausch (2003) designated existing studies as either “strong” or “weak” in terms of the experimental design and its ability to actually assess competition. In Table 1 below, I report their characterization of the past population-level study designs (weak versus strong). I designate the most recent effort (Meyer et al. 2012) as a “strong” study based on the manipulative design and extensive spatial and temporal replication (Table 1).

## EVIDENCE SUGGESTING NEGATIVE COMPETITIVE EFFECTS OF CATCHABLES

### Vincent (1975; 1984; 1987)

This study is extensively summarized in two Wild Trout Symposia proceedings and a follow-up published paper. It comprised an observational comparison of wild trout population statistics for 3 years when trout were stocked versus 5 years of no stocking on the Madison River and 3 years with and 3 years without stocking on Odell Creek. Additional design details including stocked trout sizes

Table 1. Design features of the five studies evaluating competition between stocked catchables and wild trout at the population level.

Authors/Year	Study Design Rating <sup>a</sup>	Species and Mean Size Stocked <sup>b</sup>	Stream Name	Stream m n	Primary Wild Species	Study Site n	$\bar{x}$ Site Length	Statistical Design/Tests	Density Increase from Stocking	Response Variables Examined
Miller (1958)	Strong	HCT, 232 mm	Gorge Creek	1	WCT	8	1200 m	None % comparison	NA	Lactic acid levels Survival (Summer) Weight loss
Vincent (1984, 1987)	Weak	HRBT, 254 mm	Madison River	1	WBRN, WRBT	2	6.8 km	t-tests % comparison	NA	Abundance/biomass Movement Mortality rates
Petrofsky & Bjorn (1984, 1988)	Strong	HRBT, 254 mm	Big Springs Creek	1	WRBT	15	130 m	Blocked ANOVA	0.3-9X	Abundance (Age 1+) Abundance (Autumn YOY) Condition factor Growth rate Mean weight Movement Mortality (Summer/ Annual)
Weiss & Schmutz (1999)	Strong	HBRN, 274 mm	Kleiner Kamp River, Treusen River	2	WBRN, WRBT	18	200 m	Repeated Measures ANOVA t-tests	2X, 3X, 11X	Abundance Behavior Distribution
Meyer et al (2012)	Strong	HRBT, 249 mm	Numerous	12	WRBT	24	719 m	Repeated Measures Blocked ANOVA Repeated Measures Blocked ANCOVA Paired t-tests	2X, 3X +0.75X <sup>c</sup>	Abundance/biomass Growth rate Movement Survival Abundance (>75mm) Growth rate Percent habitat saturation Recruitment Relative weight Survival (Annual)

<sup>a</sup> Rated by Weber and Fausch (2003) except Meyer et al. (2012) which was rated strong by present author

<sup>b</sup> HBRN = hatchery Brown Trout, HCT = hatchery Cutthroat Trout, HRBT = hatchery Rainbow Trout, WBRN = wild Brown Trout, WCT = wild Cutthroat Trout, WRBT = wild Rainbow Trout

<sup>c</sup> Stocking levels based on Idaho Department of Fish & Game statewide stocking levels

are provided below (Table 1). The author reported large (160-868%) increases in abundance for age-2 and older wild Brown Trout and Rainbow Trout, respectively, within 4 years after stocking ceased on a Madison River section and a 49% reduction in total number and biomass of wild trout in nearby Odell Creek following initiation of stocking. He also reported increased downstream emigration of wild trout from the stocked study station relative to the control in Odell Creek. Vincent noted the mechanism or actual causes of the large population declines in wild trout were not clearly understood, but he suggested disruption of the stable wild fish social structure may be a major factor.

However, a number of subsequent investigators citing this work have questioned the reliability of Vincent's conclusions. These authors (McLaren 1979; Marnell 1986; Petrosky and Bjornn 1988; Weber and Fausch 2003) have noted that, on the Madison River, an obvious strong correlation between flows and wild trout biomass existed across study years and flows were therefore confounding. Many of the poorest flow conditions existed during the years when trout were stocked and the very best flows were in years of no stocking; this was problematic because the stocking treatments were replicated in time, but the study lacked control sections for a sufficient period (Petrosky and Bjornn 1988). Petrosky and Bjornn (1988) also struggled to envision large Madison River age-2 and older wild trout forced from established foraging and resting stations by hatchery trout that were generally much smaller in length (about 254 mm), an unlikely scenario also noted by Weber and Fausch (2003). Finally, Vincent (1987) noted that stocking of catchable Rainbow Trout had no detectable adverse effect on small wild brown trout throughout their first 18 months of life in either stream. This creates another paradox since size is the crucial factor determining the winner of agonistic encounters (Petrosky and Bjornn 1988; Weber and Fausch 2003), and the hatchery trout in these early size classes were usually the larger fish.

These latter two observations hint at a more likely explanation for Vincent's study results than competition. During years when the Madison River was stocked, there were 40% more tags returned by anglers for larger wild trout than in years without stocking (Vincent 1987). Stocking of trout has long been known to increase angling effort and harvest of

wild trout (Butler and Borgeson 1965; also see Baer et al. 2007). The study on both Montana streams was highly controversial, and its intent and progress was followed closely by the angling public throughout the region (Vincent 1994). Harvest-oriented anglers would certainly have known which areas were being stocked. Perhaps as a result, Madison River summer mortality rates averaged 43% for the years with stocking versus less than 20% for years with no stocking. On Odell Creek, "stocking tended to raise the summer mortality rate from 25% to 42% for the first two stocking years" (Vincent 1987). Rather than the very large social disruption effect (competition) suggested by Vincent, at a scale unobserved by any other competition study before or since, it seems more likely that poor streamflow and increased exploitation associated with stocking reduced the larger, harvestable-sized wild components of the two populations.

## EVIDENCE SUGGESTING NO OR MINIMAL EFFECTS OF CATCHABLES

### Miller (1952; 1954; 1958)

Miller constructed upstream and downstream containment weirs, enumerated wild Cutthroat Trout in residence and stocked groups of hatchery and nonresident wild trout into 0.9- to 1.3-km sections (mean = 1.2 km) of stream over several years (Table 1). Although several weirs washed out in flood events, making some of his data difficult to interpret, his results generally demonstrated poor survival of stocked Cutthroat Trout relative to introduced wild Cutthroat Trout when resident wild trout were present. All groups of introduced trout (whether wild or hatchery fish) lost weight for 30 or 40 d when superimposed on a resident wild population, although the loss was more severe in hatchery trout than in transplanted wild trout. Statistically greater blood lactic acid levels were found in hatchery trout residing with resident wild trout relative to hatchery fish that were allopatric. In addition, wild trout experienced lower lactic acid levels than hatchery trout when residing in the same study reaches. Miller concluded that hatchery trout are at a disadvantage in competitive situations, and he did not express concern for wild trout stocks as a result of stocking.

### **Petrosky (1984); Petrosky and Bjornn (1984); Petrosky and Bjornn (1987)**

Stocking of catchable-size Rainbow Trout was studied in two Idaho streams to determine if hatchery trout would negatively affect the resident wild trout. A diverse array of response variables were examined via ANOVA using 15 and 22 study sites averaging 130 m and 106 m in length on two streams, respectively (Table 1). In an infertile stream, doubling or tripling the density of trout via stocking over 3 years did not reduce abundance of wild Cutthroat Trout. In a fertile stream, stocking 50 or 100 catchables in sections containing 26-120 similar-sized wild trout did not increase dispersion or reduce the growth, survival, or abundance of wild Rainbow Trout. Summer mortality of wild trout increased only at the highest stocking density (9.4 times the abundance of wild trout). Normal stocking densities in Idaho generally averaged much less than the high experimental densities where this effect occurred (Petrosky and Bjornn 1984). Further, mortality of wild trout did not differ significantly from wild trout in control reaches at these sites later in the year and no other variables evaluated were significantly different. Petrosky and Bjornn (1988) concluded “we do not believe that stocked trout, by themselves, will decimate naturally adapted reproducing populations of trout”.

### **Weiss and Schmutz (1999)**

The authors investigated stocking of hatchery Brown Trout (average 274 mm TL) on wild Rainbow Trout and Brown Trout populations in two Austrian streams for slightly over a single year. The blocked study design involved replication ( $n = 3$ ) of two treatment levels that doubled and tripled the number of large-sized resident fish in study sites of both streams (Table 1). An equal number of additional sites were left unstocked within the blocks as controls. Response variables included instantaneous growth, movement out of the study sites, and wild trout abundance and biomass. Percent movement of wild trout was affected by stocking density in a productive limestone stream but not in an unproductive crystalline stream. Wild Brown Trout growth was negatively affected by stocking in the unproductive stream but was unaffected in the productive stream. Despite the recorded movements noted above, there was no statistical change in biomass or population size of wild brown trout populations from stocking in either stream.

### **Meyer et al. (2012)**

The authors stocked 249-mm, sterile, catchable Rainbow Trout in the middle 3 years of a 5-year study to determine if stocking at the current Idaho statewide average stocking intensity negatively affected wild Rainbow Trout residing in 12 streams across southern Idaho. A total of seven survival, abundance, growth and condition-related response variables were evaluated using repeated measures blocked ANOVA\ ANCOVA and paired t-tests (Table 1). The use of 12 study streams resulted in over a four-fold increase in stream kilometers involved annually relative to the other “strong” designs reported above.

Recruitment of wild Rainbow Trout to age 1 was not affected by stocking, nor were wild Rainbow Trout abundance ( $>75\text{mmTL}$ ) or percent habitat saturation, another index of population size (Grant and Kramer 1990). Graphical summary results for abundance were typical of these three variables with no clear patterns associated with stocking (Figure 1). Neither measure of wild Rainbow Trout survival (total annual-S) nor apparent survival ( $\theta$ ) were affected by stocking, and relative weight ( $W_p$ ) was also unaffected. Although annual growth of PIT-tagged fish clearly differed across streams, it was unaffected by stocking. Two other growth-related variables, length at ages 2 and 3, were also unaffected.

In summary, the most comprehensive competition study yet conducted reported that abundance, survival, growth, condition, and recruitment to age 1 of wild Rainbow Trout were unaffected by stocking catchable trout in 12 streams.

## **DISCUSSION**

### **Wild Trout: Catchable Competition**

If competitive interactions between wild and hatchery trout are important in the wild, then there must be measurable population-level responses (Weiss and Schmutz 1999). Taken collectively, the above studies do not present a solid case for wild trout population impacts from competition following stream stocking of hatchery catchables. Although Miller (1958) provides no insight on angling activity in his study, authors of the three other “strong” efforts all noted that the limited to virtual complete lack of angler harvest during their studies probably resulted in more behavioral interaction than might normally occur when hatchery trout are stocked to supplement wild

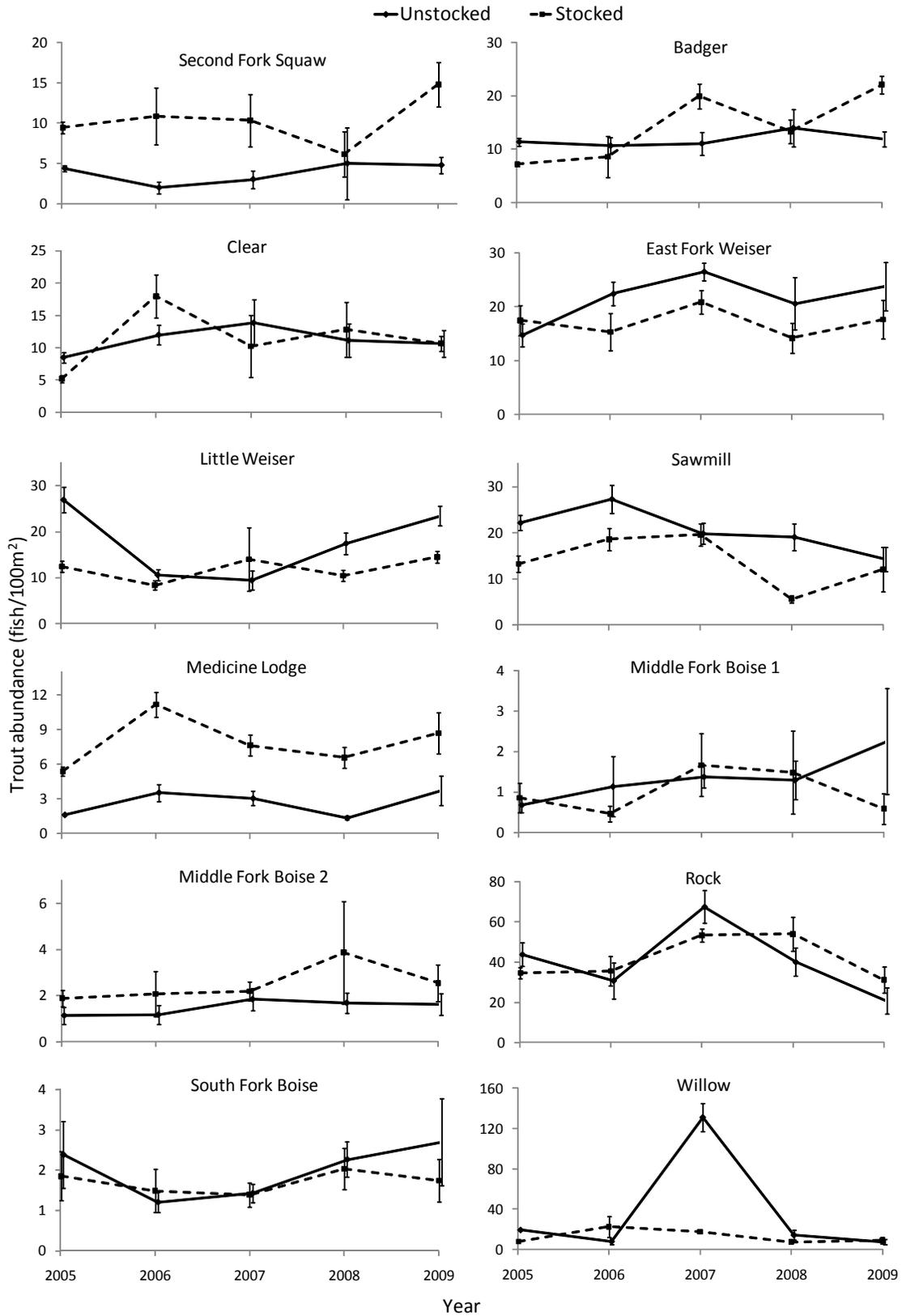


Figure 1. Estimated abundance of wild Rainbow Trout (fish/100m<sup>2</sup>) and 95% confidence intervals of all trout in unstocked and stocked reaches of streams from 2005 to 2009 in southern Idaho. Catchable stocking occurred from 2006 to 2008. (From Meyer et al. 2012).

populations (Petrosky and Bjornn 1985; Weiss and Schmutz 1999; Meyer et al. 2012). This is because a lack of hatchery trout exploitation by anglers in those studies would mean more total trout in the streams (hatchery + wild) than normal for stocked streams and, theoretically more opportunity for competitive interactions. Despite this observation, few competitive effects were observed in these studies, and no long-term abundance or biomass declines were reported. Given the low survival and short tenure of hatchery trout stocked in streams, typically only a few weeks (e.g., High and Meyer 2009), perhaps few negative demographic effects from competition on wild trout populations should be expected (Weiss and Schmutz 1999; Baer et al. 2007; Meyer et al. 2012).

The disparity between the results I report above from the existing literature and the widely held belief in the existence of catchable: wild trout competition may simply be due to ecological ideology. According to Underwood (1997), the “thought-police” of ecological theory sometimes dictate that competition must be important and therefore it is presumed to be. Such a scenario can lead to the desire to find evidence to prop up the competition model (Underwood 1986). In regard to Vincent (1987), in the words of a highly experienced colleague of mine with nearly five decades of wild trout research under his belt, “we wanted it to be the truth”. Having read the papers discussing agonistic encounters between stocked and wild trout (Butler 1975; McClaren 1979; Bachman 1984; Petrosky 1984) and read about large population declines in an additive (but weakly designed) population-level study conducted several decades ago, many in the wild trout profession ascribed the cause of such population declines to competition, and likely erred.

Having called into question the results of the most often cited study supporting stocked catchable: wild trout competition, an alternative explanation of such observed results is called for. The most likely cause of declines in wild trout abundance associated with stocking reported by a few past studies (Thuemler 1975; Vincent 1987) is increased angler exploitation in stocked stream reaches (e.g. Moring 1993). Based on available evidence, this would seem a more likely explanation than competitive interactions (Meyer et al. 2012). While some biologists may argue this observation is simply semantics, it is important to clarify which of these two is invoked to explain

reported declines when they occur. First, if the competition theory is off-target, it is simply bad science to argue it is supported. Second, if the wrong explanation is provided, an ineffective or unnecessary solution may be pursued. For example, if exploitation is the likely cause of wild population declines due to stocking, and a high yield fishery in a specific water is strongly desired by the angling public, it may be possible to craft a fishery that protects the wild stock while enabling extensive harvest of hatchery trout. For example, one could envision a special regulation protecting wild trout while permitting harvest of adipose-clipped, hatchery catchables that can readily be treated to induce sterility for protection of wild stock genetics (Kozfkay et al. 2006). Similar angling regulations have been used extensively in Columbia River anadromous fisheries and in several Idaho fisheries for lentic salmonids relying on adipose-clipped fish stocked as fingerling trout.

## THE SOCIOLOGY OF SCIENCE

Despite the lack of consistent empirical support confirming the existence of competition-related declines in wild trout stocks from catchable stocking, professional dialog in the literature, and certainly at professional meetings often appears to assume that the competition hypothesis has been rigorously supported. The view expressed by White et al. (1994) and others at Wild Trout V is certainly not unusual and comments about negative “competition” aspects of stocking catchable-sized trout are commonly expressed in American Fisheries Society meeting presentations and other forums wherever wild trout biologists gather. However, given the existing literature reviewed in this paper, the support for such firm views is questionable.

Further, the widespread professional support for “competition” appears to include a measure of citation bias. As noted above, two of the most influential catchable: wild competition studies in the literature were first presented together at Wild Trout III (Petrosky and Bjornn 1984, Vincent 1984) with the authors reaching opposite conclusions. Both senior authors eventually took their respective datasets to the primary literature at virtually the same time period (Vincent 1987; Petrosky and Bjornn 1988). It is instructive to note that, despite being published in the Canadian Journal of Fisheries and Aquatic Sciences (CJAFS), a journal with roughly twice the impact factor (annual citation frequency per paper) of

the North American Journal of Fisheries Management (NAJFM), the study whose main conclusion was that competition from stocking catchables had little competitive effect on wild trout (Petrosky and Bjornn 1988) has been cited (according to Google Scholar) 2.6 times less often than the NAJFM study by Vincent (1987) who reported a large competitive effect.

Perhaps the reason for this citation disparity and the widespread belief in the competition hypothesis may lie in the values of wild trout researchers themselves. It is likely that over 95% of the biologists attending this Symposium today consider a great day of angling to be one that involves fishing over wild trout. It is also no secret that most of the biologists in the room today would not prefer fishing for hatchery catchables over a wild trout stock. Indeed, if a similar preponderance of wild trout biologists in this room, and across the continent, were also “hatchery fish fanatics” I question if the above-noted citation disparity would exist.

Although I am sensitive to the fact that scientists have been trained to believe they are objective in the pursuit of their work, there is a large body of evidence in the philosophy and history of science literature that, in fact, demonstrates the importance of values in affecting the direction and outcomes of science (Kuhn 1962; Milbrath 1989; Cole 1992). Values can play an even more important role in natural resource management where the boundaries between scientist and policy are often blurred, especially where disagreements over management options become emotional and expert scientists have strong personal opinions themselves (Magill 1988; Lackey 2007). In some instances, a scientist may express an opinion that she or he believes is a scientific judgment but is in fact, an ethical judgment or personal policy preference, a scenario that has been recently dubbed Inadvertent Advocacy (Wilhere 2011).

Of perhaps even more concern, who you work for or at least receive income or support from, has been shown to directly affect scientific outcomes (Stelfox et al. 1998). Some professions have made more progress in this arena than the fishery profession. For example, since 1984, authors publishing in the *New England Journal of Medicine* are required to disclose their financial connections with industry. In the fisheries world it would be refreshing if authors of hatchery: wild competition papers such as Meyer et al. (2012) would be required to state up front in their paper, that

the three authors worked for an agency that stocks roughly a half a million sterile catchable trout a year in streams, roughly 40% of which go into streams containing wild trout populations. Likewise, it would have been useful for readers of Vincent (1987) to know that by the time that paper was published, the state of Montana had already had an established statewide policy of not stocking in streams with self-sustaining wild trout stocks in them for roughly a decade. Thus the authors of both papers published results that supported the longstanding policies of their respective agencies. While disclosure of such information should hopefully not directly affect the scientific acceptance of a study, provisioning of readers up front with such information may be informative as they judge the technical merits and possible study limitations of a published paper.

It is for the above reasons that I stated in the introduction that my employer (Idaho Department of Fish and Game) is in the business of stocking trout in a variety of waters. During the writing of this paper, I have striven to be as objective as possible while reminding myself of the potential for a skewed view. To tell yourself and others you could have no such biases is an indication that you have many (Silver 2012). Having stated my possible employer bias up front, it is now up to informed readers to consider the merits and rigor of this review.

In his seminal work, Kuhn (1962) introduced the concept of scientific paradigms, noting how difficult it is to switch once one has become established, in many cases requiring a “revolution” to change established scientific thinking. It seems to me that the concept of stocked catchable trout resulting in negative competitive effects on wild trout has risen to the level of such a paradigm. However, since the work of Vincent, completed by the mid-1970’s, no follow-up study has measured a remotely similar abundance or biomass effect size at the population level and attributed it to competition. Bacon (1620), the father of the scientific method, notes that good science is rooted in reality, and so it develops and grows, with evidence that grows always more compelling, whereas wishful sciences remain “stuck fast in their tracks” or “rather the reverse, flourishing most under their first authors before going downhill”. Wolfgang Panofsky, a former presidential science advisor, is credited with a more concise statement about experimental physics that would seem to apply to the hatchery catchable:

wild trout competition issue; “if you throw money at an effect and it doesn’t get larger, that means it is not real”.

## CONCLUSIONS

It is important to remind readers here that this review does not apply to stocking of smaller “sub-catchable” trout in a variety of settings (e.g. the anadromous salmonid arena) where there is an expectation that stocked trout will survive and hopefully contribute to a fishery for long periods, or in a few cases, even interbreed with wild trout. Rather this review is solely in reference to catchable-sized trout produced and released for immediate angler harvest. While there is indeed a chance that the next well designed manipulative study of catchable: wild trout competition will show a substantive, negative population-level effect on wild trout, the existing “strong” studies as designated by Weber and Fausch (2003) have not. Likewise, the latest and most extensive study of the issue (Meyer et al. 2012) did not. Instead, in the four strong studies reviewed here the total reported competitive effects include increased movement in one study stream, decreased growth in one other, and a short-term increase in summer mortality that by winter, had been obscured in one other stream. These limited effects from extensive, manipulative population dynamics work conducted on 19 streams, along with the observation that none of these streams experienced negative density or biomass effects, is at strong odds with Vincent’s work and widespread professional acceptance of the competition paradigm. Those entities desiring to improve upon the five existing population-level datasets on this issue should plan for the use of considerable manpower and expense to conduct additional work. Until then, the wild trout community should re-think the widespread belief that stocking of hatchery catchables results in major competitive impacts on wild trout. Of equal note, our past and likely misplaced professional confidence in the quality of support for a negative competitive effect has been readily accepted as bedrock fact by lay authors worldwide (e.g. Cassell 2014; Phillips 2014). Re-engaging the public on what the existing studies collectively do and do not reveal, while a tall order, is in my view, our collective professional obligation.

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## LITERATURE CITED

- Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. *Transactions of the American Fisheries Society* 113:1-32.
- Bacon, Lord F. 1620. *Novum Organum*. Edited by Joseph Devey, M.A. (New York: P.F. Collier, 1902).
- Baer, J., K. Blasel, and M. Diekmann. 2007. Benefits of repeated stocking with adult, hatchery reared brown trout, *Salmo trutta*, to recreational fisheries? *Fisheries Management and Ecology* 14:51-59.
- Butler, R.L. 1975. Some thoughts on the effects of stocking hatchery trout on wild trout populations. Pages 83-87 in W. King, ed. *Wild Trout Management: Proceedings of the Wild Trout I Symposium at Yellowstone National Park*. Bozeman, Montana.
- Butler, R. L., and D. P. Borgeson. 1965. California “catchable” trout fisheries. *California Department of Fish and Game Bulletin* 127. Sacramento.
- Cassell, J. 2014. Tightrope, Is there a way to balance wild, native and hatchery trout in our nation’s waters. *Trout Spring* 2014: 29-38.
- Cole, S. 1992. *Making science, between nature and society*. Cambridge University Press, Cambridge Massachusetts.
- Grant, J.W.A. and D. L. Kramer 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 47(9): 1724-1737.
- High, B. and K. A. Meyer. 2009. Survival and dispersal of hatchery triploid rainbow trout in an Idaho river. *North American Journal of Fisheries Management* 29:1797-1805.
- Kozfkay, J. R., J. C. Dillon, and D. J. Schill. 2006. Routine use of sterile fish in salmonid sport fisheries: are we there yet? *Fisheries* 31:392-401.
- Lackey, R.T. 2007. Science, scientists, and policy advocacy. *Conservation Biology* 21(1):12-17.
- Magill, A.W. 1988. Natural Resource Professionals: The reluctant public servants. *The Environmental Professional* 10:295-303.
- Mallet, J. 1978. Catchable trout and wild trout management in Idaho. Pages 9-11 in J.R. Moring, ed. *Proceedings of the Wild Trout – Catchable Trout Symposium*. Oregon Dept. of Fish & Wildlife, Research and Development Section. Eugene, Oregon.

- Marnell, L.F. 1986. Impacts of hatchery stocks on wild fish populations. Pages 339-347 in R.H. Stroud, Ed. Fish culture in fisheries management. American Fisheries Society, Fish Culture Section and Fisheries Management Section, Bethesda, Maryland.
- McLaren, J.B. 1979. Comparative behavior of hatchery-reared and wild brown trout and its relation to intergroup competition in a stream. Ph.D. dissertation, Pennsylvania State University, University Park.
- Meyer, K.A., B. High and F.S. Elle. 2012. Effects of stocking catchable-sized hatchery rainbow trout on wild rainbow trout abundance, survival, growth, and recruitment. Transactions of the American Fisheries Society 141:224-237.
- Milbrath, L. W. 1989. Envisioning a sustainable society, learning our way out. State University of New York Press, Albany, New York.
- Miller R. B. 1958. The role of competition in the mortality of hatchery trout. Journal of the Fisheries Research Board of Canada 15:27-45.
- Moring, J. R. 1993. Effects of angling effort on catch rate of wild salmonids in streams stocked with catchable-sized trout. North American Journal of Fisheries Management 13:234-237.
- Petrosky, C. E. and T.C. Bjorn. 1984. Competition form catchables – a second look. Pages 63-68 in F. Richards and R.H. Hamre, eds. Proceedings of the Wild Trout III Symposium at Yellowstone National Park. Bozeman, Montana.
- Petrosky, C. E., and T. C. Bjornn. 1988. Response of wild Rainbow trout (*Salmo gairdneri*) to stocked rainbow trout in fertile and infertile streams. Canadian Journal of Fisheries and Aquatic Sciences 45:2087-2105.
- Phillips, R. 2014. Montana's disaster that never happened: ending trout stocking. Idaho Statesman, July 22, 2014.
- Reed, N.P. 1975. Concluding statement to Wild Trout I Symposium. Pages 100-102 in W. King, ed. Wild Trout Management: Proceedings of the Wild Trout I Symposium at Yellowstone National Park. Bozeman, Montana.
- Underwood, T. 1986. The analysis of competition by field experiments. Pages 240-268 in J. Kikkawa and D.J. Anderson, editors. Community ecology: pattern and process. Blackwell Scientific Publications, Palo Alto, California.
- Vincent, E.R. 1975. Effect of stocking catchable trout on wild trout populations. Pages 88-91 in W. King, ed. Wild Trout Management: Proceedings of the Wild Trout I Symposium at Yellowstone National Park. Bozeman, Montana.
- Vincent, E.R. 1984. Effect of stocking hatchery rainbow trout on wild stream-dwelling trout. Pages 48-52 in F. Richards and R.H. Hamre, eds. Proceedings of the Wild Trout III Symposium at Yellowstone National Park. Bozeman, Montana.
- Vincent, E. R. 1987. Effects of stocking catchable-size hatchery rainbow trout on two wild trout species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7:91-105.
- Vincent, E.R. 1994. Oral interview with Richard Vincent, October 26, 1994. Interviewer: Art Whitney, Helena, Montana. 10 pp.
- Weber, E. D., and K. D., Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Canadian Journal of Fisheries and Aquatic Sciences 60:1018-1036.
- Weiss, S. and S. Schmutz. 1999. Performance of hatchery-reared brown trout and their effects on two small Austrian streams. Transactions of the American Fisheries Society 128:302-316.
- White, R.J., W. Nehlsen and J.R. Karr. 1994. Why wild trout matter. Pages 105-114 in R.H. Hamre and J. McGurrin, eds. Wild Trout in the 21<sup>st</sup> Century: Proceedings of the Wild Trout V Symposium in Yellowstone National Park, Bozeman, Montana.
- Wilhere, G.F. 2011. Inadvertent advocacy. Conservation Biology 26(1):39-46.

# Session 7

## Wild Trout Monitoring





Photo courtesy of Eric Stark.

# NATURAL MARKS FOR IDENTIFYING INDIVIDUAL FISH IN SMALL POPULATIONS OF AT-RISK WESTSLOPE CUTTHROAT TROUT

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**Abstract**—Noninvasive marking methods are highly desirable for identifying individual fish in small populations of at-risk trout species. We used photographs of unique natural spotting patterns and other individual morphological marks to study abundance and fall movements in a remnant population of threatened Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* in an Alberta mountain stream. We show that unique natural marks are stable and suitable for short-term studies up to at least 6 weeks duration for large juvenile- to adult-size Cutthroat Trout, that with effort large juveniles can be recognized as adult fish at least 2 years later, and that individual adults are readily recognizable over periods of at least 2 years. We used a simple spreadsheet and *ad hoc* sort routines to assist in matching the identifying marks from recapture runs. Using individual natural marks, we determined that the large juvenile to adult abundance in fall 2010 was approximately 108 (95% CL 48-270) in this 4-km stream segment, that some individuals moved downstream up to 1.6 km in late fall, and that about half the population was likely to use a single waterfall plunge-pool as an overwintering site. Using data from the literature and our abundance estimate, we calculated that this population has less than a 25% probability of persisting for 40 generations. Natural marks show considerable promise as a means of recognizing individual Westslope Cutthroat Trout while keeping handling injuries and stress to a minimum. We recommend further development of the approach to manage at-risk, critically-small remnant trout populations as well as using it in conjunction with other minimally-invasive techniques such as underwater photography.

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## INTRODUCTION

Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*) were once widespread and abundant in the Bow and Oldman River drainages of Alberta, but the current distribution of genetically-pure native populations is now severely contracted from the historical range (Cleator *et al.* 2009). Alberta populations of genetically-pure native WCT are listed as “threatened” under the federal *Species at Risk Act* in Canada (Government of Canada 2013), and under the regulations of the Alberta *Wildlife Act* (Province of Alberta. 2013). The few remnant populations are small, highly fragmented and limited to headwaters of the Bow and Oldman River drainages due to losses from hybridization, habitat reduction, and historical overexploitation (Cleator *et al.* 2009). Introduced Rainbow Trout (RT; *Oncorhynchus mykiss*) have damaged the genetic integrity of WCT through introgressive hybridization throughout the subspecies range (Allendorf and Leary 1988). When WCT and RT exist sympatrically they commonly form a fully

introgressive hybrid population called a hybrid swarm in which the characteristics unique to the native fish are lost (Allendorf *et al.* 2001). A competitive advantage for WCT may exist in headwater streams where cooler water temperatures limit RT and hybrids (Rasmussen *et al.* 2010, Rasmussen *et al.* 2012). However, these small refugium stocks are also vulnerable to extirpation from stochastic events and a variety of anthropogenic threats (Cleator *et al.* 2009).

Techniques are needed that allow these sensitive populations to be managed with minimal mortality. Most methods available for trout population studies use invasive marking techniques and require lethal sampling to obtain reliable structures for age estimation. Such approaches threaten the typically small populations they are intended to assist. Some form of external, noninvasive method for marking individual fish would permit analysis of abundance, movements and growth, critical information needed to manage small, vulnerable stocks.

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Morphological markings are widely used to identify individual vertebrates and invertebrates from whales (Wurzig and Jefferson 1990) and felids (Kelly 2001) to octopus (Huffard *et al.* 2008). In salmonids, natural marks have been used to identify individual Brown Trout *Salmo trutta* (Bachman 1984), European Grayling *Thymallus thymallus* (Persat 1982), and Chinook Salmon *Oncorhynchus tshawytscha* juveniles (Merz *et al.* 2012). To our knowledge, external morphological marks have not been used to identify individual Cutthroat Trout.

Diverse spotting patterns are found in WCT. Here we (1) show that these patterns can be used as natural marks to identify individual fish; and (2) use the individual marks to estimate abundance and detect fall movements in a small at-risk population.

## METHODS

Evan-Thomas Creek (50° 52' N, 115° 07' W), a tributary of the Kananaskis River in the Bow River basin of southwestern Alberta, Canada, holds a rare remnant stock of genetically-pure native WCT (Nine diagnostic markers, N = 34, mean WCT > 0.99; Alberta Fish and Wildlife unpublished data). We studied the creek above the Highway 40 bridge and below the waterfall approximately 4 km upstream. No WCT have been found upstream of the 3-m vertical drop waterfall as it is a major barrier to upstream movement. The creek below the Highway 40 bridge has been channelized, creating unfavorable trout habitat that tends to isolate the upstream population.

We sampled WCT by angling with flies during two widely-spaced periods; five occasions between September and October 2010 and in the fall of both 1997 and 1999. We photographed with a tripod-mounted digital camera each fish on the left and right sides, measured fork length to the nearest millimeter, recorded injuries and previous marks, then revived and released specimens in calm water, noting condition at release. We recorded the position of each capture with a geographic positioning system (GPS) receiver (Garmin GPSmap 60Cx).

Our 2010 results encouraged us to examine detailed field notes and archival color slides of WCT captured in Evan-Thomas Creek from three consecutive dates in October 1997 as well as two dates in September 1999 that were 12 d apart. In 1997 and 1999, the same methods were used as 2010 except fish were photographed on the left side only with a handheld single-lens reflex film camera, fork

length measured to the nearest millimeter, the location recorded with a Garmin GPS 38 and the adipose fin of each fish was clipped before release.

Trout photographs were analyzed using a variety of computer photo applications, especially a public domain image analysis system, Image J (Rasband 2011), to identify individually distinct spotting and marking patterns. For the 2010 fish, shape and position of markings on the entire body of the left side were manually compared between individuals of similar fork length ( $\pm 15$  mm) after each sampling event. When two captures were found with identical markings on the left side, the images of both captures on their right side were also compared. If both the left and right side photographs had identical marking patterns, the fish were treated as recaptures. The 1990s photos were digitized with a scanner and analyzed in the same method as the 2010 photos, but within years, and on the left side only. If a match could not be made in the 1999 samples, the 1997 photos were searched. In addition, we divided the photographed fish into 21 fields using a truss diagram (Strauss and Bookstein 1982) defined by landmarks readily identifiable in most photos (top corner of operculum, insertions of pectoral, pelvic, anal, dorsal and adipose fins; upper and lower caudal lobe insertions). We found 10 fields consistently visible on most photos, and recorded spot numbers in each field for each fish in a spreadsheet database.

Google Earth (<http://www.google.com/earth/index.html>) and a topographic map were used to measure distance and direction traveled by recaptured individuals. Population estimates and 95% confidence limits were calculated by Schnabel, Peterson, and Schumacher-Eschmeyer methods (Ricker 1975). The number of unique individuals captured provided a measure of the absolute minimum population size. If calculated as described by Ricker, the upper 95% confidence limit of the Schumacher-Eschmeyer population estimate is a negative in our data, so the limits do not bracket N. Instead, the reciprocal of  $1/N$  was used to calculate the upper limit of N in Ricker's equations 3.13 and 3.14.

## RESULTS

Of the 39 WCT captured in the fall of 2010, 35 had unique spotting patterns. Four fish had identical markings, on both sides, as a previous capture (e.g.; Figure 1), identifying them as recaptures.

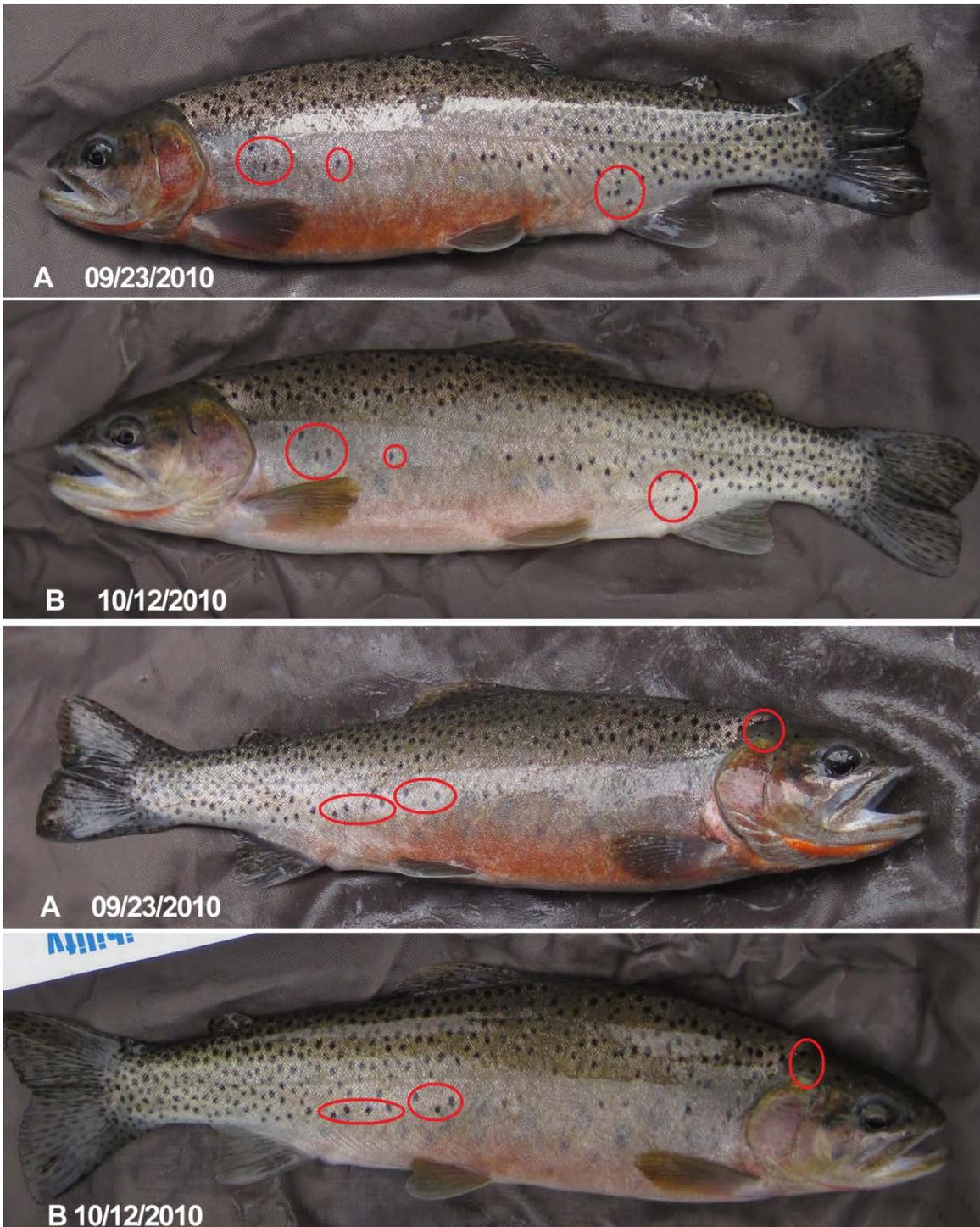


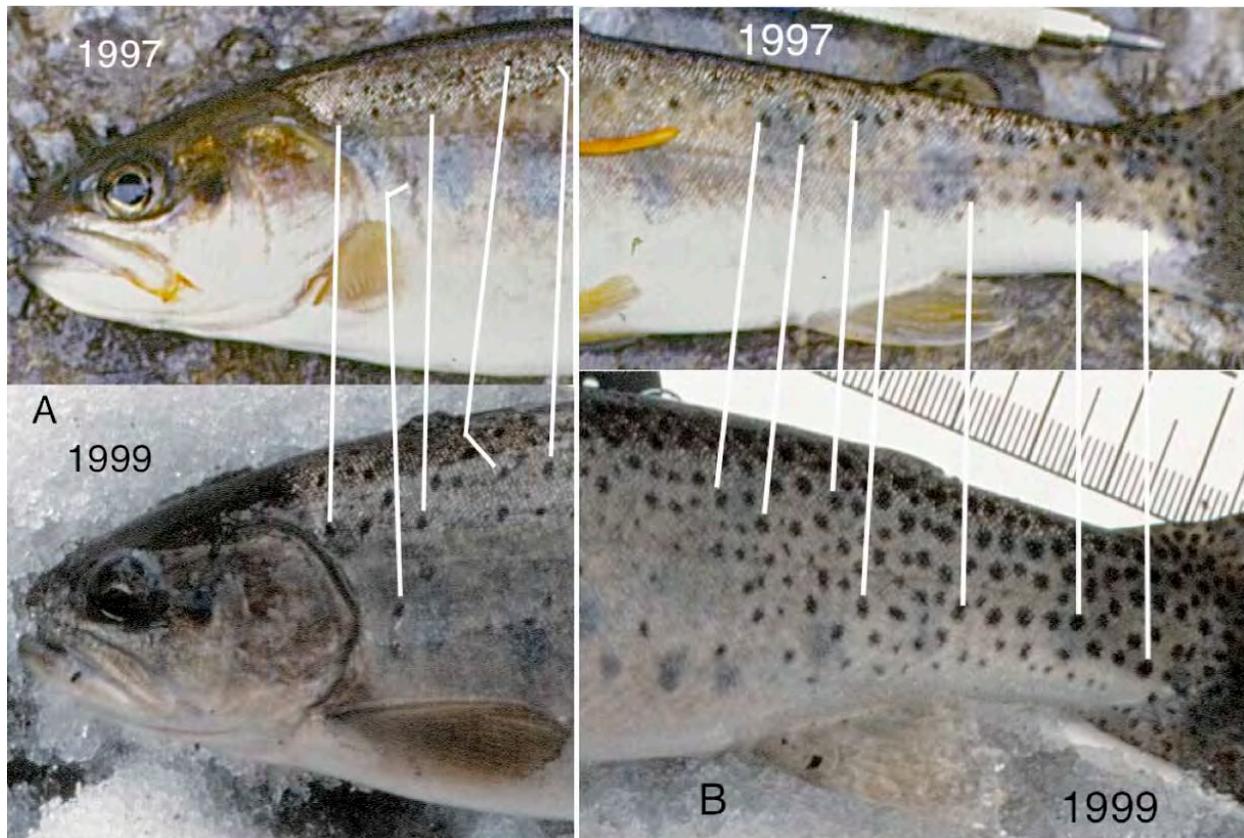
Figure 1. Identification of recaptured individual Westslope Cutthroat Trout from left and right side photos of initial capture in Evan-Thomas Creek on September 23, 2010 (A) and recapture on October 12, 2010 (B). Key identification patterns are circled in red.

In 1997, 10 fish were caught between 28 and 30 October. On the latter date one fish was identified in the field from the clipped adipose, markings and size as a recapture from October 28, but was not photographed again (the original purpose of that study did not call for a second photo). The remainder of the October 1997 specimens had individually unique spotting patterns.

In September 1999, 37 trout were captured. Of these, all but four had fully unique spotting patterns. Four fish captured on September 29, 1999 had missing adipose fins, indicating that they were recaptures. The spotting patterns of two of these recaptures matched to fish captured 12 days earlier. One more specimen, a distinctively large fish (> 400 mm long), more than 65 mm longer than the next largest caught in the 1997-1999 sampling, had a spotting pattern identical to a trout of similar length caught almost 2 years earlier on October 29, 1997 at the identical location.

One 239-mm specimen captured September 29, 1999 proved to be problematic. It had a missing adipose fin showing that it was a recapture, but initially could not be matched in photos to any previously-caught fish; it had a unique set of spots. Its adipose clip had completely healed, the overlying skin being pigmented with the green ground color of the rest of the dorsum, and spotted black. It was clearly an old wound. On closer inspection it was matched to a much smaller (144 mm) specimen captured almost 2 years earlier on October 28, 1997. The smaller fish had spots, but fewer spots than the larger specimen. Those spots matched spots on the larger fish in a corresponding location, forming identical patterns (Figures 2), thereby identifying the larger fish as that same individual recaptured almost 2 years later, having grown 95 mm in fork length and added more spots.

Spot counts by area defined in the truss diagrams varied widely among all fish and between capture



**Figure 2.** Left, head, and right, caudal region of Westslope Cutthroat Trout captured October 28, 1997 at 144 mm fork length (top), recaptured September 29, 1999 at 239 mm (bottom). Lines connect spots on the 1997 fish to spots in identical locations on the 1999 fish. Nearby patterns on the top photo are visible and identical among new spots in the bottom photo. The fish in the top photo had the adipose removed on collection; that in the bottom photo had a completely-healed scar where the adipose fin should be.

and recapture photos of recaptured specimens due to the varying orientations of the fish in the photos. Two areas below the lateral line between the pectoral and pelvic fins varied widely among individuals, and were useful as sorting criteria to limit the number of photos of possible matches that had to be inspected.

Four different methods place the fall 2010 population of Evan-Thomas Creek between 77 and 147 individuals, and certainly not less than 35, the number of unique individuals caught (Table 1). All four estimate methods assume a closed population. Of the total 35 fish captured in 2010, 17 (49%) were found in the plunge pool below the falls. The 1997 and 1999 sampling did not provide sufficient recaptures within a short time to permit us to estimate abundance.

**Table 1. Population estimates of Westslope Cutthroat Trout in Evan-Thomas Creek in fall 2010 by four methods, with 95% confidence limits.**

Estimate Method	N	95% confidence limits
Schumacher-Eschmeyer	147	69 - 272
Schnabel (Chapman Adjustment)	108	48 - 270
Petersen (Chapman Adjustment)	77	34 - 194
Absolute Minimum	35	n/a

Two recaptures in 2010 were caught 1,640 m and 1,260 m downstream of their original capture point, the plunge pool below the falls. The other two 2010 recaptures and the recaptured fish in 1997 were found in the same location as the initial capture. Three of the four recaptures in 1999 had not moved from the location of their first capture; two of these were found in the same locations they occupied almost 2 years earlier. The single remaining recapture in 1999 had moved 225 m upstream over a 12-d period.

We solved for  $N_e$  in Equation 1 of Soulé (1980), a rule-of-thumb estimating time-to-extinction of populations  $< 50$ , setting generations to 40 and assuming a probability of persistence of 1%, since in very small populations it must be low but not 0 for any mixed-sex adult population greater than 1. This gave us an estimate of persistence probability for populations with  $< 50$  adults, and with the above data from Reed *et al.* (2003) allowed us to relate probability of persistence to population size by another rule-of-thumb (Equation 1):  $y = 40 \log_{10} x - 57$ , (1)

where  $y$  is probability of persistence (%) for 40 generations, and  $x$  is adult population size.

Estimated from Equation 1 for the fall 2010 population of 108 mostly adult-size WCT in Evan-Thomas Creek, there is less than a 25% probability that this stock can persist for at least 40 generations.

## DISCUSSION

In the 2010 study, we reasoned that fish of similar length with identical spotting patterns on both sides of the body—in a population in which most individuals had spotting patterns that could not be matched—must be the same individuals. This seems highly likely, but without independent evidence of recapture it is not incontrovertible. We addressed this issue by examining the 1997 and 1999 archival photographs and accompanying field notes, in which independent evidence of recapture was available from adipose fin clips administered when fish were collected. When in later sampling runs we encountered specimens with the adipose fin removed, we had independent evidence of recapture. Photos of these recaptured fish in each case could be matched to a previously-caught fish by its identical spotting pattern on the left side. Fish without adipose clips had spotting patterns on the left side that were unique, and could not be matched. This is good evidence that spotting patterns in this population of Westslope Cutthroat Trout are unique to individual fish, and that their spotting patterns can be used as individual markers.

Spotting patterns appear to be stable over at least 2 years for large adults. The largest trout collected, could be matched by its left-side spotting pattern, and by its adipose clip, to a photo of a fish captured almost 2 years earlier in the same location. We suggest further that juveniles will have a reduced set of spots with patterns that persist into adulthood and can be detected in the adults, even though the adults have additional spots. We found such evidence in one of the few juvenile-sized fish (144 mm fork length) captured in 1997, whose suite of spot patterns was visible within the more elaborate spotting pattern of an adult-sized (239 mm fork length) trout caught two years later in 1999. The adult fish had a well-healed scar in place of its missing adipose fin, showing that it had been clipped prior to the season in which it was caught, and that it was a recaptured fish. The only spotting pattern match that could be made was with the 1997 juvenile.

These observations suggest that spotting patterns may be useful as individual markers for periods longer than a single season for large juveniles and adults.

Two issues remain to be resolved in using spotting patterns routinely as natural markers to identify individual cutthroats. First, pattern-matching by visual inspection can be tedious, time-consuming, and only reasonable for small datasets of the size used in this study. Our approach using sort routines in a spreadsheet database of spot counts by area can work, but requires that the spots be counted, another tedious and time-consuming procedure. The system developed by Merz *et al.* (2012) for young Chinook Salmon, or by Kelly (2001) for cheetah may be adaptable for use on lateral views of Cutthroat Trout. Second, while our evidence of long-term pattern stability is suggestive, it is based on just two fish and requires verification.

The best Petersen population estimate of several possible, and that reported here, used 21 and 23 September as the marking run and 12, 14 and 24 October as the census runs, which gave the largest number of recaptures and best met the assumption of one brief marking event followed by a prolonged census event (Ricker 1975). Schnabel and Schumacher-Eschmeyer estimates are multiple census estimates which better fit our study design. The Schumacher-Eschmeyer estimate is close to the Schnabel estimate, and confidence limits for the 2 estimates are nearly identical. The best single estimate is the Schnabel estimate due to its assumption of random sampling and increasing number of marked fish, which are closely satisfied by the data. The confidence limits for the three mark-recapture estimates all widely overlap, lending confidence that the most likely population size is within the range 77 - 147. The population cannot be lower than 35, the number of unique fish captured, which is effectively identical to the lower 95% confidence limit of 34 for the Petersen estimate.

Population size is a good predictor of population persistence (O'Grady *et al.* 2004). Adult abundances in the thousands are ordinarily required to ensure long-term persistence of vertebrate populations (Reed *et al.* 2003, Reed 2005). Reed *et al.* (2003) estimated that approximately 5,800 adult animals are needed for a 95% chance of persistence over 40 generations, 4,700 for 90% persistence, and 550 for a 50% chance of persistence. At very low numbers, inbreeding effects become important (Soulé 1980). The fall 2010

population of adult-size WCT in Evan-Thomas Creek has less than a 25% probability of persistence over 40 generations.

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## LITERATURE CITED

- Allendorf, F. W., and R. F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species, the cutthroat trout. *Conservation Biology* 2:170-184.
- Allendorf, F. W., R. F. Leary, P. Spruell, and J. K. Wenburg. 2001. The problem with hybrids: setting conservation guidelines. *Trends in Ecology & Evolution* 16:613-622.
- Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. *Transactions of the American Fisheries Society* 113:1-32.
- Cleator, H., J. E. Earle, L. Fitch, S. Humphries, M. Koops, K. E. Martin, D. Mayhood, S. Petry, C. J. Pacas, J. D. Stelfox, and D. Wig. 2009. Information relevant to a recovery potential assessment of pure native westslope cutthroat trout, Alberta population. Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Research Document 2009/036, revised February 2010, iv+26 p.
- Government of Canada. 2013. Order amending Schedule 1 of the Species at Risk Act. SOR/2013-34. *Canada Gazette Part II* 147:625-655.
- Huffard, C. L., R. L. Caldwell, N. DeLoach, D. W. Gentry, P. Humann, W. H. MacDonald, B. Moore, R. Ross, T. Uno, and S. Wong. 2008. Individually unique body color patterns in octopus (*Wunderpus photogenicus*) allow for photoidentification. *PLoS One* 3:e3732. doi:10.1371/journal.pone.0003732
- Kelly, M. J. 2001. Computer-aided photograph matching in studies using individual identification: An example from Serengeti cheetahs. *Journal of Mammology* 82:440-449.
- Merz, J. E., P. Skvorc, S. M. Sogard, C. Watry, S. M. Blankenship, and E. E. Van Nieuwenhuyse. 2012. Onset of melanophore patterns in the head region of chinook salmon: A natural marker for the reidentification of individual fish. *North American Journal of Fisheries Management* 32:806-816.

- O'Grady, J. J., D. H. Reed, B. W. Brook, and R. Frankham. 2004. What are the best correlates of predicted extinction risk? *Biological Conservation* 118:513-520.
- Persat, H. 1982. Photographic identification of individual grayling, *Thymallus thymallus*, based on the disposition of black dots and scales. *Freshwater Biology* 12:97-101.
- Province of Alberta. 2013. Wildlife Act: wildlife regulation. Alberta Regulation 143/1997. Alberta Queen's Printer, Edmonton, AB. 323 p.
- Rasband, W. 2011. ImageJ64 1.46a. Public domain image analysis software, National Institutes of Health, USA. <http://imagej.nih.gov/ij/> (September 2010)
- Rasmussen, J. B., M. D. Robinson, and D. D. Heath. 2010. Ecological consequences of hybridization between native westslope cutthroat (*Oncorhynchus clarkii lewisi*) and introduced rainbow (*Oncorhynchus mykiss*) trout: effects on life history and habitat use. *Canadian Journal of Fisheries and Aquatic Sciences* 67:357-370.
- Rasmussen, J. B., M. D. Robinson, A. Hontela, and D. D. Heath. 2012. Metabolic traits of westslope cutthroat trout, introduced rainbow trout and their hybrids in an ecotonal hybrid zone along an elevation gradient. *Biological Journal of the Linnean Society* 105:56-72.
- Reed, D. H. 2005. Relationship between population size and fitness. *Conservation Biology* 19:563-568.
- Reed, D. H., J. J. O'Grady, B. W. Brook, J. D. Ballou, and R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation* 113:23-34.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 191:1-382.
- Soulé, M. E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. pp. 151-169. *in* M. E. Soulé, and B. A. Wilcox, editors. *Conservation biology: an evolutionary-ecological perspective*. Sinauer Associates, Inc., Sunderland, MA. xv+395 p.
- Strauss, R. E., and F. L. Bookstein. 1982. The truss: body form reconstructions in morphometrics. *Systematic Zoology* 31:113+135.
- Wurzig, B., and T. A. Jefferson. 1990. Methods of photo-identification for small cetaceans. Report of the International Whaling Commission Special Issue 12:43-52.

## GPS-BASED SNORKEL VIDEO-MAPPING AS AN INNOVATIVE SURVEY TECHNIQUE FOR MONITORING AND MAPPING WILD BROOK TROUT POPULATIONS IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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**Abstract**—The success of snorkel surveys for wild trout population monitoring can vary, depending on the stream condition, survey technique, and snorkeler. Training, reliability, and consistency are critical for accurate wild trout population monitoring. A GPS-based snorkel video-mapping system (GSVMS) was developed to provide video-documented, geo-referenced snorkel surveys of wild trout populations, size, species, location, and habitat. The GSVMS consists of a dive mask with an embedded video camera capturing underwater video and a GPS receiver mounted to the mask back strap creating a concurrent track log. Snorkel video-mapping surveys for wild Brook Trout *Salvelinus fontinalis* were conducted at three study sites on Lynn Camp Prong in the Great Smoky Mountains National Park (GRSM). Using the GSVMS, Brook Trout numbers, size, and habitat were observed and video recorded. The underwater video attributes and GPS data were incorporated into ArcGIS providing a geo-referenced video survey. The archived geo-referenced (historical) video database provides a visual confirmation for the sampled river reach, and virtual site revisit opportunities in remote survey locations. Data for the snorkeling effort included time in water, activity, distance covered, and locations snorkeled with ArcGIS reference points, so that population density could be easily and accurately determined. The population of Brook Trout estimated from GSVMS surveys and electrofishing were reasonably consistent.

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### INTRODUCTION

Wild trout population monitoring is needed to evaluate trends and impacts for trout population management. New technology, including GPS and underwater videography provide unique opportunities to create innovative geo-referenced population monitoring techniques.

Fish population census using underwater observation with snorkeling gear is considered an acceptable monitoring approach (Thurow 1994). Although problems with snorkel surveys were identified (including misidentification of fish species), the advantage of the non-invasive and simple survey approach is recognized. In multiple comparisons between snorkel and electrofishing estimates, snorkelers observed from 75 to 110% of the electrofishing counts (Thurow 1994). The need for reliable, unbiased, consistent survey techniques is important for an accurate population census.

For small, rare, non-trout species, snorkeling was effective for estimating site occupancy when compared to electrofishing (Albanese et al. 2011).

But, the effectiveness of snorkeling is much reduced in highly turbid streams. Cunjack et al. (1988) found that snorkel counts underestimated the populations of small fish (compared to electrofishing), possibly due to visibility and habitat complexity. Mixed success was found between the populations of two trout species when comparing snorkel surveys to depletion electrofishing (Joyce and Hubert 2003); both species (differential) and fish size (directly) were related to population estimates. High correlation was found between depletion electrofishing and snorkel survey for three trout species, with snorkel surveys underestimating electrofishing populations by 65% (Mullner et al. 1998). Snorkel surveys for trout populations have been used in large streams where electrofishing is not effective (Slaney and Martin 1987). Counts of large (>20 cm long) trout were underestimated by 26%, and population counts were affected by the number of snorkelers actively surveying (Slaney and Martin 1987).

Factors affecting snorkel count accuracy include daily and seasonal movement and activity, turbidity,

and flow (Korman et al. 2006). The relationship between underwater visibility and count accuracy was documented in mark-capture snorkel surveys (Baxter and Hagen 2010). Baxter and Hagen (2010) determined snorkel survey population estimates are a reliable monitoring technique.

In 2008, Moore and Kulp (2008) initiated a project on Lynn Camp Prong in the Great Smoky Mountains National Park (GRSM), to restore native Brook Trout *Salvelinus fontinalis* to 12.9 km of the stream. Prior to and after restoration was completed, three-pass depletion electrofishing techniques were used at standardized sites to determine Rainbow Trout *Oncorhynchus mykiss* (pretreatment) and Brook Trout (post treatment) density and biomass (Habera et al. 1996; 2010). Although snorkel surveys are commonly used in coolwater Southern Appalachian streams for benthic species (Shute et al. 2005), the techniques have not been widely used in the southeast for salmonids. This study provides an opportunity to evaluate the new GPS-based snorkel survey approach and compare the results to an electrofishing census on the Lynn Camp Prong.

The objective of this study is to evaluate a GPS-based snorkel mapping system for conducting geo-referenced and video-supported snorkel surveys and to determine if GPS-based snorkel mapping assists (add value to) the snorkel-based trout population survey

## STUDY SITE

The Lynn Camp Prong (LCP) (35.607° N, 83.637° W) watershed is located in Sevier and Blount counties, Tennessee and positioned in the southwestern interior of GRSM (Figure 1). Thunderhead Prong (THP) and LCP, both 4th order streams, converge to form Middle Prong Little River (MPLR) which flows northwest to the park boundary at the confluence with East and West Prongs Little River. There is a 60-m barrier cascade roughly 600 m upstream from the confluence of THP and LCP, which serves as a barrier to reinvasion of nonnative fish species. The section of LCP above the barrier falls is separated into 100-m stream study reaches. Sites are numbered moving upstream from the barrier falls every 100 m. The study sites were sites 11, 33, and 37.

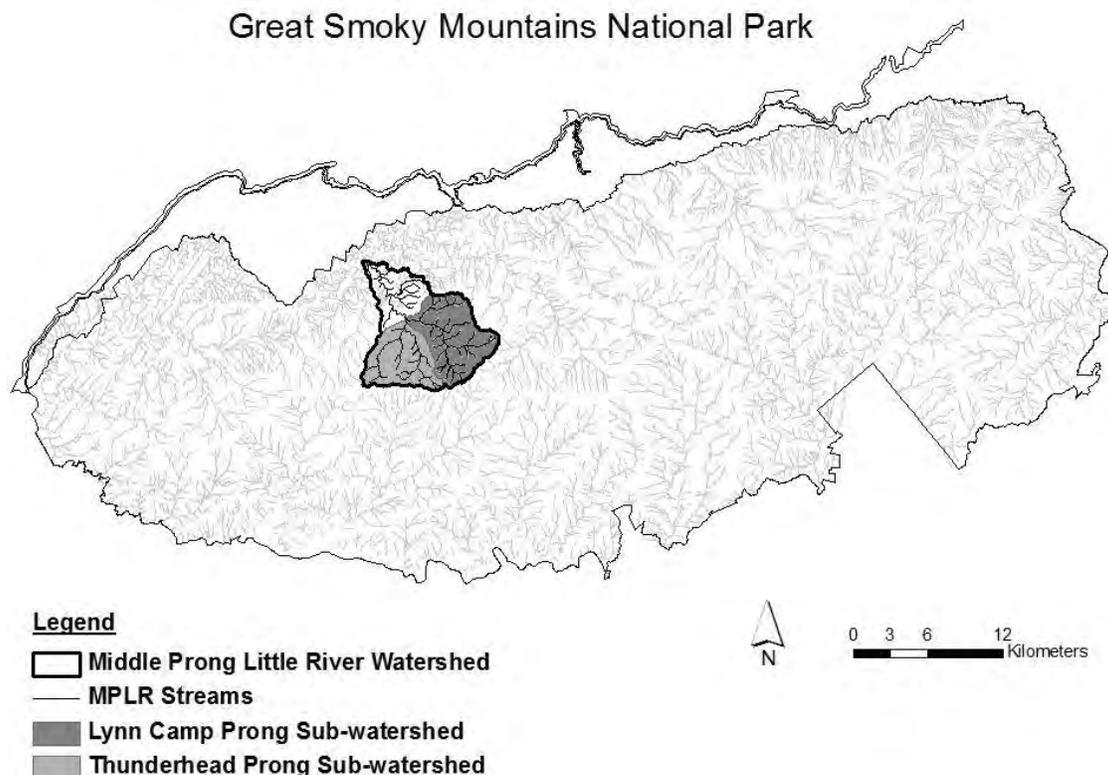


Figure 1. The Lynn Camp Prong (LCP) and Thunderhead Prong (THP) sub-watersheds are located in the southwestern interior of Great Smoky Mountains National Park (GRSM) and converge to form Middle Prong Little River (MPLR).

## METHODS

The GPS-based snorkel mapping system (Figure 2) uses a Garmin 60csx GPS receiver recording GPS position at a 1 Hz rate. The GPS is attached to the backstrap of the snorkel mask allowing the antennae to remain out of water during the survey. A Liquid Image video-mask (snorkel mask with embedded video camera) captures underwater video. Two snorkelers conducted the 100-m snorkel surveys, each covering one-half of the 5- to 10-m wide stream. Hand gestures were used to indicate fish counts (number of fingers) and size (large > 10 cm and small < 10 cm hand signals) and were recorded by the video camera. The video snorkel surveys at sites 11, 33, and 37 were conducted on 25 June 2013, between 9 am and 4 pm. Due to recent rainfall, the flows were relatively high for that time of year and turbidity was high. Missing video counts and video footage were estimated and incorporated into the population counts.

The underwater video was reviewed and counts of fish and size were recorded with video times. The video record times (VTR) were merged with Universal Time Coordinated (UTC) times, and GPS positions were determined for each fish location. In addition, snorkeler event studies were conducted to determine the times the snorkeler was (1) searching for fish, (2) recording count and size, (3) moving to new location, (4) orienting the snorkeler and looking for direction to move, and (5) conducting equipment maintenance (clearing mask, adjusting strap).

The 2013 electrofishing surveys were delayed until August 2013 due to excessive rain and high water flow. Each 100-m study site was sampled using backpack electrofishing units similar to those described by Habera et al. (1996) and fish populations were enumerated using the 3-pass depletion technique (Trout Committee, SD AFS 1992). Block nets were placed at the top and bottom of each site, experienced personnel completed all electrofishing passes, and at least 30 min elapsed between all passes to ensure all depletion estimate assumptions were being met. Total length (mm) and weight (g) were measured for each fish and recorded by pass. All fish were held in holding cages outside of the sampling area until all sampling was completed. Population estimates were generated using Microfish 3.0, which utilizes the Burnham maximum-likelihood estimate model (van Deventer and Platts 1989).



**Figure 2. GPS-based snorkel video mapping system used for the LCP Brook Trout visual surveys.**

## RESULTS

The GPS-based video snorkel surveys were conducted in 50.8, 50.9 and 51.1 min for Sites 11, 33 and 37, respectively. Population counts and size for the June 2013 video snorkel survey and the August 2013 electrofishing are listed in table 1.

**Table 1. Comparison of video snorkel (conducted June 2013) and electrofishing (conducted August 2013) Brook Trout counts at three sites on Lynn Camp Prong, Great Smoky Mountains National Park.**

Site	Video			Electrofishing		
	Small	Large	Total	YOY	Adult	Total
11	42	2	44	5	12	17
33	14	2	16	25	24	49
37	28	16	44	28	23	51
Total	84	20	104	58	59	117

In addition, the video survey was reviewed to determine the length of time the snorkeler was involved in actually searching for fish. The catch per effort (CPE) can be estimated from the start and stop times of the snorkel survey determined from the snorkel video. The average time spent searching for fish was 85.6% of the total survey time (Figure 3).

In addition to the counts and size estimated from the video, the location of the fish counts can be determined and incorporated into ArcGIS (Figure 4).

As individual fish are identified, the image (depending on video quality), location, and time can be stored (Figure 5). In addition, the habitat (substrate) and depth can be estimated.

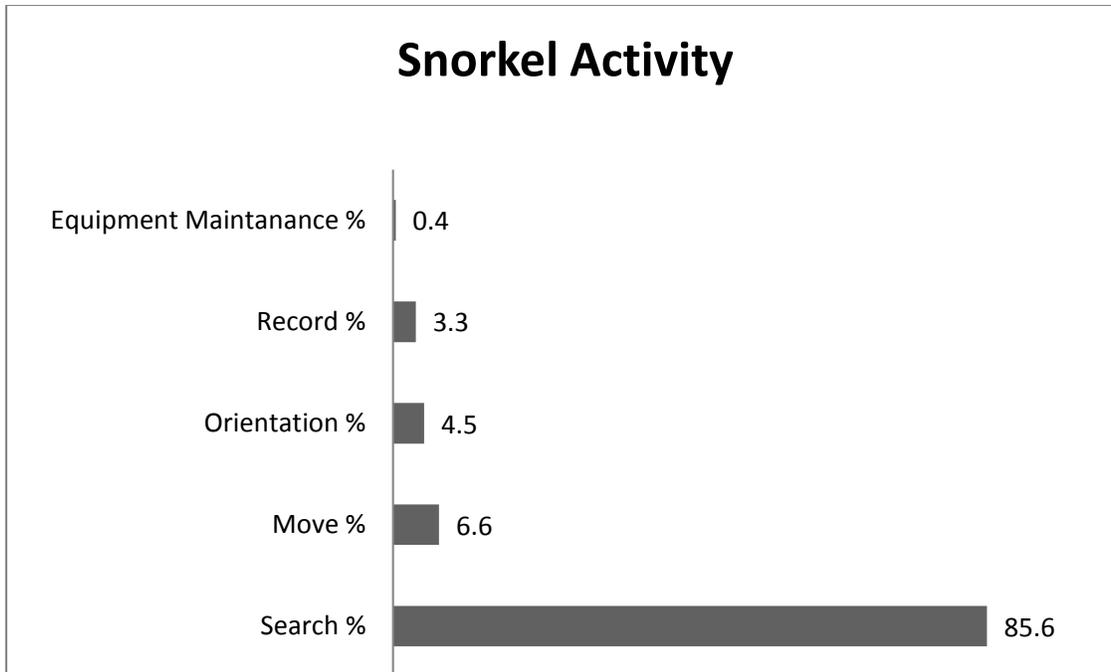


Figure 3. Average percent of snorkeling activity time expended on various components during the three video surveys conducted June 25, 2013 at the Lynn Camp Prong, Great Smoky Mountains National Park.

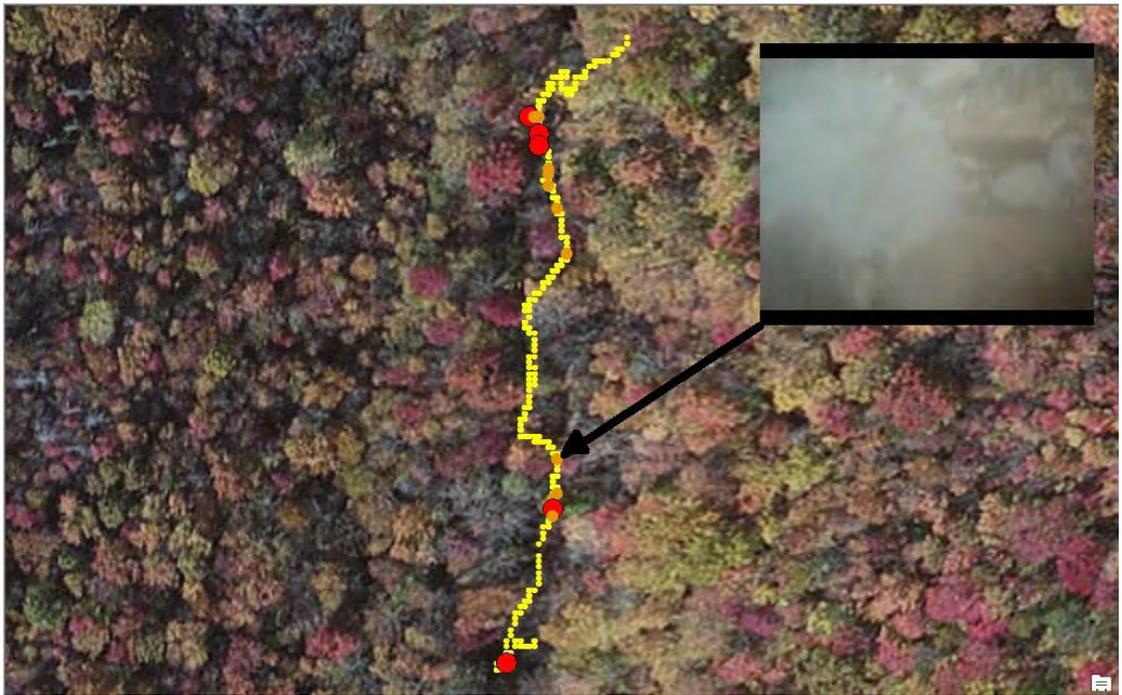


Figure 4. ArcGIS plot of snorkel track and fish locations (sizes are indicated) at site 37, conducted June 25, 2013 on the Lynn Camp Prong, Great Smoky Mountains National Park.



**Figure 5. Brook Trout image with associated GPS location, date and time that was recorded during a video snorkel survey of Lynn Camp Prong, Great Smoky Mountains National Park.**

## DISCUSSION

The Brook Trout counts revealed a reasonable comparison of total trout observed using the snorkel and electrofishing surveys. Snorkel counts were 11% less than electrofishing estimates for all sizes of fish. This underestimate is consistent with findings by Mullner et al. (1998). However, small trout accounted for 81% of all fish counted by snorkelers, and YOY trout accounted for only 50% of all trout captured by electrofishing. This difference in estimated young fish may be due to the inexperience of the snorkelers in estimating fish size.

Although snorkel surveys have some disadvantages compared to electrofishing, the introduction of GPS and underwater video provide opportunities to acquire additional data while conducting snorkel surveys. The ability to determine the location of each trout provides the opportunity to determine variations in density among individual habitat types along the reach, not just an average for the total reach. The video generates a historical

database for the trout and surrounding habitat that can be used to evaluate future trends. Review of the snorkel video provides additional training opportunities and allows supervisors to maintain quality control of the snorkeling effort. The catch per effort can be easily determined and compared between individual snorkelers.

For habitat determination, there is no need to drop flags for return site visits. Estimates of substrate and depth can be determined from the video. The snorkel mask provides the opportunity to mount underwater lasers that can be used to assist in determining fish size and depth. As GPS and underwater video technology continue to improve, applications to snorkel survey activity will be forthcoming.

## ACKNOWLEDGEMENTS

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## REFERENCES

- Albanese, B., K. A. Owers, D. A. Weiler, and W. Pruitt. 2011. Estimating occupancy of rare fishes using visual surveys, with a comparison to backpack electrofishing. *Southeastern Naturalist* 10(3):423-442
- Baxter, J. S., and J. Hagan. 2010. Use of radio telemetry with mark-capture snorkel surveys to improve population estimates of fluvial trout species. Pages 234-240, *in* B. Carline and C. LoSapio, editors. *Wild Trout IX: Conserving Wild Trout*. Wild Trout Symposium, Bozeman, Montana.
- Cunjack, R. A., R. G. Randall, and M. P. Chadwick. 1988. Snorkeling versus electroshocking: a comparison of census techniques in Atlantic salmon rivers. *Canadian Naturalist* 115:89-93.
- Habera, J. W., R. J. Strange, B. D. Carter, and S. E. Moore. 1996. Short-term mortality and injury of rainbow trout caused by three-pass AC electrofishing in a southern Appalachian stream. *North American Journal of Fisheries Management* 16:192-200.
- Habera, J. W., M. A. Kulp, S. E. Moore, and T. B. Henry. 2010. Three-pass depletion sampling accuracy of two electric fields for estimating trout abundance in a low-conductivity stream with limited habitat complexity. *North American Journal of Fisheries Management* 30:757-766.
- Joyce, M. P., and W. A. Hubert. 2003. Snorkeling as an alternative to depletion electrofishing for assessing cutthroat trout and brown trout in stream pools. *Journal of Freshwater Ecology* 18:215-222.
- Korman, J., M. Yard, and D. Speas. 2006. An evaluation of the utility of snorkel surveys for estimating population size and tracking trends in relative abundance of rainbow trout in the Lee's ferry reach of the Colorado River. Final research Report prepared for the Arizona Game and Fish Department, Phoenix.
- Moore, S. E., and M. A. Kulp. 2008. Native Brook Trout restoration on Lynn Camp Prong Great Smoky Mountains National Park. Progress Report submitted to the Great Smoky Mountains National Park, Resource Management and Science.
- Mullner, S. A., W. A. Hubert, and T. A. Wesche. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. *North American Journal of Fisheries Management* 18: 947-953.
- Shute, J.R., P.L. Rakes, and P.W. Shute. 2005. Reintroduction of four imperiled fishes in Abrams Creek, Tennessee. *Southeastern Naturalist*. 4(1):93-110.
- Slaney, P. A., and A. D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. *North American Journal of Fisheries Management* 7:117-122.
- Thurrow, R.F. 1994. Underwater methods for study of salmonids in the intermountain West. U.S. Forest Service General Technical Report INT-GTR-307.
- Van Deventer, J.S. and W.S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data. Users guide for Microfish 3.0. General Technical Report INT-254. Ogden, Utah. U.S. Department of Agriculture, U.S. Forest Service, Intermountain Research Station. 29pp.

## REDD COUNTING FOR MONITORING SALMONIDS IN FINNISH INLAND WATERS

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**Abstract**—During recent years, systematic redd counting has been used as a monitoring method of wild Brown Trout *Salmo trutta* spawning stocks, both resident and lake-migrating, in the Lake District in Southern Finland. Counting is done by wading and viewing with an aqua-scope, and is related to channel microhabitat measurements, to estimation of gravel origin, to regression between redd length and female length, to regression between female length and egg number in redd, and to parr density. This produces valuable information about spawning environment, spawning stocks, and stock-recruitment ratio for management of stream-spawning fishes and river channels. Number of trout redds and of female spawners was mostly 10–30 (length of each stream sampled 200–500 m), and a maximum about 100 redds or individuals, per stream in Kymijoki watercourse. Average redd length was 1.71 m, water depth 57 cm, and water current velocity in 3 cm above bottom surface 27 cm/s. Most common dominant gravel size was 64–128 mm in pot and 32–64 mm in tail. Both natural and artificial gravel were important as spawning grounds, but gravel carried in with buckets by volunteers produced much more redds per gravel volume than gravel deposited with an excavator. Most often, redds were situated in small pools or holes inside riffle sections, but also in upstream edges of riffles in some larger rapids. About 70 % of redds were situated no more than 50 cm from a shelter, like a stone or a channel bank. In Kymijoki streams, mean fork length of female spawners was 38 cm, estimated from redd tail lengths. In other Finnish and Swedish spawning rivers of lake-migrating Brown Trout, average redd length was 2.5–3.0 m, and average female length 45–52 cm. In one Kymijoki stream, parr density was linearly correlated with egg density, estimated from redd number and redd tail lengths.

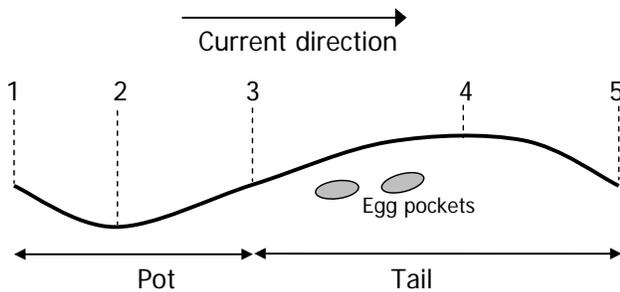
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### INTRODUCTION

Lake-migrating and sea-migrating Brown Trout *Salmo trutta* are classified as endangered and critically endangered, respectively, in Finland in the drainage area of the Baltic Sea (Rassi 2010). A century ago, landlocked Atlantic Salmon *Salmo salar* m. *Sebago* lived as wild in Vuoksi watercourse, the largest Finnish watercourse situated in the southeast, but now after being bred only in hatcheries for the past 42–45 years, the subspecies will possibly be returned into one of its three historical spawning streams in fall 2013. Main reasons for the weakness of wild trout stocks are strong fishing pressure on lakes (Syrjänen and Valkeajärvi 2010) and on the coastal Baltic Sea, mainly with gillnets, and stream damming. High fishing mortality will make it hard to restore the wild stock of landlocked Atlantic Salmon, too. On the other hand, stream channel restoration projects have been going on in Finland for the past 30 years, and restorations have been done mainly for fisheries. New artificial gravel beds have been usually created in channel restorations, but no information is available about the use of these beds by spawners.

In monitoring wild stocks of stream spawning salmonids, electrofishing of parr has been the most commonly used method. Horizontal echo sounding, fish counting on dams or in fishways, and rod catch have been used for Atlantic Salmon and migrating Brown Trout, too. In the Lake District in Southern Finland, stream channels are mainly short lake-outlet streams between lakes. There, redd counting has been used for monitoring of wild spawning stocks of Brown Trout in the 21st century. However, redd counting has been used for decades in some parts of Europe (e.g. Dauphin et al. 2010), and especially in North America (Beland 1996; Callagher et al. 2007).

A female Brown Trout usually makes one redd, sometimes two, when spawning, each redd includes several nests or egg pockets (Klemetsen et al. 2003), and buries the eggs in gravel to depths of 1–20 cm. A redd consists of an upstream pot, which is a deeper hole compared to surrounding substratum, and a downstream tail or hump, where the female has piled gravel from the pot over the eggs (Figure 1). In Finland, main spawning time is from mid-September to mid-October. Parr emerge from late



**Figure 1. Side profile of the spawning redd of salmonids. Five example points are shown, where depth and current velocity can be measured. 1 = upstream edge of pot, 2 = deepest point in pot, 3 = border between pot and tail, 4 = highest point in tail, and 5 = downstream edge of tail.**

May to late June. Thus, incubation time of eggs and alevins in bottom substrate is long, 7–9 months, depending on latitudinal location of the stream. To estimate spawning environment, redd structure, redd microhabitat factors, and female spawner length, 1,367 redds were sampled in six large watercourses in Finland and Sweden.

## METHODS

### Study Streams

Most of the trout redd data set was collected from streams of Kymijoki watercourse, situated in the Finnish Lake District, during years 2000–2012. Seven separate streams of five sub-watercourses were sampled: Arvaja (mean low flow 0.66, mean flow 2.0, and mean high flow 8.7 m<sup>3</sup>/s; flowing into Lake Päijänne), Rutajoki (0.35, 1.2 and 5.2 m<sup>3</sup>/s; Päijänne), Muuramenjoki (1.3, 3.3 and 11.1 m<sup>3</sup>/s; Päijänne), Rautalampi sub-watercourse (33, 45 and 92 m<sup>3</sup>/s; Konnevesi), Koivujoki (0.59, 2.2 and 7.6 m<sup>3</sup>/s; Pielavesi-Nilakka), Kärnä sub-watercourse (6.6, 15, and 32 m<sup>3</sup>/s; Keitele), and Läsänköske (6.5, 15, and 25 m<sup>3</sup>/s; Puula). The seven streams include the most important spawning streams of trout in Kymijoki watercourse. Water quality is good or excellent in all streams and lakes, but bottom ice formation occurs in streams in some winters. Each lake has a surface area of 100–1,100 km<sup>2</sup>, and has good or excellent Vendace *Coregonus albula* stocks as prey for lake-migrating trout. Each stream channel was dredged between the 1850s and the 1960s, but was restored in 1982–2011. However, restoration actions were usually

slight, and channels were probably not returned to their natural condition. In restoration by environmental administration in 1997, 50–100 m<sup>3</sup> of gravel deposited by excavator was added in the channel of Rutajoki. Then, in voluntary restoration in 2000, 10 m<sup>3</sup> of gravel carried in with buckets by volunteers was added. In corresponding restoration actions in Koivujoki, 100–300 m<sup>3</sup> of excavator gravel was added in 1994, and 10 m<sup>3</sup> of bucket gravel in 2009. In these streams, excavator gravel was of smaller size and included both crushed rubble and filtered gravel, while bucket gravel was slightly larger than filtered gravel. Some graveling volunteers also carried out the redd counting, remembering exact points of bucket gravel beds. Thus, excavator gravel and bucket gravel beds could be identified in the two streams. In Arvaja, 50–100 m<sup>3</sup> of excavator gravel was added in 1996, and 5 m<sup>3</sup> of bucket gravel in 2000s, but these two gravel classes could not be identified separately there. All data were collected after channel restoration and extra gravel restoration in each stream.

Additional trout redd data sets were collected from other watercourses from known spawning streams of lake-migrating Brown Trout. These were Heinävesi sub-watercourse flowing out from Lake Kermajärvi situated in Vuoksi watercourse in Southern Finland; rivers Oulanka and Kuusinki in Koutajoki watercourse in North-Eastern Finland flowing into Lake Päijärvi in Russia; river Juutua in Paatsjoki watercourse flowing into Lake Inari in Northern Finland; rivers Hjoån and Hjällöbacken flowing into Lake Vättern in Southern Sweden; and rivers Gullspångsälven and Klaraälven flowing into Lake Vänern in Southern Sweden, in 2008–2012. Vänern tributaries were sampled before spawning time of landlocked Atlantic Salmon. Each lake has a surface area of 100–5,000 km<sup>2</sup>. Water quality is excellent in all streams and lakes, and Vendace stocks are excellent in all lakes.

### Redd Sampling

Most of sampled riffle sections of a stream or whole rapids were waded through completely with aqua-scope from bank to bank in an upstream direction. If it was not possible to sample the whole section, best spawning areas were sampled to find most of the redds in the section. In Kymijoki streams and sub-watercourses, size of sampling area was 0.3–2 ha in each stream and included 2–4 riffle sections per stream. Largest streams, Rautalampi, Heinävesi,

Oulanka, Juutua and Klaraälven, were waded from bank to depth of 1–1.5 m. Clear, redd-shaped pits were classified as redds, but small and unclear-shaped pits were carefully dug out, so that 1–2 eggs were found, and the pit was identified as a redd. If no eggs were found despite vigorous digging, the pit was abandoned and not measured. In Finnish streams, redd superimposition, i.e. several females spawned over each other's redds, was rare, as redds touched only occasionally each other. No more than of 2% of redd-shaped objects containing eggs could not be identified clearly as one redd or several redds. Thus, estimation of redd microhabitat factors was reliable in all Finnish streams, and estimation of the number of female spawners possible in Kymijoki sub-watercourses. In Vättern and Vänern inlets, superimposition was more common, but microhabitat factors could be measured by rigorous sampling for each redd.

Total length and width of pot and tail were measured separately (Figure 1). Most important microenvironmental factors, like water depth, current velocity 3 cm above substratum, and substratum particle size with modified Wentworth scale (Heggenes 1988) were measured, again separately for pot and tail. Distance from redd edge to a nearest possible shelter suitable for spawning fish was measured. Channel bank, woody debris with diameter of 10 cm or more, or a stone with the largest diameter of 40 cm or more and situated clearly above bottom level were classified as a shelter construction. The origin of redd gravel was classified into three categories: natural gravel, artificial gravel put in channels by excavator in restorations organized by environmental authorities (excavator gravel), and artificial gravel put in channel by volunteers with buckets (bucket gravel).

### Estimation of Female Length and Egg Density

The fork length of a spawned female trout ( $L$ , cm) was estimated for each redd from the redd tail length ( $q$ , cm) as  $\ln L = 0.60 \ln q + 0.86$  (modified from Crisp and Carling 1989). This produced length distribution of females. The egg number ( $E$ ) buried by a female in her redd was calculated from female fork length ( $L$ , mm) as  $E = 0.006266 \cdot L^{2.048}$  with regression from Elliott (1995). For egg density in a riffle section, egg number was summed from all redds and divided by the size of sampling area. In Rutajoki, the egg density was related annually to next fall density of age-0 parr

in electrofishing during 12 years, and thus, a stock-recruitment curve was created for two riffle sections, Matkuksenkoski and Porraskoski. Length of both sections was 200 m, and they were separated by a 200-m long pool section.

### Statistical Analyses

Medians of total redd length, depth at the break of pot and tail, current velocity 3 cm above bottom substrate at the break of pot and tail, dominant particle size in tail, and estimated female length between lakes or (sub)watercourses were tested with nonparametric median test. In case of significant difference between medians, pairwise comparisons of medians were made. Water depth and current velocity were not tested for Vänern streams, as discharge was lowered substantially from autumnal normal by hydroelectric power plant to make redd counting possible in Gullspångälven. Current velocity was not measured for Inari stream. In Rutajoki, Spearman rank correlation was used on stock-recruitment data.

## RESULTS

As main characteristics among the five Kymijoki sub-watercourses, averages of the minimum, mean and maximum values of total redd length (total  $n = 991$ ) were 51, 171 and 429 cm, respectively, and of total (most often for tail) width 29, 79 and 238 cm, of water depth at border between pot and tail 19, 57 and 110 cm (total  $n = 970$ ), and of current velocity 4, 27 and 75 cm/s (total  $n = 421$ ). The most common dominant particle size groups were 64–128 mm and 32–64 mm just upstream from pot, 64–128 mm in pot, and 32–64 mm in tail. Redds dug into natural substrate often included all sizes of particles of 1–200 mm. Sometimes, there were stones of 200–400 mm in tail, but this size of stones had not been moved during spawning. Average distance between the redd edge and the nearest shelter was 59 cm, and 70% of redds were situated no more than 50 cm from a shelter. Often, one edge of a redd touched a big stone, channel bank or woody debris. Averages of the minimum, mean and maximum values among the five Kymijoki sub-watercourses of female spawner length estimated from redd tail length (total  $n = 991$ ) were 18, 38 and 72 cm, respectively.

Main result among five Kymijoki sub-watercourses and the five additional watercourses for total redd length was that length was larger in

the five additional watercourses compared to the five Kymijoki sub-watercourses in all cases but one (median main test:  $P < 0.001$ , each pairwise test:  $P < 0.05$ , but in one case  $P = 0.06$ ) (Table 1). In addition, median redd length was larger in Konnevesi outlet and Keitele inlet than in Päijänne inlets and Pielavesi-Nilakka inlet (each pairwise test:  $P < 0.05$ ), and larger in Puula inlet than in Pielavesi-Nilakka inlet ( $P < 0.001$ ). Median redd length did not differ among the five additional watercourses (each pairwise test:  $P = 1.00$ ). Median depth was smaller in Vättern inlets than all other watercourses (median test:  $P < 0.001$ , each pairwise test:  $P < 0.01$ ), and smaller in Pääjärvi, Päijänne (Kymijoki) and Pielavesi-Nilakka (Kymijoki) compared to Puula (Kymijoki), Keitele (Kymijoki), Konnevesi (Kymijoki), Inari and Kermajärvi (each pairwise test:  $P < 0.001$ ). No differences were detected among eight watercourses for current velocity (median test:  $P = 0.07$ ). Median of the most common particle size in redd tail was larger in Inari and Vänern than in other eight watercourses (median test:  $P < 0.001$ , each pairwise test:  $P < 0.05$ ) (Table 1).

On a mesoscale, in smaller Kymijoki streams Rutajoki, Muuramenjoki, Arvaja and Koivujoki, 80–85% of redds ( $n = 189$ ) were situated in riffles in downstream edges of holes or small pools, 10–15% in upstream edges of riffles, and less than 10 % in

downstream glides of riffles. On larger Kymijoki streams, 80–83 % of redds ( $n = 317$ ) were situated in riffles, and 17–20% in upstream edges of riffles. Only riffle sections sampled thoroughly were included here. However, largest excavator gravel beds were always observed in upstream edges of riffles, and these beds were often situated in low current areas without shelter nearby, and some of beds were grown over with macrophytes.

In Rutajoki in 2000–2003, 40 % of all redds (total  $n = 72$ ) were situated in natural gravel, 26% in excavator gravel, and 33 % in bucket gravel. In 2004–2007, corresponding proportions in natural gravel, excavator gravel, and bucket gravel were 22, 47 and 31 % (total  $n = 54$ ), respectively, and in 2008–2011, proportions were 44, 45 and 11 % (total  $n = 64$ ). Bucket gravel beds created by volunteers were small, and spring floods and trout redd digging most likely moved gravel downstream. Gradually, bucket gravel beds disappeared, so that 10–20% of beds was left in fall 2011. Almost all excavator gravel beds, which were much larger, persisted to fall 2011. In Koivujoki in 2009–2012, 38% of redds were in natural gravel, 19 % excavator gravel, and 35% in bucket gravel. Still, 80–90% of bucket gravel beds were left in fall 2012. In Arvaja in 2007–2012, 42% of redds were situated in natural gravel and 58% in restoration gravel.

**Table 1. Median and range of total length (cm), water depth (cm), current velocity (cm/s), and dominant particle size (mm) in tail of Brown Trout spawning redds, and female fork length (cm) in five Kymijoki sub-watercourses and five additional watercourses. Water depth and current velocity 3 cm above substratum were measured at point 3, at border between pot and tail (Figure 1). N was minimum on current velocity and near maximum on all other factors. ND = no data .**

Watercourse	N	Total length	Water depth	Current velocity	Dominant particle	Female length
	cm/s	cm	cm	cm/s	mm	cm
Kymijoki						
Pielavesi-Nilakka	71–137	133 (60–420)	48 (15–95)	23 (2–102)	32–64 (8–256)	33 (18–79)
Konnevesi	8–179	170 (50–450)	80 (15–150)	21 (13–41)	32–64 (8–516)	37 (19–68)
Keitele	10–136	188 (70–460)	61 (22–100)	23 (12–78)	32–64 (16–128)	33 (18–71)
Päijänne	270–400	150 (35–450)	47 (13–117)	23 (2–105)	32–64 (8–256)	36 (16–72)
Puula	69–138	175 (55–450)	60 (24–101)	28 (2–63)	32–64 (2–128)	37 (18–77)
Kermajärvi	17–96	230 (90–600)	86 (34–150)	22 (4–66)	32–64 (16–128)	45 (23–90)
Pääjärvi	67–76	245 (85–580)	43 (28–72)	32 (1–68)	32–64 (16–256)	45 (22–85)
Inari	30	300 (180–580)	82 (42–104)	ND	64–128 (32–256)	52 (35–77)
Vättern	41–101	265 (105–585)	35 (13–69)	23 (3–70)	32–64 (8–256)	50 (26–77)
Vänern	26–74	235 (100–590)	ND	ND	64–128 (16–516)	44 (25–92)

In Kymijoki watercourse, number of redds, and thus the number of female spawners, was mostly 10–30 redds or individuals per stream, and in maximum about 100 redds or individuals in Rautalampi sub-watercourse, and mostly 5–15 redds or individuals per a riffle section. In some cases, no redds were found in a riffle section. Median female length was smaller in Pielavesi-Nilakka (Kymijoki) than in other nine watercourses (median test:  $P < 0.001$  and each pairwise test:  $P < 0.05$ ). Median length was smaller in Konnevesi (Kymijoki) and Päijänne (Kymijoki) compared to all five additional watercourses (each pairwise test:  $P \leq 0.001$ ), and smaller in Keitele (Kymijoki) and Puula (Kymijoki) compared to Kermajärvi, Pääjärvi, Inari and Vättern (each pairwise test:  $P < 0.05$ ) (Table 1).

In Rutajoki, egg density was 0–13 eggs/m<sup>2</sup> in Matkuksenkoski and 1–8 eggs/m<sup>2</sup> in Porraskoski among years. Density of age-0 parr was positively correlated to egg density of previous fall in both sites, *Spearman's rho* = 0.82 ( $P = 0.001$ ) and 0.66 ( $P = 0.02$ ), respectively.

## DISCUSSION

Redd counting by wading could well be a reasonable method in surveying and monitoring spawning stocks or stream-spawning fish. The method is sufficiently easy and cheap to be used especially in small streams or short riffle sections. However, the estimated number of redds and the size of female spawning stock is a minimum estimation, if real redds are identified by finding eggs. Some proportion of redds, especially of small ones less than one meter long and redds situated in deep water, is likely not to be found in counting. Moreover, only experienced redd counter personnel can give reliable estimations about the number of redds. In two streams in Idaho, different counters gave redd number estimations of 28–254 % of the numbers estimated by experts, but counters were not allowed to search eggs to verify deposition. (Dunham et al. 2001).

Spawning depth of Brown Trout varies considerably in published records. In three regulated Norwegian rivers with mean flow of 18–105 m<sup>3</sup>/s and seasonal flow highly fluctuating, average depth of redds was 90–137 cm, but sampling was done by diving (Wollebæk et al. 2008). On the contrary, Louhi et al. (2008) reported the most common depth of 20

cm and common range of 15–45 cm in their review of 17 published reports of spawning microhabitats of the species, but sampled rivers were mainly small and located more south than North Europe. Average depth in Kymijoki watercourse, 57 cm, was between these. In our data, smallest median, 35 cm, was in the smallest and southernmost streams, Vättern inlets. Highest medians, 80–86 cm, were detected in largest streams, and are most probably underestimations, as deepest areas could not be sampled by wading. In Nordic Countries, trout might be adapted to spawn relatively deep if possible, because of long incubation time of eggs and alevins, and thus of higher risk of eggs or alevins to face drought during long periods of low temperatures and low flows. On the other hand, current velocity was similar, 29 cm/s, in Wollebæk's et al. (2008) work measured 5 cm above bottom substrate in front of the redd, compared to our medians of 21–32 cm/s. Louhi et. al (2008) reported most common velocity of 40 cm/s, but did not give the measurement depth used. In our data, most common dominant particle size was slightly larger, 32–64 mm, than 16–64 mm in the Louhi et. al (2008) review.

Environmental authorities preferred to deposit gravel mainly in upstream edges of riffles without shelter sites in their channel restoration actions during previous decades in Finland, but trout preferred to spawn mainly inside riffle sections very near stones, woody debris, or channel bank. Bucket gravel carried by expert volunteers produced clearly more redds than excavator gravel compared by gravel volume, but bucket graveling should be repeated each decade to maintain the small artificial gravel beds.

Redd length range was large, 51–429 cm, in Kymijoki watercourse, indicating wide range in female length. Because sub-watercourse medians were all less than 200 cm, small redds dominated in the sample. Redds in additional watercourses with migratory spawners were longer on average, and the length difference cannot be explained with microhabitat factors, as no differences were detected in current velocity among sites and only few differences in redd particle size. In the three Norwegian rivers, where spawning stocks were mainly lake-migrating, partly resident, mean length of redds was 192–236 cm (Wollebæk et al. 2008), falling between Kymijoki watercourse and the additional watercourses in our data. Most probable explanation for dominance of small redds in Kymijoki watercourse is the small

size of female spawners, which in turn indicate that spawning stocks consist mainly of resident spawners, and lake-migrating larger females are few. Number of female spawners is probably low compared to environmental capacity, as redds were usually of low number in Kymijoki streams. Egg density estimations by redd counts seem reliable, because parr density was strongly correlated to egg density in Rutajoki. Thus, size of spawning stock controls parr abundance, at least in this stream.

Yet, absolute length values of females estimated from redd tail lengths should be used with caution, and reliability of length distributions estimated from redds should be tested by comparing it to distributions in rod catch, in trap catch for hatcheries, or in fish counter device in fishways. However in the 1910s, mean total length of female spawners caught for hatcheries in streams of Keitele and Puula sub-watercourses was 69 cm, females of 65–75 cm were abundant in catches, and no females less than 56 cm existed in samples (Järvi 1936). Largest observed individuals were 10–15 kg in Kymijoki watercourse at that time (Syrjänen and Valkeajärvi 2010). Although sampling methods between Järvi's (1936) work and this work are different, we believe that size and probable number of female spawners have collapsed in a century in Kymijoki watercourse, and the main reason for this is previous and current high fishing mortality on lakes because of almost unregulated fishing, and previous high fishing mortality also on streams during 20th century (Syrjänen and Valkeajärvi 2010). In Kymijoki watercourse, total number of female spawners per lake is now some tens or up to some hundreds, but not more, and number of lake-migrating larger females is probably much less. In Vuoksi watercourse, condition of migratory spawning stock is not better as a whole, as Kermajärvi outlet is almost the only area left in the watercourse, where migratory trout spawn naturally.

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## REFERENCES

- Beland, K. F. 1996. The relation between redd counts and Atlantic salmon (*Salmo salar*) parr populations in Dennys River, Maine. *Canadian Journal of Fisheries and Aquatic Sciences* 53:513–519.
- Callagher, S. P., P. K. J. Hahn, and D. H. Johnson. 2007. Redd counts. Pages 197–231 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neal, and T. N. Pearsons, editors. *Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations*. American Fisheries Society, Bethesda, Maryland.
- Crisp, D. T., and P. A. Carling. 1989. Observations on siting, dimensions and structure of salmonids redds. *Journal of Fish Biology* 34:119–134.
- Dauphin, G., E. Prévost, C. E. Adams, and P. Boylan. 2010. Using redd counts to estimate salmonid spawner abundances: A Bayesian modeling approach. *Fisheries Research* 106(1):32–40.
- Dunham, J., B. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts for bull trout. *North American Journal of Fisheries Management* 21:343–352.
- Elliott, J. M. 1995. Fecundity and egg density in the redd for sea trout. *Journal of Fish Biology* 47:893–901.
- Heggenes, J. 1988. Effect of experimentally increased intraspecific competition on sedentary adult brown trout (*Salmo trutta*) movement and stream habitat choice. *Canadian Journal of Fisheries and Aquatic Sciences* 45:1163–1172.
- Järvi, T. H. 1936. Yhtä ja toista Huopanan ja Keiteleen järvilohista. *Suomen Kalastuslehti* 43:200–206. In Finnish.
- Klemetsen, A., P.-A. Amundsen, J. B. Dempson, B. Jonsson, N. Jonsson, M. F. O'Connell, and E. Mortensen. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* 12:1–59.
- Louhi, P., A. Mäki-Petäys, and J. Erkinaro. 2008. Spawning habitat of Atlantic salmon and brown trout: general criteria and intragravel factors. *River Research and Applications* 24:330–339.
- Rassi, P., E. Hyvärinen, A. Juslén, and I. Mannerkoski. 2010. The 2010 Red List of Finnish Species. *Ympäristöministeriö & Suomen ympäristökeskus*, Helsinki. 685 p.

Syrjänen, J., and P. Valkeajärvi. 2010. Gillnet fishing drives lake-migrating brown trout to near extinction in the lake Päijänne region, Finland. *Fisheries Management and Ecology* 17(2):199–208.

Wollebæk, J., R. Thue, and J. Heggenes. 2008. Redd site microhabitat utilization and quantitative models for wild large brown trout in three contrasting boreal rivers. *North American Journal of Fisheries Management* 28:1249–1258.

# INCIDENCE OF SPINAL INJURIES IN MIGRATORY YELLOWSTONE CUTTHROAT TROUT CAPTURED AT ELECTRIC AND WATERFALL-VELOCITY WEIRS

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**Abstract**—The South Fork Snake River in Idaho supports a native Yellowstone Cutthroat Trout population YCT *Oncorhynchus clarkii bouvieri* jeopardized by nonnative Rainbow Trout *O. mykiss*. Electric weirs prevent Rainbow Trout passage into YCT spawning tributaries, but may cause spinal injuries. Yellowstone Cutthroat Trout YCT captured at electric weirs on Palisades and Pine creeks and a control waterfall-velocity weir on Burns Creek were x-rayed in 2012 and 2013 to estimate spinal injury rates. Electrical pulse frequency increased from 2012 to 2013 at the Palisades (from 11.5 to 20 Hz) and Pine weirs (13 to 20 Hz), with spinal injury rates increasing from 11.3% to 21.3% at Palisades Creek and from 6.5% to 14.7% at Pine Creek, while Burns Creek injury rates remained relatively unchanged (4.5% in 2012 and 6.0% in 2013), suggesting the electric weirs caused spinal injuries in YCT. Lower pulse frequencies may minimize YCT spinal injury while preventing Rainbow Trout from accessing YCT spawning tributaries.

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## INTRODUCTION

The South Fork Snake River in eastern Idaho, United States, supports an abundant population of Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* (Meyer et al. 2006). This population is considered important because it is one of the few robust fluvial populations of Yellowstone Cutthroat Trout (YCT) remaining in Idaho (Thurrow et al. 1988; Meyer et al. 2006; Gresswell 2011). However, the long-term persistence of YCT in the South Fork Snake River drainage is jeopardized by the increasing abundance of nonnative Rainbow Trout *O. mykiss* (High 2010). Rainbow Trout and YCT have similar life histories in the South Fork Snake River, including the fluvial nature of their spawning behavior (Henderson et al. 2000). While Rainbow Trout in the South Fork Snake River drainage tend to spawn slightly earlier (mid- to late May) than YCT (mid- to late June) and are more likely to spawn in the main-stem river (Henderson et al. 2000), both species also ascend the four main tributaries below Palisades Dam (Burns, Pine, Rainey, and Palisades creeks) to spawn (Fig. 1). Rainbow Trout and Cutthroat Trout have no reproductive isolation mechanisms and readily hybridize throughout the native range of Cutthroat Trout (Young 1995; Behnke 2002). Rainbow Trout and hybrids may also outcompete Yellowstone Cutthroat Trout in juvenile life history stages, causing a growth

disadvantage for YCT in the presence of Rainbow Trout and hybrids (Seiler and Keeley 2009). While Rainbow Trout and hybrids will likely never be eliminated from the entire South Fork Snake River drainage, protection of pure YCT within the main stem and in the four main spawning tributaries in Idaho has become a high priority for the Idaho Department of Fish and Game (IDFG: LaBar 2007; High 2010).

Since 2001, IDFG has operated migration traps on these four tributaries of the South Fork Snake River to prevent upstream access by Rainbow Trout and hybrids during the spawning period. Rainbow Trout and hybrids are removed from the system at the migration traps, while Yellowstone Cutthroat Trout are released upstream to spawn. Various types of weirs have been used over time, including picket, Mitsubishi, and floating panel, but most were inefficient or could not be operated in high flows during the critical period of the spring spawning migration run (High 2010). More recently, a permanent combination waterfall-velocity weir was installed on Burns Creek in 2009, which has been efficient at capturing upstream-migrating salmonids. The remaining tributaries lacked sufficient channel gradient to install velocity barriers, so permanent electric weirs were installed in Palisades Creek in 2009, Pine Creek in 2010, and in Rainey Creek in 2011. Efficiencies for the electric weirs in these tributaries have ranged

from 49 to 86% during the first few years while trying to match electrical settings to varying flow levels (B. High, unpublished data).

While fish injuries at waterfall-velocity weirs are likely negligible, electric weirs have the potential to be more injurious to upstream or downstream migrating fish. However, no empirical data exist on the incidence of spinal injuries at electric or waterfall-velocity weirs. Electrical current in the water, such as occurs during electrofishing surveys, has repeatedly been shown to cause spinal and hemorrhage injuries in fish (reviewed in Reynolds and Kolz 2012). Trout species are especially vulnerable to injury from electric fields (Snyder 2003). Larger fish are more vulnerable to injury because their length results in a greater electric potential (Reynolds et al. 1988), and injuries generally increase with increasing electrical intensity, especially pulse frequency settings when using pulsed DC (McMichael 1993; Sharber et al. 1994; Reynolds and Kolz 2012). While both spinal injuries and hemorrhages are considered important when evaluating fish injuries from electricity (Reynolds and Kolz 2012), spinal injuries are much more critical because hemorrhages typically persist for a relatively short time and therefore do not normally represent a long-term mortality or health risk to the fish (Schill and Elle 2000).

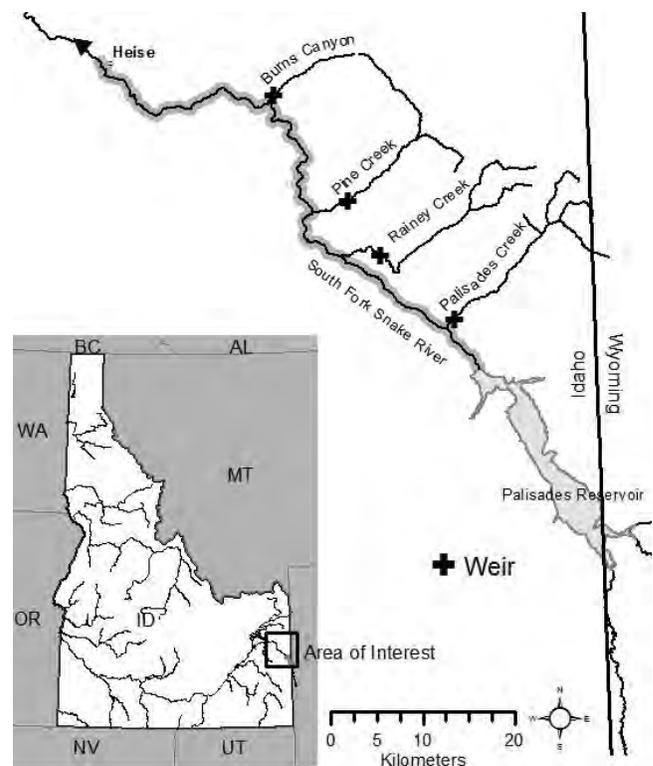
The objective of this study was to evaluate spinal injuries in YCT presumably exposed to electricity at electric weirs by using a portable x-ray machine. It was expected that (1) spinal injury rates would be higher at the electric weirs than the waterfall-velocity weir, and (2) if the electric weirs were causing spinal injuries, then injury rates would increase at the electric weirs with an increase in pulse frequency, whereas injury rate would not change at the waterfall-velocity weir.

## METHODS

The study of YCT spinal injuries was conducted in three tributaries of the South Fork Snake River (Figure 1). Palisades Creek and Pine Creek have electric weirs that prevent upstream passage of Rainbow Trout and hybrids, whereas Burns Creek has a waterfall-velocity weir, which served as a control site for assessing spinal injuries at the electric weirs (Figure 2). Rainey Creek, another tributary of the South Fork Snake River, also has an electric weir, but its spawning migration run of YCT was too small to include fish from this stream in our analyses.

The weirs were operated each year from mid-March to mid-July, covering the entire spawning runs of Rainbow Trout, hybrids, and YCT. Fish were x-rayed from the three study streams on June 12-14 and June 25-26 in 2012, and again on June 10-12 in 2013. Ambient conductivity averaged 185, 298, and 359  $\mu\text{S}/\text{cm}$  at Burns, Palisades, and Pine creeks, respectively (See Table 1 for additional stream characteristics).

Both electric weirs in this study have six parallel electrodes made of metal railing embedded in a concrete apron along the stream bottom, with the upper surfaces of the railings exposed to the water. The railings span the entire stream channel and continue up the concrete walls enclosing the entire stream except for the fish trap. Fish traps at both weirs are located on the right bank looking upstream, outside the electric field. The most downstream and upstream electrodes are parasitic, meaning that electrical current does not diffuse upstream or downstream of these electrodes. Consequently, fish that approach the electric field from



**Figure 1. Location of South Fork Snake River tributaries and the electric and waterfall-velocity weirs where x-ray images were captured in Yellowstone cutthroat trout.**

a downstream location can enter the fish trap without experiencing any electrical current.

The waterfall-velocity weir consists of a 0.6-m drop that falls on a 3.7-m concrete apron with high water velocity. Typical flows during spring runoff result in water depths of less than 10 cm on the concrete apron of the velocity barrier. The combination of fast water on the apron and the lack of water depth below the waterfall from which to jump from effectively blocks upstream fish passage. Adjacent to the barrier, the fish trap is located on the left bank when looking upstream, at the top of a fish ladder which guides upstream migrants into the trap.

In 2012, the Palisades Creek electric weir output was set at 11.5 Hz, 2.5 milliseconds (ms) pulse width,

and 265 volts, and the Pine Creek weir output was set at 13 Hz, 2 ms pulse width, and 270 volts. These electrical settings produced similar horizontal voltage gradients at each weir, ranging from -11 to +12 V/cm but with most values falling within the range of -5 to +5 V/cm. In 2013, pulse frequency settings were increased to 20 Hz at both weirs to evaluate whether higher electrical settings would improve fish capture efficiency; voltage and pulse width were held constant. The change in pulse frequency also provided a means of comparing injury rates between different pulse frequency settings at the weirs.

Yellowstone Cutthroat Trout were netted from the trap box at each weir, anesthetized using MS-222, and measured for total length (TL). A MinXRay HF



Figure 2. View looking upstream of waterfall-velocity (left) and electric weirs (right) on Burns Creek and Palisades Creek, respectively. The fish trap is located on the left bank at the waterfall-velocity weir and on the right bank at the electric weir.

Table 1. Characteristics of three tributaries of the South Fork Snake River that served as study streams in our analyses.

Tributaries	Weir type	Drainage area (km <sup>2</sup> )	Stream width at weir (m)	Spawning run size				Weir capture efficiency (%)	
				2012		2013		2012	2013
				YCT	RBT/HYB	YCT	RBT/HYB		
Palisades	Electric	166	13	232	20	619	23	88	96
Pine	Electric	188	7.4	1,427	3	1,908	1	-	89
Burns	Waterfall-velocity	55	6.6	496	0	898	6	90	98

100+ portable digital x-ray generator and a TruDR lx system plate and computer program were used to generate x-ray images. Images were taken with a peak kilovoltage of 100 and an exposure of ~1.3 milliampere seconds, but settings were adjusted slightly as needed to obtain clear x-ray images for each fish. After recovering from anesthesia, YCT were released upstream of the weir and fish trap to continue their spawning migration.

The x-ray images were analyzed for presence of spinal injuries. Injuries were classified using the injury criteria in Reynolds (1996) of 0 for no spinal damage, 1 for vertebral compressions only, 2 for misalignments and compressions, and 3 for fracture of one or more vertebrae or complete separation of two or more vertebrae along with misalignments or compressions. Both vertical and horizontal x-rays were taken for nearly all injured fish and a subsample of uninjured fish to confirm that spinal injuries could be detected using horizontal x-rays only. Compressions were always visible using either vertical or horizontal x-rays, and we never detected misalignments or fractures with one view that was not also visible in the other view. Hairline fractures, which would be classified as a class 3 injury, were likely not visible in our x-ray images (Dalbey et al. 1996).

Data were analyzed in SAS (SAS Institute 2009) using a generalized linear model (at  $\alpha = 0.10$ ) with a dummy response variable of 0 for uninjured fish and 1 for fish with a spinal injury. The primary explanatory variable of interest was a combination variable of stream and year, with each of the six stream  $\times$  year combinations considered as a separate treatment. Total length was also included in the model because of the aforementioned greater electrical potential in larger fish that makes them more vulnerable to spinal injury when exposed to electric currents (Reynolds et al. 1988).

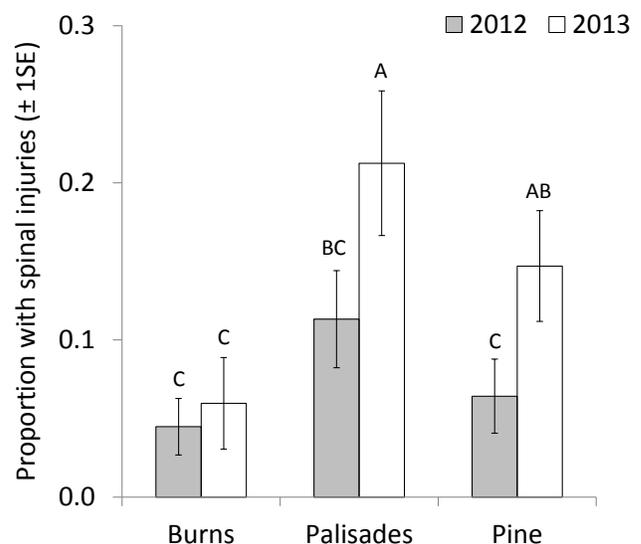
## RESULTS

In 2012, a total of 349 YCT were x-rayed, including 134 fish at Burns Creek, 106 at Palisades Creek, and 109 at Pine Creek. A total of 25 spinal injuries were detected in 2012. In 2013, a total of 251 fish were x-rayed, including 67 fish at Burns Creek, 80 at Palisades Creek and 104 at Pine Creek. A total of 36 spinal injuries were detected in 2013. A small number of fish with spinal malformations, always in the caudal peduncle, were determined to have congenital

defects ( $n = 2$  in 2012 and  $n = 1$  in 2013) and were not categorized as injured for our analyses. The average length of fish at each site ( $\pm 1$  standard error) was  $385 \pm 3$  mm at Burns Creek,  $389 \pm 3$  mm at Palisades Creek, and  $374 \pm 3$  mm at Pine Creek.

The full general linear model explained only 4% of the variation in spinal injuries, but the model was statistically significant ( $F = 4.52$ ,  $P = 0.0002$ ). Spinal injury rates differed among stream  $\times$  year treatments ( $F = 4.64$ ,  $P = 0.0004$ ), and Duncan's multiple range test indicated that injury rates at both electric weirs were higher in year two than in year one, but did not differ between years at the waterfall-velocity weir (Figure 3). In 2012, at the lower electrical settings, injury rates did not differ significantly among the two electric weirs and the waterfall-velocity weir, but in 2013, at the higher electrical settings, injury rates were significantly higher at the two electric weirs than the waterfall-velocity weir. Individual estimates of spinal injury rate ( $\pm 90\%$  confidence intervals) in 2012 and 2013 were  $6.5 \pm 3.9\%$  and  $14.7 \pm 5.9\%$ , respectively, at Pine Creek,  $11.3 \pm 5.1\%$  and  $21.2 \pm 7.7\%$  at Palisades Creek, and  $4.5 \pm 3.0\%$  and  $6.0 \pm 4.9\%$  at Burns Creek.

Spinal injury rates for YCT also increased as fish size increased ( $F = 5.64$ ,  $P = 0.018$ ). Excluding fish captured at the waterfall-velocity weir to evaluate



**Figure 3. Spinal injury rates in Yellowstone cutthroat trout captured at a waterfall-velocity weir (Burns Creek) and two electric weirs (Palisades and Pine creeks). Estimates with different letters indicate statistical significance at  $\alpha = 0.10$ .**

the effect of fish size on spinal injuries at the electric weirs, estimates of injury rate ( $\pm 90\%$  confidence intervals) for fish  $\geq 375$  mm TL ( $22.1 \pm 4.6\%$ ) was nearly double that for fish  $< 375$  mm ( $11.3 \pm 4.3\%$ ).

The number of vertebrae involved in YCT spinal injuries in 2012 and 2013 ranged from 2 to 34, with an average of 16.6 vertebrae affected in each injured fish across all streams and years. Injuries of varying severity occurred across streams and years; however, 100% of all spinal injuries involved vertebral compressions, while spinal fractures and misalignments were encountered less frequently and were involved in 55% and 22% of all spinal injuries, respectively.

## DISCUSSION

The fact that spinal injury rates doubled in 2013 compared to 2012 at both electric weirs following a near doubling of pulse frequency, while the injury rates at the waterfall-velocity weir remained unchanged in 2013, suggests that the electric weirs caused injuries in YCT at the higher electrical settings. Injury rates at the lower electrical settings were also higher at the electric weirs (mean = 8.9%) compared to the waterfall-velocity weir (4.5%), but the lack of statistical significance leads to the conclusion that these lower settings were causing little if any injuries, although low overall sample size reduced the statistical power to detect a real difference.

The low level of spinal injuries at the Burns Creek waterfall-velocity weir likely represents a background level of injuries in the entire YCT population in the South Fork Snake River drainage. Indeed, it is unlikely that the spinal injuries we observed at the waterfall-velocity weir were caused by (1) fish jumping at the waterfall, since there is no pool from which to jump, or (2) fish handling. It is also unlikely that wild trout that have never been exposed to electricity have an elevated background level of spinal injuries (Kocovsky et al. 1997). A more likely source for these injuries is boat electrofishing surveys conducted each September and February in the main stem of the South Fork Snake River to monitor trout populations. These electrofishing surveys span 75 km, encompass the confluences of all three study streams (Figure 1), and occur at a time when most migratory YCT spawners are located in the mainstem and thus could potentially be exposed to boat electrofishing. Although spinal

compressions can heal visibly within a year (Dalbey et al 1996; J. Reynolds, personal communication), these types of injuries were likely visible in x-ray images for several months after the February electrofishing surveys and perhaps the September surveys as well. If all or nearly all of the injuries at Burns Creek can be attributed to main-stem electrofishing surveys, then a similar level of injuries at the two electric weirs should also be attributed to these same electrofishing surveys. Thus, all of this study's estimates of spinal injury rates were likely overestimated to a similar degree (i.e.,  $\sim 5\%$ ). Many salmonid populations that are monitored through time with electrofishing surveys have background levels of spinal injury in the survey reaches (e.g., Kocovsky et al. 1997; McMichael et al. 1998). Nevertheless, the difference in injury rates between 2012 and 2013 at the two electric weirs and the unchanged injury rate at the waterfall-velocity weir leads us to conclude that the electric weirs at the higher electrical settings caused some spinal injuries in upstream migrating YCT.

Mean spinal injury rate at the two electric weirs combined was 17.6% in 2013, when pulse frequency was 20 Hz at both weirs. With or without a slight downward adjustment to this estimate to account for main-stem electrofishing injuries, these findings concur with Sharber et al. (1994), who reported spinal injury rates of 3% for wild Rainbow Trout exposed to pulsed DC current at 15 Hz and 24% at 30 Hz. Similarly, McMichael et al. (1998) reported electrofishing-induced spinal injury rates of 27.7% at 30 Hz pulsed DC for Rainbow Trout  $> 250$  mm (fork length). There were no estimates of fish injury rates at electric weirs or waterfall-velocity weirs to which these results could be compared directly. Additional studies of spinal injuries at both types of weirs would help substantiate or refute these results.

Not all detrimental effects to the YCT population at the electric weirs are the result of spinal injuries. For example, while x-raying fish at Pine Creek, two dead YCT were found caught in the electric field of the weir, circling in an eddy. The two dead fish were x-rayed but did not have any spinal injuries, suggesting they likely died from asphyxiation or some other severe physiological stress response to electricity (Snyder 2003). Although rare, fish are sometimes observed challenging the electric fields at the Pine and Palisades weirs, occasionally reaching the headboards before becoming immobilized and

eventually washing downstream. While fish are recovering their equilibrium, they may asphyxiate or get caught in instream structures downstream such as root wads or woody debris. Mortalities observed at the electric weirs have generally been low, averaging only 0.8% of the entire spawning run (across both weirs and years) and are often due to handling stress rather than exposure to electricity (B. High, unpublished data). However, unobserved mortality resulting from overexposure may occur in fatally wounded fish that float downstream without being observed by the weir operators. Annual exposure to electricity for the migratory component of the YCT population may also lead to a long-term reduction in fish growth rates (Gatz et al. 1986), or may reduce egg survival for fish that are passed upstream of the electric weirs (Marriott 1973; Dwyer et al. 1993; Roach 1999).

Given that Cutthroat Trout have an average of 60–63 vertebrae, an average of 17 vertebrae involved in the injured YCT in this study constitutes a significant level of injury. Other studies have found an average of 6 to 8 vertebrae involved in salmonid spinal injuries due to electrofishing (Sharber and Carothers 1988; Hollender and Carline 1994), although these studies involved fish with lower mean lengths (136 mm and 360 mm, respectively, compared to 382 mm in this study) and thus the fish were likely not as affected by electricity as were the larger fish in this study (Reynolds et al. 1988). Although most of the injuries observed in this study were compressions, Dalbey et al. (1996) found that vertebrae with hairline fractures (class 3), were not always detected in initial x-rays and that the proportion of fish with class 3 injuries increased markedly from day 1 to day 335 of their study. Therefore, the proportion of class 3 injuries for fish captured at the electric weirs could be higher than this study was able to detect.

Although the electric weirs appear to be causing a low level of spinal injuries in Yellowstone Cutthroat Trout migrating to spawning tributaries of the South Fork Snake River, for several reasons we do not consider the observed injury rates to be detrimental to the population. First, spinal injury rates were much lower at the lower pulse frequency settings, so that using pulse frequencies <15 Hz should help minimize or eliminate injuries. Second, capture efficiencies at the electric weirs are reasonably high at the lower pulse frequency settings and were not dramatically improved at the higher settings (Table 1), so most of

the Rainbow Trout and hybrids attempting to migrate into these tributaries should be excluded even at the lower frequency settings. Third, since the weirs are operated only from mid-March to mid-July, and outmigration of YCT usually occurs after mid-July, the majority of YCT only encounter the electric weirs once a year. Fourth, some YCT are captured via annual electrofishing surveys in the main stem of the South Fork Snake River, at pulse frequencies much higher than used at the electric weirs. Thus the additional exposure to low-level electricity at the migration weirs may be minor compared to the electrofishing surveys conducted biannually on the entire YCT population. Finally, YCT that spawn in consecutive years make up a substantial portion of each run, and the proportion of consecutive spawners does not differ significantly among the three tributaries (B. High, unpublished data). Thus, we believe that the benefits the electric weirs provide to the South Fork Snake River YCT population by preventing upstream passage of Rainbow Trout and hybrids far outweigh the harm caused by the low level of spinal injuries likely due to the electric weirs.

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## LITERATURE CITED

- Behnke, R. J. 2002. Trout and salmon of North America. Free Press, New York.
- Dalbey, S. R., T. E. McMahon, and W. Fredenberg. 1996. Effect of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild rainbow trout. *North American Journal of Fisheries Management*. 16:560-569.
- Dwyer, W. P., W. Fredenberg, and D. A. Erdahl. 1993. Influence of electroshock and mechanical shock on survival of trout eggs. *North American Journal of Fisheries Management* 13:839-843.
- Gatz, A. J., J. M. Loar, and G. F. Cada. 1986. Effects of repeated electroshocking on instantaneous growth of trout. *North American Journal of Fisheries Management* 6:176-182.
- Gresswell, R. E. 2011. Biology, status, and management of the Yellowstone cutthroat trout. *North American Journal of Fisheries Management* 31:782-812.

- Henderson, R., J. L. Kershner, and C. A. Toline. 2000. Timing and location of spawning by non-native wild rainbow trout and native cutthroat trout in the South Fork Snake River, Idaho, with implications for hybridization. *North American Journal of Fisheries Management* 20:584-596.
- High, B. 2010. Yellowstone cutthroat trout conservation efforts on the South Fork Snake River. Pages 275–284 in R. F. Carline and C. LoSapio, editors. *Wild Trout X: Conserving wild trout*. Proceedings of the Wild Trout Symposium, Bozeman, Montana.
- Hollender, B. A., and R. F. Carline. 1994. Injury to wild brook trout by backpack electrofishing. *North American Journal of Fisheries Management* 14:643-649.
- Kocovsky, P. M., C. Gowan, K. D. Fausch, and S. C. Riley. 1997. Spinal injury rates in three wild trout populations in Colorado after eight years of backpack electrofishing. *North American Journal of Fisheries Management* 17:308-313.
- LaBar, G. 2007. Management plan for conservation of Yellowstone cutthroat trout in Idaho. Idaho Department of Fish and Game, Boise, Idaho.
- Marriott, R. A. 1973. Effects of electric shocking on fertility of mature pink salmon. *The Progressive Fish-Culturist* 35:191-194.
- McMichael, G. A., A. L. Fritts, and T. N. Pearsons. 1998. Electrofishing injury to stream salmonids; injury assessment at the sample, reach, and stream scales. *North American Journal of Fisheries Management* 18:894-904.
- McMichael, G. A. 1993. Examination of electrofishing injury and short-term mortality in hatchery rainbow trout. *North American Journal of Fisheries Management* 13:229-233.
- Meyer, K. A., D. J. Schill, J. A. Lamansky Jr., M. R. Campbell, and C. C. Kozfkay. 2006. Status of Yellowstone cutthroat trout in Idaho. *Transactions of the American Fisheries Society* 135:1329-1347.
- Reynolds, J. B. 1996. Electrofishing. Pages 221–254 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Reynolds, J. B., and A. L. Kolz. 2012. Electrofishing. Pages 305-362 in A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. *Fisheries Techniques*, 3rd edition. American Fisheries Society, Bethesda, Maryland.
- Reynolds, J. B., A. L. Kolz, N. G. Sharber, and S. W. Carothers. 1988. Electrofishing injury to large rainbow trout. *North American Journal of Fisheries Management* 8:516-518.
- Roach, S. M. 1999. Influence of electrofishing on the mortality of Arctic grayling eggs. *North American Journal of Fisheries Management* 19:923-929.
- SAS Institute Inc. 2009. *SAS/STAT® 9.2 User's Guide*, Second Edition. Cary, NC: SAS Institute Inc.
- Schill, D. J., and F. S. Elle. 2000. Healing of electroshock induced hemorrhages in hatchery rainbow trout. *North American Journal of Fisheries Management* 20:730-736.
- Seiler, S. M., and E. R. Keeley. 2009. Competition between native and introduced salmonid fishes: cutthroat trout have lower growth rate in the presence of cutthroat-rainbow trout hybrids. *Canadian Journal of Fisheries and Aquatic Sciences* 66:133-141.
- Sharber, N. G., and S. W. Carothers. 1988. Influence of electrofishing pulse shape on spinal injuries in adult rainbow trout. *North American Journal of Fisheries Management* 8:117-122.
- Sharber, N.G., S.W. Carothers, P. Sharber, J.C. De Vos Jr., and D.A. House. 1994. Reducing electrofishing-induced injury in rainbow trout. *North American Journal of Fisheries Management* 14:340-346.
- Snyder, D.E. 2003. Electrofishing and its harmful effects on fish. Information and Technology Report USGS/BRD/ITR-2003-0002, U.S. Geological Survey Biological Resources Division. U.S. Government Printing Office, Denver, CO, 149 pp.
- Thurrow, R. F., C. E. Corsi, and V. K. Moore. 1988. Status, ecology, and management of Yellowstone cutthroat trout in the upper Snake River drainage, Idaho. *American Fisheries Society Symposium*.
- Young, M. K. 1995. Conservation assessment for inland cutthroat trout. U.S. Forest Service General Technical Report RM-GTR-256.

## IMPROVING MANAGEMENT AND CONSERVATION PRACTICES THROUGH AN EVALUATION OF MOVEMENT AND SPATIAL POPULATION STRUCTURE IN THE LOGAN RIVER, UTAH

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**Abstract**—We studied movement distances and destinations of native Bonneville Cutthroat Trout *Oncorhynchus clarkii utah* within the Logan River watershed in northern Utah in order to understand the population structure so as to inform the suitability of current fishing regulations. We tagged Cutthroat Trout with Passive Integrated Transponders (PIT) tags during the summers of 2009-2012 within seven 100-200 meter main-stem and tributary reaches of the Logan River using standard electrofishing, three-pass depletion techniques. We gathered date and location of re-sightings throughout the spring spawning period of 2013 using a combination of stationary and mobile antennas. Distances traveled by spawning Cutthroat Trout were not significantly different between main-stem and tributary residing trout, contrary to popular assumptions about the system. The majority of trout moved short distances while a few individuals made extensive movements to destinations dispersed throughout the watershed. Using a watershed scale, river reach delineation protocol combined with long-term population estimates, we estimated approximately 40% of spawning-sized fish within the watershed remain subject to harvest during the spawning season under current fishing regulations.

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### INTRODUCTION

A growing segment of research in the field of fisheries management, particularly involving fluvial salmonid species, is evaluating metapopulation structure within larger watersheds or river systems (Rieman and Dunham 2000). The term metapopulation refers to a spatially-structured population, whether that be fish in a single river, or wildlife dispersed across a region (Hanski 1998). The general approach to delineate metapopulations is the assessment of three conditions: (1) understanding how the pattern of discrete habitat patches supports local breeding populations, (2) the populations dynamics of these discrete habitat patches are not synchronous, and (3) how the dispersal among populations affects the dynamics and/or persistence of the metapopulation or localized populations (Rieman and Dunham 2000). Due to the difficulty of monitoring numerous local populations across discrete habitat patches over long time periods, there are few empirical studies describing metapopulation structure and dynamics in fishes (Koizumi and Maekawa 2004). Instead, fisheries studies have largely focused on movement of adult

trout in response to metabolic requirements, habitat preferences, and spawning (e.g. Harvey et al. 1999; Hilderbrand and Kershner 2000; Albanese et al. 2004; Colyer et al. 2005; Olsson et al. 2006).

Understanding how metapopulations are structured across large spatial scales has potential to inform effective resource management (Bowerman 2013). Without robust empirical evidence, assumed population structures can be easily misinterpreted by fisheries managers. Inland trout are known to exhibit a number of different life histories, and may utilize numerous areas of a basin for spawning (Rieman and Dunham 2000), depending upon the distribution of available spawning habitat. Due to the importance of high quality spawning habitat, many subspecies of Cutthroat Trout, including Bonneville Cutthroat Trout *Oncorhynchus clarkii utah*, demonstrate high seasonal migratory abilities to and from spawning locations (Budy et al. n.d.; Bernard and Israelsen 1982; Colyer et al. 2005). Even though rearing stream habitat is high quality within the Logan River for Bonneville Cutthroat Trout; appropriate spawning habitat appears to be limited. Spawning areas are generally restricted

in the main stem due to lack of sufficient spawning-sized gravel and high stream energy (Meredith 2012). In contrast, spawning gravel and suitable stream flows are more abundant in tributaries (Seidel 2009; Budy et al. 2012). Given the spawning habitat limitations within the Logan River, it would be expected that trout (particularly in the main stem of the river) would be required to exhibit longer movement distances to prime spawning habitats, and potentially structure themselves based on the arrangement of these habitats.

Previous work has shown Cutthroat Trout movement in the Logan River increases dramatically in the spring as fish move into tributaries to spawn (Bernard and Israelsen 1982; Randall 2012). Hilderbrand and Kershner (2000) found that 39% of Cutthroat Trout they tagged exhibited long movement distances, potentially in an attempt to take advantage of patchily distributed resources. Therefore, mobility and site fidelity behaviors may be influenced by the distribution of suitable habitats. Seasonal movement estimates have varied across the Bear River system, with differences ranging from 5.2 river kilometers (rkm) (Hilderbrand and Kershner 2000) in the Logan River to 86 rkm for large fluvial Bonneville Cutthroat Trout in the nearby main-stem Bear River (Colyer et al. 2005). These movements were interpreted as large Cutthroat Trout migrating to tributaries to spawn. Similar research within tributaries of the Logan River suggests most Cutthroat Trout are resident fish moving less than 500 m (Randall 2012). That this same species exhibits different strategies in differing habitats suggest a basin-wide study of movement is necessary to inform management decisions.

The small number of suitable spawning tributaries, extensive high quality rearing habitat, high connectivity among habitats and numerous previous studies make the Logan River a prime area to evaluate movement patterns and determine the potential applicability of metapopulation concepts to conservation and management in this basin. Bonneville Cutthroat Trout occupy, without impediment, approximately 64 rkm from the top of the watershed in Idaho to the third dam reservoir in Logan Canyon. The population of Bonneville Cutthroat Trout within the Logan River has fish densities of up to 694 fish/km, much higher than densities of Bonneville Cutthroat Trout populations in other watersheds within their native range (Budy et al. 2007). Previous work has described egg survival rates, quantified number

of redds, and suggested several major tributaries contribute to the overall Logan River Bonneville Cutthroat Trout population (Seidel 2009; Budy et al. 2012). Additionally, it has been shown that fish move varying distances throughout the year (Hilderbrand and Kershner 2000; Randall 2012). Even though there have been numerous studies, there has been little effort to tie these studies together by looking at large-scale movement distances, spawning migration, or the population's structure.

In the Logan River, current Bonneville Cutthroat Trout management is very conservative in the upper 20 km of the Logan River Watershed. In this area, fishing is prohibited from January 1 until the second Saturday in July, the time by which the majority of spawning is assumed to have ceased. After this time two fish can be harvested. Fishing elsewhere in the river is open year-round and limits are either two fish or four fish. Therefore, fish spawning in areas of the main stem and tributaries below this protected zone are susceptible to harvest. In one of the largest tributaries, Temple Fork, fishing is permitted year-round but the road is closed from early November until the following June making access to these fish more difficult during the early portion of the spawning season. Knowing the effects of these protection zones and how fish move between them could assist managers in adjusting regulations aimed at benefiting the entire river population.

The goal of our research was to quantify movement distances and destinations of spawning Bonneville Cutthroat Trout in order to help inform the management practices of this imperiled species. Given that this species is currently listed under a multi-agency 'Conservation Agreement' and is listed as a 'species of special concern' in Utah (Lentsch et al. 1997), it is imperative to protect one of the largest populations within its native range found in the Logan River. Our primary objectives were to (1) compare movement distances between tributary and main-stem residing Cutthroat Trout, (2) determine the percentage of mobile individuals in different areas of the watershed, and to (3) use a watershed population estimate adjusted by observed destinations of Cutthroat Trout to determine percentages of fish that are affected by current recreational fishing regulations. By addressing movement distances and destinations at a watershed-scale, we provide context necessary to management this imperiled species during a critical time of the year.

## METHODS

The study area included the upper 50 km of the Logan River and major tributaries critical to Cutthroat Trout reproductive output based the presence of high-quality spawning habitat. Spawning tributaries include Spawn Creek, Temple Fork, Franklin Basin, and Beaver Creek (Figure 1). Main-stem reaches with low amounts of spawning gravel but high fish densities included stream reaches near Twin Bridges, Forestry Camp, and Red Banks. Additionally, the Twin Bridges site represents the approximate lowest point in the river where Cutthroat Trout densities are greater or proportionally equal to Brown Trout *Salmo trutta* densities (McHugh and Budy 2005); below this point Brown Trout are the dominant species. It is because of this change in relative abundance we limited this study only to the stream sections above this lowest reach.

We tagged a total of 2,194 (1,744 in tributaries, 450 in main-stem reaches) Cutthroat Trout using Passive Integrated Transponder (PIT) tags within seven long-term sites in the Logan River system sampled as part of ongoing population demographic study since 2001 (Figure 1; Budy et al. 2007). Each sampled reach was approximately 100-200 m in length. Cutthroat Trout in these reaches were tagged during the summers of 2009-2012. Trout were collected using standard three-pass depletion techniques. The capture and tagging of fish throughout the basin allows assessment of the proportion of fish exhibiting movement patterns into, out of, and remaining in reaches to spawn.

We used two primary methods to monitor fish movement, location, and distance traveled. We installed and maintained two continually operating passive interrogation arrays (PIAs) and mobile PIT-tag scanners. Locations of PIAs include the confluence of Spawn Creek and Temple Fork, the confluence of Temple Fork, and within the Logan River (Figure 1). These PIAs were established in 2008 and 2009, respectively while the PIA at the Forestry Camp site was installed in November 2012. This Forestry Camp antenna partitions the Logan River into an upper section (Franklin Basin and Red Banks) and lower section (Twin Bridges and Forestry Camp). This PIA also detects movement into Little Bear Creek, a tributary of the Logan River, as well as movement into or out of upstream reaches protected by regulations during primary spawning months (May to July). We used mobile antennas during the spring of 2013 to

determine the location of fish within scanning reaches. We scanned eleven 1-rkm-long reaches using mobile antennas that overlay the 100-200 m sampled during the summer three-pass survey a total of 33 times during the spawning months. Using these methods we detected a minimum distance moved and percentages of fish that moved to different sections of the watershed in response to spawning in spring 2013.

Lastly, we estimated the total population of spawning individuals within the entire Logan River basin to characterize the portion of the trout population affected by different management regimes. To do this, we drew from several sources of information including population estimates from long-term sites (Budy et al. 2007) and snorkeling data from a previous study (Meredith 2012). Based on an investigation of vegetation, elevation, ecoregions, rock types, landscape units, known fault lines, and aerial assessments of river features classified all stream reaches in the basin using the River Styles methodology (Brierley and Fryirs 2008). Most study sites coincidentally occurred within different river styles; thus, we used long-term population estimates (fish per kilometer) from study sites and expanded across each River Style as a basis of a whole river population estimate for the Logan River. Finally, by constraining the estimate to a known size-class of spawning sized fish (>225 mm) and by adjusting for observed movement destinations within the watershed, we quantified the number of spawning individuals in the Logan River in the upper protected area and the lower, less protected area.

Minimum detected movement distances between tributary-tagged and main-stem-tagged individuals were evaluated by determining the percentage of Cutthroat Trout out of the total re-sightings that moved a specific distance. A two-sample Kolmogorov-Smirnov test was used to test for differences in distributions. In order to account for mortality between when fish were tagged and spawning movement the following spring we first used established survival estimates from long-term sites (Budy et al. 2007) in order to project the number of individuals expected to be present within the system and available to spawn in the spring of 2013. The number and percentage of mobile individuals moving between different sections of the Logan River are reported along with estimates of error generated from a standard binomial distribution test.

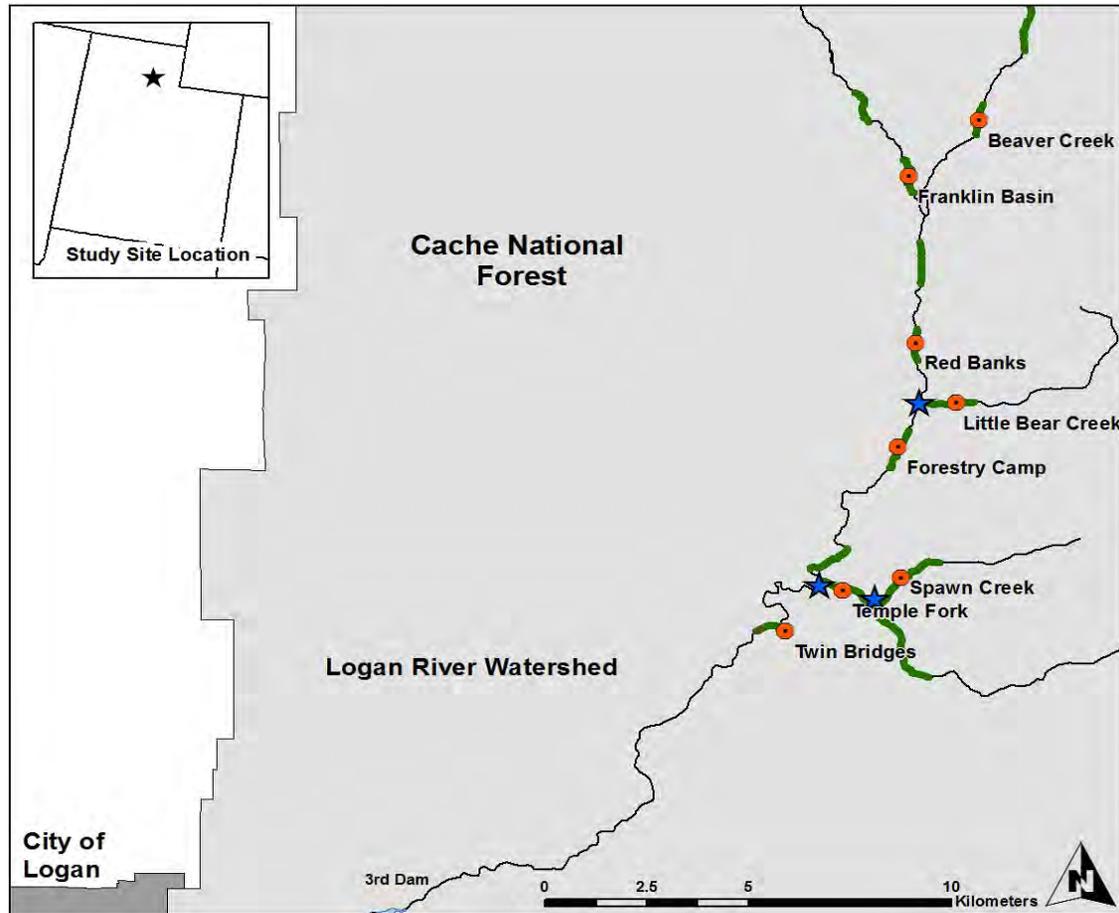


Figure 1. Map of the Logan River drainage in northern Utah. Study sites are labeled with orange circles and scanning reaches are indicated by green highlights. Locations of passive interrogation arrays are indicated by stars.

## RESULTS

Within the Logan River watershed, 191 (21 main-stem residing and 170 tributary residing individuals) Cutthroat Trout were re-sighted at least once during the spawning months. Analysis of the minimum Cutthroat migration distance indicates fish in the main stem and tributaries of the Logan River, show a very similar pattern of movement ( $p=0.15$ ): most travel short distances during the spawning period but a few traveled much longer distances (Figure 2).

Most fish tagged over the course of this study did not move far enough during the spring spawning season to be detected by the stationary PIAs during the spring of 2013 (Table 1). This suggests most fish remained in the stream sections in which they were initially tagged. Those fish that did make longer migrations moved to destinations distributed throughout the watershed. A small percentage of

total individuals tagged (17%) moved from the lower section to the upper portion of the watershed where fishing during the spawning season was prohibited. From the upper section, approximately 5% of tagged fish migrated into the lower, less restrictive section of the river. Within tributaries similar trends were found: approximately 11% of individuals in tributaries made migrations between tributaries and remained within fishable sections of river. A couple of individuals moved long distances to other tributary and main-stem sections of the watershed.

Based on a watershed-level population estimate, 61% of spawning fish are protected from fishing and harvest while 39% of fish remain susceptible within the entire lower river basin during the spawning season. This estimate accounted for percentages of fish moving during spawning or those that were non-mobile and remained in the upper watershed.

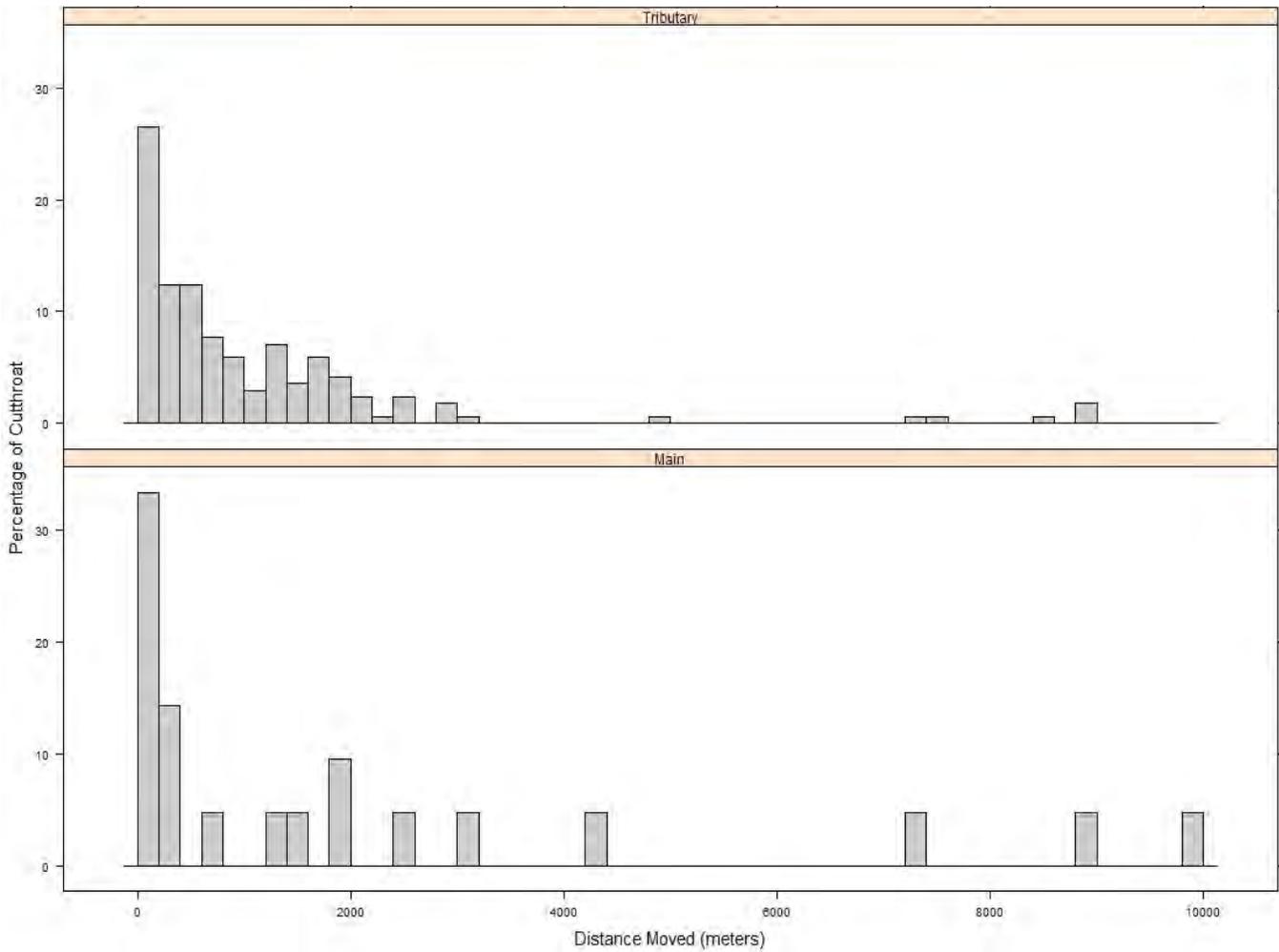


Figure 2. All fish detected by PIA or mobile antennas during spawning months (April-June) of 2013 within tributary or main-stem reaches of the Logan River, Utah.

Table 1. Numbers of mobile Cutthroat Trout detected versus total tagged moving out of the listed section of the Logan River into other river sections. The percentage of mobile fish from each section is listed with associated error estimations.

	Mobile Individuals (Total Tagged)	Percentage Mobile (95% C.I.)
Lower Section	13 (76)	17% (9.4-27.4%)
Upper Section	7 (150)	5% (1.9-9.4%)
Tributaries	88 (793)	11% (8.9-13.5%)

## DISCUSSION

This study suggests there is not a strong metapopulation structure in the Logan River, Utah because the population is not organized into discrete spawning aggregates. We found fish from each river section migrated to other sections with no apparent pattern, while most of the fish likely spawning in a reach were nearby residents. While the Logan River Watershed does have discrete areas of prime spawning habitats, there are also many pockets of usable habitat throughout the river system. Based on the lack of fish movement, most lower tributary fish likely use this spawning habitat (Seidel 2009; Meredith 2012). Spawning occurs over a long time frame, and spawning Cutthroat Trout movements do not appear to influence the dynamics and/or persistence of localized populations. If metapopulations were present in this system, we would expect higher percentages of fish moving out of main-stem reaches to seek out discrete patches of prime habitat found in tributaries or upstream reaches of the Logan Watershed. Few fish moved long distances within the basin, fish moved to all areas of the basin, and these habitats are not isolated; therefore, we assume no metapopulation structure exists within the Logan River based on an evaluation protocol put forth by Rieman and Dunham (2000). Study results will be complemented by a genetic, microsatellite analysis performed on fin clips from approximately 140 native trout. This analysis will likely add evidence to the panmictic-type population we presume resides in this river system.

The results from this study indicate that decades-old regulations with the goal of protecting spawning fish in the upper watershed may not be working as intended and may no longer be needed. Presently, the Logan River boasts a recreational fishery with a 97% catch-and-release fishery which includes the upper reaches (Budy et al. 2007). This is contrary to known historical uses that included high harvest rates.

Based on the lack of movement and high numbers of fish in the main stem of the river, it is apparent fish must spawn quite readily in the main stem, an area often assumed unsuitable for spawning. Given our population estimate suggests nearly 40% of fish remain less protected in the lower portion of the river (primarily in the main stem) where the harvest may be higher, a change in regulation that protects Cutthroat Trout while harvesting Brown Trout could

be desirable. While we focused on regulations that specifically affect spawning Cutthroat Trout, a host of other issues common to many watersheds (i.e. grazing, excessive sedimentation, climate change) also need to be addressed to ensure population persistence of this, and other populations into the future.

## ACKNOWLEDGEMENTS

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## REFERENCES

- Albanese, B., P.L. Angermeier, and S. Dorai-Raj. 2004. Ecological Correlates of Fish Movement in a Network of Virginia Streams. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 857–869.
- Bernard, D.R., and E.K. Israelson. 1982. Inter- and Instream Migration of Cutthroat Trout (*Salmo clarki*) in Spawn Creek, a Tributary of the Logan River, Utah. *Northwest Science* 56: 148–158.
- Bowerman, T. 2013. A Multi-Scale Investigation of Factors Limiting Bull Trout Viability. Utah State University. PhD Dissertation. Utah State University. Logan.
- Brierley, G.J., and K.A. Fryirs. 2008. *Geomorphology and River Management: Applications of the River Styles Framework*. Blackwell Publishing, Oxford, UK.
- Budy, P., G.P. Thiede, and P. McHugh. 2007. Quantification of the Vital Rates, Abundance, and Status of a Critical, Endemic Population of Bonneville Cutthroat Trout. *North American Journal of Fisheries Management* 27: 593–604.
- Budy, P., G.P. Thiede, C. Meredith, and S. Seidel. (n.d.). Logan River Whirling Disease Study: Factors Affecting Trout Population Dynamics, Abundance, and Distribution in the Logan River, Utah. 2008 Annual Report: Utah Cooperative Fish and Wildlife Research Unit 2009(2):1–43.
- Budy, P., S. Wood, and B. Roper. 2012. A Study of the Spawning Ecology and Early Life History Survival of Bonneville Cutthroat Trout. *North American Journal of Fisheries Management* 32: 436–449.
- Colyer, W.T., J.L. Kershner, and R.H. Hilderbrand. 2005. Movements of Fluvial Bonneville Cutthroat Trout in the Thomas Fork of the Bear River, Idaho–Wyoming. *North American Journal of Fisheries Management* 25: 954–963.

- Hanski, I. 1998. Metapopulation Dynamics. *Nature* 396: 41–49.
- Harvey, B.C., R.J. Nakamoto, and J.L. White. 1999. Influence of Large Woody Debris and a Bankfull Flood on Movement of Adult Resident Coastal Cutthroat Trout (*Oncorhynchus clarki*) During Fall and Winter. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 2161–2166.
- Hilderbrand, R.H., and J.L. Kershner. 2000. Movement Patterns of Stream-Resident Cutthroat Trout in Beaver Creek, Idaho – Utah. *Transactions of the American Fisheries Society* 129: 1160–1170.
- Koizumi, I., and K. Maekawa. 2004. Metapopulation Structure of Stream-Dwelling Dolly Varden Charr Inferred from Patterns of Occurrence in the Sorachi River Basin, Hokkaido, Japan. *Freshwater Biology* 49: 973–981.
- Lentsch, L., Y. Converse, and J. Perkins. 1997. Conservation Agreement and Strategy for Bonneville Cutthroat Trout (*Oncorhynchus clarki utah*) in the State of Utah. Utah Division of Wildlife Resources, Publication 97–19, Salt Lake City.
- McHugh, P., and P. Budy. 2005. An Experimental Evaluation of Competitive and Thermal Effects on Brown Trout (*Salmo trutta*) and Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) Performance Along an Altitudinal Gradient. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2784–2795.
- Meredith, C. 2012. Factors Influencing the Distribution of Brown Trout (*Salmo trutta*) in a Mountain Stream : Implications for Brown Trout Invasion Success. PhD Dissertation. Utah State University. Logan.
- Olsson, I.C., L.A. Greenberg, E. Bergman, and K. Wysujack. 2006. Environmentally Induced Migration: the Importance of Food. *Ecology Letters* 9: 645–651.
- Randall, J.W. 2012. The Survival and Growth of Adult Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) in Response to Different Movement Patterns in a Tributary of the Logan River, Utah. Masters Thesis. Utah State University. Logan.
- Rieman, B.E., and J.B. Dunham. 2000. Metapopulations and salmonids: a Synthesis of Life History Patterns and Empirical Observations. *Ecology of Freshwater Fish* 9: 51–64.
- Seidel, S.E. 2009. Exploring the Spawning Dynamics and Identifying Limitations to the Early Life-History Survival of an Important, Endemic Fish Species. Masters Thesis. Utah State University. Logan.

# TRENDS IN THE ABUNDANCE OF WESTSLOPE CUTTHROAT TROUT IN IDAHO

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**Abstract**—Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) are the most widely distributed subspecies of Cutthroat Trout in western North America. Despite known declines, data on trends in abundance are generally lacking range-wide for this subspecies. We evaluated WCT trends in abundance throughout much of Idaho using daytime snorkeling, screw trap, and angler catch data to index abundance. We also evaluated whether data sets contained observation error, and whether any easily-measured, broad-scale bioclimatic indices were correlated to WCT abundance through time. A total of 17 data sets were available within nine river drainages that contained WCT; on average, data sets covered a period of record of 25 years and averaged 19 years of data. Of these 17 data sets, 10 showed statistically significant population growth (at  $\alpha = 0.10$ ), two showed statistically significant population declines, and five were stable (with 90% error bounds that overlapped zero). Seven of the 17 datasets were estimated to have high observation error, which likely inflated the error bounds around those trend estimates. The bioclimatic variables we included in our study (indices of streamflow, water temperature, marine-derived nutrient influx, and drought) explained little of the variation in WCT abundance.

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## INTRODUCTION

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) are the most widely distributed subspecies of Cutthroat Trout in western North America (Behnke 2002), but despite their widespread distribution, declines in occupancy and abundance have occurred (Shepard et al. 2005). In Idaho, WCT now occupy approximately 50% of their historic range (Wallace and Zaroban 2013). Concerns about the status of WCT resulted in two petitions for listing under the Endangered Species Act, both of which were denied. Nevertheless, the U.S. Forest Service and the Bureau of Land Management regard WCT as a sensitive species, and the Idaho Department of Fish and Game (IDFG) has designated it as a Species of Greatest Conservation Need.

Concern over the status of WCT across their native range has resulted in numerous status assessments (e.g., Schill et al. 2004; Shepard et al. 2005). These assessments have highlighted a lack of information on trends in WCT abundance. One exception was a summary of several long-term trend monitoring data sets in Idaho (Schill et al. 2004); these authors concluded that WCT abundance in Idaho was generally stable or increasing. However, this study included only data from the St. Joe, Coeur d'Alene, Selway, and Middle Fork Salmon rivers, so that the area of inference from their study was small relative to

the entire distribution of WCT in Idaho. Our primary objective was to more completely summarize trends in WCT abundance in Idaho, using all available data. Secondly, because trend monitoring data is often subject to substantial observation error (Dennis et al. 2006), which can diminish the ability to detect statistically significant changes in abundance (Dunham et al. 2001), we estimated how much observation error was present in these WCT trend data sets. Finally, we examined whether trends in WCT abundance were correlated with several broad-scale bioclimatic variables, in an attempt to partially explain patterns in WCT trends in abundance that we observed in Idaho.

## METHODS

### Trends in WCT Abundance

Westslope Cutthroat Trout occurrence is well documented in Idaho, but metapopulation boundaries have not been well defined. The IDFG delineated geographic management units (GMUs) to provide spatial reference for conservation efforts, and they included several river basins and multiple WCT populations. Studies have demonstrated that WCT can move substantially between large river drainages (Bjornn and Mallet 1964; Schoby and Keeley 2011). Herein, we make inferences on WCT trends at the smallest scale possible, which is generally at the

scale of major river drainages. Areas of inference will hereafter be referred to as populations, though we acknowledge that several WCT populations may exist within these aggregates.

Several sources of data were used to index WCT abundance, including daytime summer snorkeling observations, screw trap catch, and angler catch. For snorkel surveys, from one to five observers (depending on stream width) counted all salmonids  $\geq 150$  mm total length (TL). Because Cutthroat Trout exhibit daytime concealment behavior at temperatures below 6–8°C (Griffith and Smith 1993), and such behavior would have negatively biased snorkel counts, we discarded all snorkel surveys conducted at water temperatures  $< 6^\circ\text{C}$ . We also discarded surveys when snorkeler visibility was  $< 2$  m (Thurow 1994).

For some populations, 1.5-m rotary screw-traps were used to capture WCT during routine monitoring of Chinook Salmon *O. tshawytscha* and Steelhead Trout *O. mykiss* outmigration. Screw traps were deployed as early as possible in the spring, usually in the last week of February or the first week of March, and operated until ice-up (usually the first week of December). Screw-trap data were included when a minimum of 10 continuous years of data were available from a consistent sample location. Total annual catch of WCT ( $> 50$  mm) at the screw trap was used as an index of abundance for the population.

In the Middle Fork Salmon River and Selway River, hook-and-line surveys have been collected annually by IDFG survey crews descending those rivers in raft trips to monitor resident and anadromous salmonid abundance. For the angling data, WCT of all size classes were summed as an index of abundance for the population.

We assessed trends in WCT abundance with least squares regression, using sample year as the independent variable and the index of abundance ( $\log_e$ -transformed) as the dependent variable. The regression line fit to these data is equivalent to the intrinsic rate of change ( $r_{intr}$ ) for the population (Maxell 1999) and produces unbiased estimates of  $r_{intr}$  despite the potential presence of observation error within the data (Humbert et al. 2009). Values of  $r_{intr} < 0$  indicate population declines whereas  $r_{intr} > 0$  indicate population growth. We used a significance level of  $\alpha = 0.10$  to increase the probability of detecting trends (Peterman 1990; Maxell 1999).

## Observation Error

A Gompertz state-space model (Dennis et al. 2006) was used to estimate observation error for each sampling method in each population (also see Meyer et al. 2014). This model estimates the amount of observation or sampling error ( $\hat{\tau}^2$ ) in abundance monitoring data that otherwise would be ascribed to process noise ( $\hat{\sigma}^2$ ). The formula for the model is as follows:

$$\hat{r}_t = \hat{a} - \hat{b} \ln N_t + \hat{\tau}^2 + \hat{\sigma}^2,$$

where  $\hat{r}_t$  is the estimated instantaneous rate of change in year ( $t (\ln N_t + 1 - \ln N_{t+1})$ ),  $\hat{a}$  is the estimated intercept,  $\hat{b}$  is the estimated slope (a measure of the strength of density dependence),  $\hat{\tau}^2$  is the estimated observation error, and  $\hat{\sigma}^2$  is the estimated process noise (a measure of environmental and demographic variation). The Gompertz state-space model was therefore used to identify data sets that were estimated to have no observation error and thus (presumably) no bias in the error bounds around the trend estimates. We also identified data sets with estimates of minimal observation error, which we arbitrarily set at  $\hat{\tau}^2 < 0.10$ ; we assumed that minimal observation error only slightly inflated the error bounds on estimates of trend. We assumed that estimates of  $\hat{\tau}^2 \geq 0.10$  would have produced error bounds around trend estimates that may have been substantially inflated and thus were less reliable.

## Bioclimatic Variables

We assessed whether abundance was related to several broad-scale bioclimatic variables, including drought, mean winter streamflow, mean annual air temperature (as a surrogate for water temperature), and the number of Chinook Salmon redds counted within the WCT population (as an index of marine-derived nutrient influx). The mean annual Palmer Drought Severity Index (PDSI) was computed for each population by the National Climatic Data Center ([www.ncdc.noaa.gov](http://www.ncdc.noaa.gov)). A point local to each population was selected from an area central to the population and along each respective stream channel. Mean winter streamflow was calculated for December through February from the U.S. Geological Survey gauge station (<http://waterwatch.usgs.gov/?m=real&r=id&w=map>) located most

centrally within each WCT population. Mean annual air temperature was calculated from the West Wide Drought Tracker (<http://www.wrcc.dri.edu/wwdt/time/>) at a point near the center of the dendritic stream network of each WCT population. The number of Chinook Salmon redds was summed annually within each WCT population (IDFG, unpublished data), except for WCT populations outside the natural range of Chinook Salmon (i.e., the Coeur d'Alene and St. Joe rivers).

Because each bioclimatic variable could have potentially affected WCT recruitment or had other delayed impacts that outweighed effects on within-year abundance, we related each bioclimatic variable to WCT abundance within that same year as well as with a one-year time lag (Copeland and Meyer 2011). Because Chinook Salmon redds were often counted after WCT abundance data had been collected in a given year, evaluating whether Chinook Salmon redd abundance affected WCT abundance in the same year was illogical; instead, one-year and two-year time lags were used for this relationship. We used multiple linear regression models to relate bioclimatic data through time to WCT abundance through time. Akaike's information criterion was used to identify the best model for each data set.

## RESULTS

A total of 17 data sets were available within nine WCT populations that indexed WCT abundance through time (Table 1), including nine snorkeling data sets, six screw-trap data sets, and two angling data sets. Data sets on average covered a period of record of 25 years and averaged 19 years of data.

Of the 17 data sets used to estimate WCT trends, 10 showed statistically significant population growth, two showed statistically significant population decline, and five were considered stable with 90% error bounds that overlapped zero (Table 1; Figure 1). In the Coeur d'Alene River sub-basin,  $r_{intr}$  was statistically positive for both data sets. In the Clearwater River sub-basin,  $r_{intr}$  was statistically positive for six data sets, statistically negative for no data sets, and stable for two data sets. In contrast,  $r_{intr}$  in the Salmon River sub-basin was statistically positive for two data sets, statistically negative for two data sets, and stable for three data sets.

Of the 17 data sets available for WCT trend monitoring, eight had no measurable observation error and two were estimated to have only minimal observation error (Table 2). Screw-trap and snorkeling data sets were equally prone to high observation error,

**Table 1. Description of available data sets, intrinsic rates of population change ( $r_{intr}$  with 90% confidence intervals), and estimated observation error ( $\hat{\tau}^2$ ) for Westslope Cutthroat Trout populations in Idaho.**

Sub-basin	WCT population	Data description	Collection method	Time Span (yrs)	Years of data	$r_{int}$			$\hat{\tau}^2$
						Estimate	Lower	Upper	
Coeur d'Alene	Coeur d'Alene River	Main stem data	Snorkeling	39	17	0.027	0.016	0.037	0.00
Coeur d'Alene	St. Joe River	Main stem data	Snorkeling	43	18	0.029	0.019	0.039	0.07
Clearwater	Lochsa River	Main stem and tributary data	Snorkeling	28	26	0.067	0.027	0.108	0.20
Clearwater	Lochsa River	Colt Killed Creek	Screw trap	12	12	0.050	-0.019	0.120	0.00
Clearwater	Lochsa River	Crooked Fork Creek	Screw trap	15	15	0.067	0.020	0.115	0.00
Clearwater	SF Clearwater River	Main stem and tributary data	Snorkeling	28	28	0.055	0.018	0.091	0.00
Clearwater	SF Clearwater River	Crooked River	Screw trap	13	13	0.359	0.214	0.504	0.00
Clearwater	SF Clearwater River	Red River	Screw trap	13	13	0.239	0.106	0.372	0.56
Clearwater	Selway River	Main stem and tributary data	Snorkeling	28	25	0.060	0.037	0.082	0.61
Clearwater	Selway River	Main stem data	Angling	36	27	-0.006	-0.018	0.007	0.60
Salmon	Mid-Salmon River	Tributary data	Snorkeling	24	23	-0.055	-0.105	-0.004	0.24
Salmon	South Fork Salmon River	Main stem and tributary data	Snorkeling	16	16	-0.113	-0.206	-0.019	0.00
Salmon	South Fork Salmon River	Knox bridge	Screw trap	14	14	-0.036	-0.092	0.020	0.00
Salmon	Middle Fork Salmon River	Main stem data	Snorkeling	28	18	0.096	0.073	0.118	0.00
Salmon	Middle Fork Salmon River	Tributary data	Snorkeling	28	27	0.149	0.128	0.170	0.20
Salmon	Middle Fork Salmon River	Main stem data	Angling	54	20	0.0002	-0.014	0.014	0.10
Salmon	Upper Salmon River	Sawtooth hatchery	Screw trap	13	13	0.020	-0.147	0.186	0.95

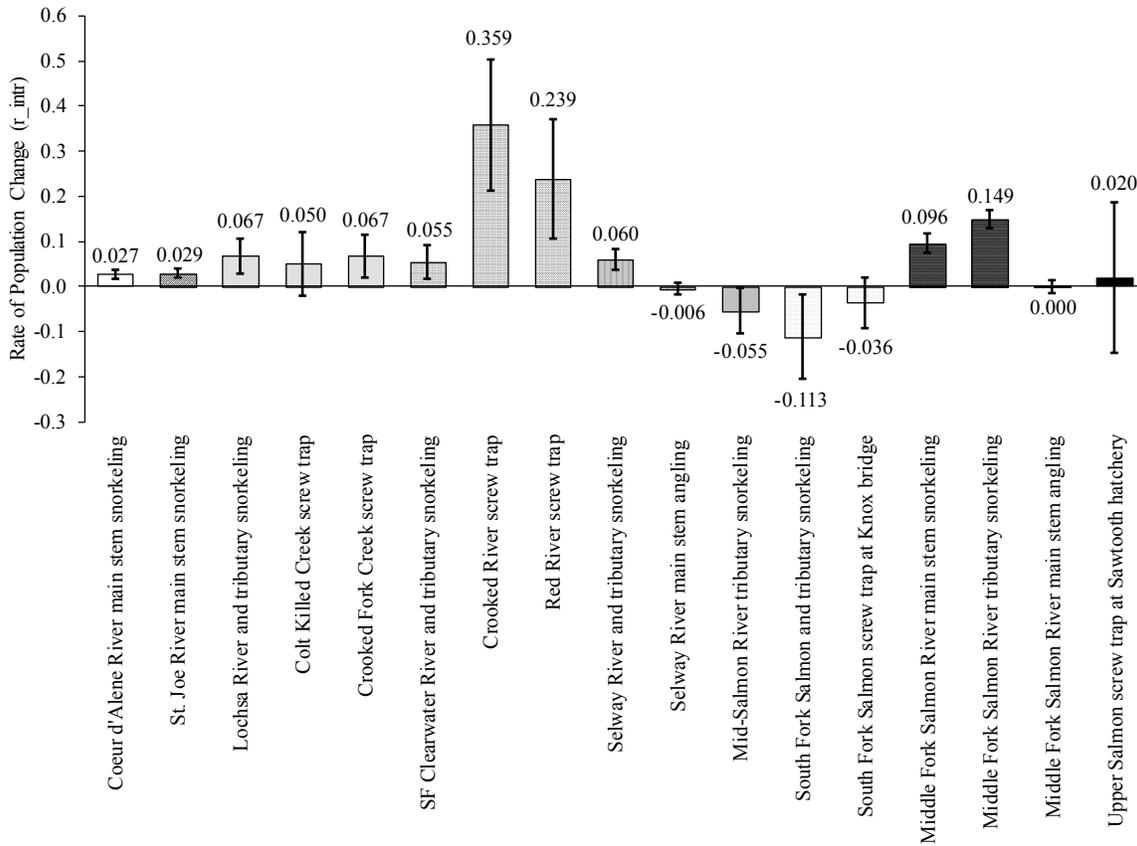


Figure 1. Intrinsic rates of population change ( $r_{intr}$ ) for Westslope Cutthroat Trout populations in Idaho. Error bars represent  $\pm 90\%$  confidence intervals.

Table 2. Best models for each Westslope Cutthroat Trout trend monitoring data set relating trout abundance to bioclimatic variables. Akaike information criterion weights ( $w_i$ ) indicate the probability that the given model is the best model. PDSI is the Palmer Drought Severity Index, AirT is air temperature, Discharge is mean winter streamflow, and Redds is the annual count of Chinook Salmon redds.

WCT population	Data description	Collection method	Variables	$w_i$	$r^2$	F-value	P-value
Coeur d'Alene River	Main stem data	Snorkeling	PDSI	0.27	0.01	0.14	0.71
St. Joe River	Main stem data	Snorkeling	PDSI	0.29	0.05	0.75	0.40
Lochsa River	Main stem and tributary data	Snorkeling	Redds	0.22	0.08	2.14	0.16
Lochsa River	Colt Killed Creek	Screw trap	Redds	0.25	0.25	3.29	0.10
Lochsa River	Crooked Fork Creek	Screw trap	Redds	0.41	0.27	4.72	0.05
SF Clearwater River	Main stem and tributary data	Snorkeling	Redds	0.19	0.07	1.96	0.17
SF Clearwater River	Crooked River	Screw trap	Redds	0.27	0.25	3.57	0.09
SF Clearwater River	Red River	Screw trap	Redds	0.22	0.18	2.36	0.15
Selway River	Main stem and tributary data	Snorkeling	AirT	0.29	0.25	7.47	0.01
Selway River	Main stem data	Angling	AirT + PDSI	0.18	0.14	1.88	0.07
Mid-Salmon River	Tributary data	Snorkeling	Redds	0.23	0.08	1.72	0.20
South Fork Salmon River	Main stem and tributary data	Snorkeling	PDSI	0.27	0.16	2.65	0.13
South Fork Salmon River	Knox bridge <sup>a</sup>	Screw trap	Redds + Discharge	0.30	0.33	4.14	0.09
Middle Fork Salmon River	Main stem data <sup>a</sup>	Snorkeling	AirT + Redds	0.42	0.42	7.13	0.03
Middle Fork Salmon River	Tributary data <sup>a</sup>	Snorkeling	AirT + PDSI + Redds	0.50	0.68	19.35	<0.001
Middle Fork Salmon River	Main stem data <sup>a</sup>	Angling	AirT	0.26	0.01	0.21	0.65
Upper Salmon River	Sawtooth hatchery	Screw trap	Discharge	0.35	0.34	4.19	0.07

<sup>a</sup> Streamflow data incomplete, therefore discharge was not tested in this model

with approximately 50% of those data sets estimated to have high observation error. Both angling data sets appeared to have no observation error.

For all bioclimatic variables except Chinook Salmon redds, correlation coefficients with WCT abundance were generally higher for one-year lags; for Chinook Salmon redds, correlation coefficients were generally higher for two-year time lags. Using these time lags in multiple regression models, the bioclimatic variables generally explained a statistically significant but low amount of variation in WCT abundance, with an average of 21% of the variation in WCT abundance being explained by the bioclimatic variables. Chinook Salmon redd counts was the most explanatory variable for 56% of the data sets, followed by air temperature (28%), and Palmer Drought Severity Index (17%). High redd counts had a positive effect and low air temperature and low PDSI had negative effects on WCT abundance.

## DISCUSSION

In our study, there were five times more statistically significant positive growth rate estimates than statistically significant negative estimates, and several more stable growth rates, suggesting that WCT are generally stable or increasing in abundance across much of Idaho. Similar increases in population abundance have been observed for a number of salmonids in Idaho (Copeland and Meyer 2011). The only area in our study that appeared to have declining WCT populations is the South Fork Salmon River and nearby tributaries to the middle reaches of the main-stem Salmon River. Causative mechanisms are difficult to elucidate at such broad scales using mensurative (rather than manipulative) study designs, but our results suggest that at least some of the positive growth in WCT populations in Idaho can be attributed to increases in wild Chinook Salmon returning from the Pacific Ocean. Salmon deliver marine-derived nutrients to the majority of WCT populations in Idaho (Cederholm et al. 1999) and marine-derived nutrients are particularly important for primary production in unproductive geologies like Idaho (Sanderson et al. 2008). Nevertheless, most bioclimatic variables were weakly correlated to WCT abundance, suggesting that environmental factors other than the ones we included in our study may have been influencing WCT abundance. Copeland and Meyer (2011) evaluated

the relationships between bioclimatic conditions and fish density for six salmonids in central Idaho and also found weak relationships for WCT. Westslope Cutthroat Trout are often closely associated with headwater habitats (Shepard et al. 2005), which are typically more stochastic than downstream reaches (Richardson et al. 2005), and therefore, may be less likely to be influenced by the large-scale bioclimatic indices we analyzed. Other factors that may be contributing to positive WCT population growth in Idaho include improvements in land management practices, and catch-and-release regulations (Quinn 1996; Mallet 2013).

We assumed that the trend data sets available for each WCT population were unbiased representations of the true trend within that population. For most populations, this assumption is tenuous because the trend data were obtained from only a portion of the WCT population. Nonetheless, for the WCT populations where more than one data set was available, trends were generally in synchrony within the population. In fact, there were no examples of trends being statistically positive and statistically negative for two different data sets within the same WCT population. Furthermore, many of the trend data sets were initiated to monitor species other than WCT, such as the screw trap and snorkel data sets for the Salmon River and Clearwater River basins. Although these data sets contained data on all salmonids encountered, they were established to monitor trends in Salmon and Steelhead, and it therefore seems unlikely that their use would have resulted in WCT data that were consistently more optimistic than the mean growth rate for the population would have been.

Observation error was high for nearly one-half of the WCT trend data sets we summarized herein. Fortunately, in our study this had little impact on our findings because for six of the seven data sets with high observation error, trends were already estimated to be statistically significant (despite the fact that CIs were likely inflated), and for the seventh data set,  $r_{intr}$  was very close to zero and likely would not have differed from zero even if the error bounds were not inflated. High observation error is often a problem in trend monitoring because it can obscure what otherwise might have been significant changes to a population's abundance (Dunham et al. 2001). Observation error is also a concern because it can inflate estimates of a population's risk of extirpation

(Morris and Doak 2002). We did not estimate risk of extirpation in our study, because we had no estimates of adult population size, which is necessary for such modeling.

The fact that screw trap data sets were as likely to have high observation error as snorkeling data sets contrasts the findings of Meyer et al. (2014); these authors used many of the same data sets and found that for Bull Trout *Salvelinus confluentus*, snorkeling data sets were much more likely to have high observation error than data obtained from screw traps. These differences may stem from behavioral and life history differences between Bull Trout and WCT in Idaho. Bull Trout are cryptic, sporadically distributed, highly migratory salmonids (Pratt 1992). In contrast, WCT are usually more abundant (Copeland and Meyer 2011), less cryptic (and therefore more easily spotted by snorkelers), and - although more mobile than most salmonids - not as mobile as Bull Trout, at least during our sampling period (Schoby and Keeley 2011). It therefore should not be surprising that at least in Idaho, snorkeling data appear to index WCT abundance better than for Bull Trout, whereas screw traps appear to better index Bull Trout abundance.

We suspected that any effect the bioclimatic variables would have on WCT abundance might be delayed by one year. Such a delayed response might indicate that the bioclimatic variables were influencing WCT recruitment (Copeland and Meyer 2011), and since for most data sets we either discarded small fish (snorkel data sets) or small fish were not vulnerable to the data collection method (angling data sets), a one-year delayed response would be expected. Although the bioclimatic variables were only weakly related to WCT abundance, in all instances these relationships were indeed strongest with a one-year lag (except the two-year lag for Chinook Salmon redds).

Our study highlights the lack of WCT trend monitoring data for many areas in Idaho, particularly the Moyie River, North Fork Clearwater River, Lemhi River, and Pahsimeroi River drainages. Until WCT trend data are available for these drainages, assessment of WCT status in Idaho will be incomplete. Nevertheless, the results of our study suggest that WCT in Idaho currently appear to be stable or increasing in abundance in most areas.

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## LITERATURE CITED

- Behnke, R. J. 2002. Trout and salmon of North America. Free Press, New York.
- Bjornn, T. C., and J. Mallet. 1964. Movements of planted and wild trout in an Idaho river system. Transactions of the American Fisheries Society 93:70-76.
- Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83–138 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.
- Cederholm, C. J., M. D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10):6–15.
- Copeland, T., and K. A. Meyer. 2011. Interspecies synchrony in salmonid densities associated with large-scale bioclimatic conditions in central Idaho. Transactions of the American Fisheries Society 140:928-942.
- Dennis, B., J. M. Ponciano, S. R. Lele, M. L. Taper, and D. F. Staples. 2006. Estimating density dependence, process noise and observation error. Ecological Monographs 76:323-341.
- Dunham, J., B. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts for bull trout *Salvelinus confluentus*. North American Journal of Fisheries Management 21: 343-352.
- Griffith, J. S., and R. W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. North American Journal of Fisheries Management 13:823–830.

- Humbert, J. Y., L. S. Mills, J. S. Horne, and B. Dennis. 2009. A better way to estimate population trends. *Oikos* 118:1940-1946.
- Mallet, J. 2013. Saving Idaho's westslope Cutthroat Trout fisheries. Idaho Department of Fish and Game. Report Number 13-14. Boise.
- Maxell, B. A. 1999. A power analysis on the monitoring of bull trout stocks using redd counts. *North American Journal of Fisheries Management* 19:860-866.
- Meyer, K. A., E. O. Garton, and D. J. Schill. 2014. Bull trout trends in abundance and probabilities of persistence in Idaho. *North American Journal of Fisheries Management* 34:202-214.
- Morris, W. F., and D. F. Doak. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer, Sunderland, Massachusetts.
- Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. *Canadian Journal of Fisheries and Aquatic Sciences* 47:2-15.
- Pratt, K. L. 1992. A review of bull trout life history. Pages 5-9 in P. J. Howell, and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.
- Quinn, S. 1996. Trends in regulatory and voluntary catch-and-release fishing. *American Fisheries Society Symposium* 16:152-162.
- Richardson, J. S., R. J. Naiman, F. J. Swanson, and D. E. Hibbs. 2005. Riparian communities associated with Pacific Northwest headwater streams: assemblages, processes, and uniqueness. *Journal of the American Water Resources Association* 41:935-947.
- Sanderson, B. L., H. J. Coe, C. D. Tran, K. H. Macneale, D. L. Harstad, and A. B. Goodwin. 2008. Nutrient limitation of periphyton in Idaho streams: results from nutrient diffusing substrate experiments. *Journal of the North American Benthological Society* 28:832-845.
- Schill, D. J. C., E. R. J. M. Mamer, and T. C. Bjornn. 2004. Population trends and an assessment of extinction risk for westslope Cutthroat Trout in select Idaho waters. Wild Trout VIII Symposium held in West Yellowstone, Montana, September 2004.
- Schoby, G. P., and E. R. Keeley. 2011. Home range size and foraging ecology of bull trout and westslope cutthroat trout in the upper Salmon River basin, Idaho. *Transactions of the American Fisheries Society* 140:636-645.
- Shepard, B. B., B. E. May, and W. Urie. 2005. Status and Conservation of Westslope Cutthroat Trout within the Western United States. *North American Journal of Fisheries Management* 25:1426-1440
- Thurow, Russell F. 1994. Underwater methods for study of salmonids in the Intermountain West. Gen. Tech. Rep. INT-GTR-307. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 28p.
- Wallace, R. L., and D. W. Zaroban. 2013. Native fishes of Idaho. American Fisheries Society, Bethesda, Maryland.

## GUERRILLA ECOLOGY: TOWARD AN EFFECTIVE STRATEGY FOR MONITORING ALBERTA'S TROUT STREAMS IN A HOSTILE CLIMATE

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**Abstract**—Alberta's Rocky Mountain East Slopes have some of the highest road densities in western North America (mean 2.7 km/km<sup>2</sup>, maximum > 8 km/km<sup>2</sup>) because of the province's multiple use policy for most public land, which permits concurrent logging, mining, grazing, petroleum exploration and extraction, motorized recreation, and suburban development. At the same time the region is experiencing changes in its climate and hydrology attributable to unchecked anthropogenic climate warming. The East Slopes provide most of the province's remaining trout sport fishery, and are the last refuge for two at-risk cold-stenothermic salmonids, Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* and Bull Trout *Salvelinus confluentus*. The Government of Canada, by removing critical habitat protection provisions from the federal *Fisheries Act* and by reducing professional staff, is making it much more difficult to protect trout stocks. Together with chronically low funding of the responsible provincial agency, these factors have placed East Slopes trout and their habitats at high risk while hobbling the ability of remnant agency biologists to respond effectively. Drawing loosely on some principles of guerrilla warfare, I outline a strategy that makes it possible, even under these onerous conditions, to monitor a wide range of human influences on the region's trout populations and habitats. The approach relies primarily on a simple map-based watershed assessment, a modification of British Columbia's Level 1 Interior Watershed Assessment Procedure, combined with a temperature logger network to identify and prioritize at-risk streams and populations for more detailed analysis. Examples are given of simple, reliable, and inexpensive methods for the more detailed studies that would support actions protecting habitats and populations.

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### INTRODUCTION

The East Slopes, a 108,000-km<sup>2</sup> area of forests, mountains, and foothills east of the Continental Divide in Alberta, includes approximately two-thirds of the native range of trout and char in the province. Approximately 83% is under Alberta Government jurisdiction, the remainder being federally administered in three national parks. The East Slopes hold most of the remaining coldwater fish habitat supporting salmonid sport fisheries in southwestern Alberta.

This paper deals with the headwaters of the Bow and Oldman river drainages, which hold approximately 27,500 km<sup>2</sup> of the historical salmonid watersheds on the East Slopes outside of the national parks. The Bow and Oldman headwaters hold 24 native species, of which six are salmonids, three supporting extensive sport fisheries: Mountain Whitefish *Prosopium williamsoni*, Bull Trout *Salvelinus confluentus*, and Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi*. Twelve more fish species have been introduced,

of which three contribute significantly to the sport fishery. Bull Trout are a sensitive species listed under Alberta's *Wildlife Act* as a Species of Special Concern in the province. The Westslope Cutthroat Trout is listed as Threatened under the *Wildlife Act*; Alberta populations are listed as Threatened under the federal *Species At Risk Act*.

The East Slopes are under heavy use and development pressure, primarily from forestry, oil and gas exploration and production, and motorized recreation. In addition, anthropogenic global warming is changing the climate, with effects on regional hydrology. How these factors are affecting East Slopes salmonids is largely unmeasured. Their effects need to be monitored to inform fisheries management. Complicating these issues is an open hostility to environmental protection, especially by the federal government, which is responsible for protecting fisheries under the *Fisheries Act*.

Here I summarize the main evidence in these areas. I then outline how at least some issues might be

addressed in a workable monitoring program. My aim is not to prescribe any particular monitoring system, but to instigate discussion toward initiating one that can be applied in the face of hostile governments and with minimal resources.

## CHALLENGES TO TROUT AND THEIR HABITATS

**Land-use planning**—The root of most environmental issues on the East Slopes has been the land-use plan. Since 1977, revised slightly in 1984, land-use on the Eastern Slopes has been governed by a policy document that, in most of the area, relegated protected lands (Prime Protection Zone) almost entirely to mountain peaks while designating the more productive valleys to multiple-use (Alberta Energy and Natural Resources 1984). Some lower-elevation lands were designated critical wildlife zones, but these were isolated patches with no special protection offered. Conservation of fish and their habitats was nominally part of the critical wildlife zones, but most critical fish habitat ended up in multiple use and general recreation zones. The effect has been that logging, petroleum exploration and development, grazing, and motorized recreation occur in the same places at the same time at the expense of ecosystem integrity. Most of the same mistakes are likely going to be repeated in a new plan, judging from advice offered to the government by its advisory committee (SSRAC no date). For example, provincially and federally listed Westslope Cutthroat Trout (Threatened) is not listed in the recommended plan. Critical spawning streams for Bull Trout and Westslope Cutthroat Trout populations, and nearly all critical populations of those fish, are placed in mixed-use forest lands. Proposed areas for conservation are again relegated mainly to mountaintops; the essential valley bottoms are turned over to every other kind of use.

**Logging**—Logging grew from the 1930s to the mid-1990s at an ever-increasing rate, so that by the late 1990s streams in 87 of 90 study basins were at moderate to high risk for 20-100 years (Mayhood *et al.* 2004). In the nearby 309-km<sup>2</sup> Carbondale River basin, more than 25% of the total basin had been logged by about the same time, and the entire basin was at high risk from the combined effects of increased peak flows and surface erosion (Sawyer and Mayhood 1998a). The Carbondale watershed has since had over 129

km<sup>2</sup> of its area burned (Silins *et al.* 2005: Figure 1), causing large, potentially long-lasting changes in the hydrology, sediment loading and water quality in the burned basins, effects that were exacerbated by salvage logging (Silins *et al.* 2009). Logging has continued despite the fact that the unrecovered burn area alone, not including previously existing cut blocks, is 42% of the total Carbondale basin area. The preferred scenario of the forest management plan for the C5 region (The Forestry Corp 2006), the relevant management area, suggests that overall, an additional 10% of the C5 forest will have been logged by 2026, more than double the existing proportion of equivalent clearcut area<sup>1</sup> in the 98 basins studied in the region. Several small watersheds will have had more than an additional 25% logged. These are large amounts, and the logging is being done in basins that are important to at-risk trout, for example, in O'Hagen and Hidden creeks. No special attempt has been made to protect these stocks; only best management practices are used. Serious sediment problems have been identified at Hidden Creek, yet further logging in the basin is planned.

**Petroleum development**—As of 1 August 2013, the Alberta Energy Regulator lists 1,674 existing wells that fall within the native range of trout in the Bow and Oldman river drainages (not including the main stems), of which 921 are abandoned and 430 are producing gas or oil. Most of these in forested areas required seismic lines and exploration trails to discover; all needed roads to drill and service them. Most producing crude oil wells and all gas wells require pipelines, which remain after the wells no longer produce. All add to the network of linear disturbance, which is a major source of fine sediment to stream networks.

All wells pose risks to aquatic ecosystems from leakage. Wells flowing under their own pressure (319 of the 430 currently producing oil or gas) particularly have the potential to leak hydrocarbons and brines into groundwater, where contaminants can eventually pollute streams. Most of the East Slopes has a high vulnerability rating for groundwater (SSRAC no date), so this is a serious issue in the region. Abandoned wells also commonly leak due to inadequate cementing of the borehole and casing. Well sites are sources of contamination from initial preparation and drilling,

<sup>1</sup> the area of forest cut, adjusted for hydrological recovery due to forest regrowth

through production and abandonment (Bertram *et al.* 1995), contributing a long list of hydrocarbon and heavy metal pollutants, among others.

**Mining**—Alberta’s Energy Regulator has mapped at least 156 abandoned coal mines on the southern East Slopes within the range of native trout. New interest in mine development has been shown in the Crowsnest area at Grassy Mountain (Stephanson 2013). The same miner holds leases apparently in the Lynx Creek and lower Carbondale River drainages (Read 2013). A coal-related mine for magnetite is actively being pursued in the Rock Creek drainage. In addition to new roads and potential contamination issues, surface mines may require extensive drainage alteration, threatening trout habitat.

**Motorized recreation**—All-terrain vehicles are a major cause of watershed degradation in parts of the Castle, upper Oldman-Livingstone, Elbow, Sheep and Ghost river drainages. Roads<sup>2</sup> developed originally for resource extraction are taken over and used by motorized recreation vehicles. Overall road density from this cause in the 1,003-km<sup>2</sup> Castle Area Forest Land use Zone averages 1.5 km/km<sup>2</sup> (Lee and Hanneman 2011); in large parts of the Castle basin it exceeds 2.2 km/km<sup>2</sup>; and in several small sub-basins it is up to 7.8 km/km<sup>2</sup> (Parkstrom 2002). The 99 small basins my colleagues and I have studied so far on the East Slopes have a mean road density of 1.5 km/km<sup>2</sup>, and reach a maximum of 3.7 km/km<sup>2</sup>. Overall mean road density for the all of the East Slopes is 2.7 km/km<sup>2</sup>, reaching maxima of over 8 km/km<sup>2</sup> in some areas (Sawyer and Mayhood 1998b). Various measures of road extent are negatively correlated with abundance or occurrence of trout (Ripley *et al.* 2005; Valdal and Quinn 2011).

**Climate change**—By 2050 atmospheric temperatures on the East Slopes will be higher by 2–4 °C throughout the region, with some small differences between the Oldman and Bow basins (Sauchyn and Kulshreshtha 2008). In general, precipitation will be higher in winter, spring, and fall, but lower in summer on the East Slopes. The most likely consequences of this combination of factors are that future ice-free conditions will be longer, extend later into the fall, and begin earlier in the spring. Spring runoff will be larger with higher peak flows, and will occur earlier.

<sup>2</sup> includes all linear disturbances used by motorized vehicles, including seismic lines, pipelines, transmission lines, cutlines, exploration trails and others

Streamflows then will tend to attenuate more rapidly through the summer, with either a small increase in fall or simply a recharge of soil moisture and groundwater drawn down over the drier summer. The higher peak flows can be expected to change stream channel morphology and the structure of the riparian zone. Temperature effects are likely to have disproportionately strong physiological and ecological effects in spring and fall, when temperatures would ordinarily be near the freezing point, and at low-temperature locations at any time of year, because physiological processes are much more sensitive to temperature change at low temperatures in poikilotherms (Winberg 1956).

**Government hostility**—Federal government hostility toward science, especially environmental science, is a major obstacle to protecting East Slopes aquatic ecosystems. A few examples: 16 clean lakes were designated as toxic dump sites; the *Fisheries Act* was gutted to remove protection for most fish and their habitats; there are numerous, repeated instances of preventing federal scientists from speaking to the public about their work or to speak freely at conferences; Federal scientists are highly restricted on how they can share data with other researchers; the Canadian Environmental Assessment Act was repealed; the Sustainable Water Management Division was cut; 1,000 jobs were cut at the Department of Fisheries and Oceans (DFO), and funding cuts are ongoing; Ocean Contaminants and Marine Toxicology Centre was axed; the Freshwater Institute was cut; Experimental Lakes area closure was announced; Fisheries Habitat Management Program was cut; development review was removed from the Navigable Waters Act on almost all rivers and lakes; DFO sabotaged scientists’ access to the Experimental Lakes Area; and DFO libraries were closed Dupuis (2013). The federal government has also repeatedly attacked environmental groups involved in environmental hearings as radicals (Payton 2012), accused them of furthering the interests of a foreign power and laundering foreign money (CBC News 2012), has limited their ability to participate in public hearings (McCarthy 2012), has investigated them in a circus-like Senate hearing (McDiarmid 2012), and has had the Canada Revenue Agency audit their financial statements (Garossino 2012).

Gutting of the *Fisheries Act* has particularly harsh consequences for protecting fishes and their habitats

(Taylor 2013). The changes mean that only habitat of those fish having value to commercial, recreational, or aboriginal fisheries are subject to the Act, and then only at the discretion of the Minister. Many important fish populations on the East Slopes do not support a fishery and are unprotected under the *Fisheries Act*: the fish are too small to attract anglers. Examples include designated threatened Westslope Cutthroat Trout remnant populations in small headwater creeks.

## MONITORING EAST SLOPES TROUT POPULATIONS AND HABITAT

The number of threats to our watersheds and their inhabitants precludes any attempt to address all threats in every place: the resources are not available. Protecting East Slopes trout and their habitats is apparently an impossible task, comparable to the prospects for success in guerrilla warfare. Yet guerrilla forces do win wars on occasion. Their victorious leaders may suggest general principles revealed by their victory (Guevara 1961). In fact, there do not appear to be general principles for success in guerrilla warfare: victory depends strongly on the specific circumstances of the conflict (Dyer 2004).

There is nevertheless a uniform strategy: wear down the enemy using repeated hit-and-run tactics. In the present context, the major concern is the continued deterioration of watershed ecosystems throughout the East Slopes. The strategy involves attacking manageable problems—targets of opportunity—one by one using whatever primitive “weapons” are to hand. In this way small successes boost morale while edging closer to the overall objective. “Victory” is achieved when all critical watersheds are secured, their ecosystems functioning with all of their components present. It is the role of the guerrilla ecologist to conduct this “war” with ingenuity and whatever meager assets are available. It is the flexible, adaptable, and ingenious use of minimal assets that distinguishes the guerrilla fighter. The same qualities can inform the work of the guerrilla ecologist. The focus below is on such cheap, simple tools available for this work.

### Role and meaning of monitoring—

Environmental scientists tend to see monitoring as maintaining regular surveillance over some elements of the environment, starting before any impact has occurred (Green 1979) so as to recognize impacts,

preferably before those impacts become a serious problem. Others seem to require that monitoring must provide proof of an impact before any further action is taken (RAMP 2010): in essence, they want to see the very thing monitoring is intended to prevent, to trigger action preventing it. Here I view monitoring as surveillance to detect evidence, not proof, that an unwanted impact is imminent. This evidence would then trigger further investigation to confirm or refute the threat, or action would be initiated to reduce the threat to acceptable levels.

**Watershed assessment**—Roads are a surrogate for development: almost every human development in East Slopes watersheds requires them and, in forested areas, clear-cuts of some sort. Trout occurrence and abundance is strongly related to measures of roads and (for Bull Trout) clear-cuts (Ripley *et al.* 2005, Valdal and Quinn 2011). A watershed assessment such as the Level 1 Interior Watershed Assessment Procedure (IWAP; BC Forest Service 1995) which relies on measures of clear-cut and roads obtained from existing public data sources, serves as a screening method to identify the level of existing risk to stream habitat posed by current development in a basin. Proposed development can then be added before approvals are granted to determine the extent of increased risk it poses. The system includes courses of action to follow up on any assessments that exceed certain thresholds. When combined with data on the distribution of critical trout populations, it is possible to focus even more closely on problem watersheds. The IWAP can also be used in restoration to identify how much of a road network, and what particular roads, need to be reclaimed, or how much clear-cut needs enhanced recovery.

**Camera stations**—A network of fixed, well-chosen camera stations used systematically with a scale such as a stadia rod is an effective and cheap way to monitor habitat features such as channel morphology, stream crossings, and changes in sediment sources. Stations should be chosen with information from the IWAP to establish effective sites. A large number of such sites can be photographed by one person in a day for the cost of tank of gas and a pack lunch. Changes in photographed features over time can be used to support management actions.

**Monitoring populations**—Direct monitoring of trout populations is necessary for obtaining some kinds of information to support management action.

Angling can be a solution that is minimally invasive and still provides specimens for genetic sampling (scales), external health assessment, sex determination, length, weight, and photography. With photographic identification of individuals (Gifford and Mayhood 2013), valuable data on abundance and movements can be obtained without the need for marking.

**Temperature logger network**—The East Slope's two most at-risk species are highly sensitive to the temperature increases that can be expected from climate change. Both will be excluded from lower main stems and restricted increasingly to cold headwaters. Westslope Cutthroat Trout headwater remnant stocks additionally will become more susceptible to hybrid invasions as more warm-tolerant Rainbow Trout *Oncorhynchus mykiss* and their hybrids with cutthroats are able to move up into the headwaters (Rasmussen *et al.* 2010). There are at least two needs for monitoring stream temperatures in a program intended to manage East Slopes trout. One is to monitor for temperatures permitting upstream Rainbow Trout allelic invasion. The other is to find unoccupied habitats, perhaps above barriers or in waters that can be reclaimed, into which remnant populations can be archived. Populations at risk from habitat contraction, and from habitat expansion favorable to Rainbow Trout, can then be identified before they are placed at more serious risk. They might then be moved to more suitable, safer habitat identified by the broader temperature monitoring. Dan Izaak's Climate-Aquatics Blog ([http://www.fs.fed.us/rm/boise/AWAE/projects/stream\\_temp/stream\\_temperature\\_climate\\_aquatics\\_blog.html](http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/stream_temperature_climate_aquatics_blog.html)) is a good source for aids in planning such a program.

**Decomposition monitoring**—Most East Slopes streams decompose allochthonous organic matter such as leaves and needles from the surrounding forest, producing trout food in the form of benthic invertebrates. Changes in decomposition measure changes in stream ecosystem function, and are likely to arise from any large-scale change in land use. Stream ecosystem function can be monitored from decomposition using leaf and needle packs (Reice and Wohlenberg 1993).

**Whole ecosystem experiments**—Every intrusion into a watershed is a whole-ecosystem experiment if properly monitored. By monitoring new and existing development with the proper study design, it is possible to detect effects of that development. Those

findings then become data that can be applied to new proposals of a similar sort. One of the greatest lost opportunities of the massive development along the East Slopes has been that new developments have so seldom been monitored as they are built, and thereafter as they are operated.

Given the extent of existing development on Alberta's East Slopes and the lack of interest—even hostility—of governments toward environmental protection, we have no reason to expect an improvement in protecting its trout populations and habitats any time soon. The few ideas presented here can form part of a guerrilla-type strategy to maintain at least some pieces of the regional aquatic ecosystems intact while we await more enlightened government policies. Properly communicated, even a skeletal monitoring system can assist in bringing such policies about.

## LITERATURE CITED

- Alberta Energy and Natural Resources. 1984. A policy for resource management of the eastern slopes: revised 1984. ENR Report No. T/38, Government of Alberta, Edmonton.
- BC Forest Service. 1995. Interior watershed assessment procedure guidebook (IWAP) level 1 analysis. BC Environment, Government of British Columbia, Victoria.
- Bertram, H. L., K. U. Weyer, and A. Altbäumer. 1995. Sources of contamination identified by oil field operation, industrial process and operating process. Section 2.21. pp. 1-33. *in* R. W. Coppock, K. U. Weyer, L. P. Penney, M. M. Schuler, and F. E. Geddes, editors. Impact of the petroleum industry on cattle production: Critical review of scientific and other literature. Alberta Environmental Centre and WDA Consultants Inc., Vegreville and Calgary, Alberta.
- CBC News. 2012. Environmental charities 'laundering' foreign funds, Kent says. <http://www.cbc.ca/news/politics/story/2012/05/01/pol-peter-kent-environmental-charities-laundering.html>.
- Dupuis, J. 2013. The Canadian war on science: A long, unexaggerated, devastating chronological indictment. p. <http://scienceblogs.com/confessions/2013/05/20/the-canadian-war-on-science-a-long-unexaggerated-devastating-chronological-indictment/>
- Dyer, G. 2004. War. Revised edition, Random House Canada, Toronto, Ontario.
- Garossino, S. 2012. "Truthiness" and the right's attack on Canada's charities. <http://www.vancouverobserver.com/politics/commentary/stephen-colbert-truthiness-and-harper-governments-attack-canadas-charities?page=0,1>.

- Gifford, C. M., and D. W. Mayhood. 2013. Natural marks for identifying individual fish in small populations of at-risk Westslope Cutthroat Trout. pp. 275-281. This volume. in editors R.F Carline and C. LoSapio. Proceedings of the Wild Trout XI Symposium, Bozeman, Montana
- Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, Toronto, Ontario.
- Guevara, E. C. 1961. Guerrilla warfare. Various publishers. In the public domain. Available from: <http://www3.uakron.edu/worldciv/pascher/che.html>. (August 2013).
- Lee, P., and M. Hanneman. 2011. Castle Area Forest Land Use Zone (Alberta): Linear disturbances, access densities and grizzly bear habitat security areas. Global Forest Watch Canada 1st Publication for International Year of Forests, Edmonton, Alberta.
- Mayhood, D. W., M. D. Sawyer, and W. Haskins. 2004. Historical risk analysis of watershed disturbance in the southern east slopes region of Alberta, Canada, 1910-1996. pp. 23-29. in G. J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins, and M. Monita, editors. Proceedings of the Forest Land - Fish Conference II—Ecosystem stewardship through collaboration. Canadian Forest Service, Natural Resources Canada, Ottawa, Ontario. Available from: <http://fwresearch.ca/Library.html> (August 2013)
- McCarthy, S. 2012. Ottawa curbs ability of green groups to intervene in review process. <http://www.theglobeandmail.com/news/politics/ottawa-curbs-ability-of-green-groups-to-intervene-in-review-process/article2405411/>.
- McDiarmid, M. 2012. Opposing oilsands never 'a charitable act,' senator says. <http://www.cbc.ca/news/canada/calgary/story/2012/03/06/pol-senate-environmental-charities.html>.
- Parkstrom, G. 2002. Effects of forest roads and road density in the South Castle River basin, Alberta. pp. 14-30. in D. H. Sheppard, G. Parkstrom, and J. C. Taylor, editors. Bringing it back: a restoration framework for the Castle Wilderness. Castle-Crown Wilderness Coaliton, P.O. Box 2621, Pincher Creek, Alberta. T0K 1W0..
- Payton, L. 2012. Radicals working against oilsands, Ottawa says. <http://www.cbc.ca/news/politics/story/2012/01/09/pol-joe-oliver-radical-groups.html>.
- RAMP (Regional Aquatics Monitoring Program). 2010. 2009 technical report final, including appendices. Regional Aquatics Monitoring Program. Available from: <http://www.ramp-alberta.org/ramp/results/report.aspx> (August 2013)
- Rasmussen, J. B., M. D. Robinson, and D. D. Heath. 2010. Ecological consequences of hybridization between native westslope cutthroat (*Oncorhynchus clarkii lewisi*) and introduced rainbow (*Oncorhynchus mykiss*) trout: effects on life history and habitat use. Canadian Journal of Fisheries and Aquatic Sciences 67:357-370.
- Read, S. 2013. Ranchland surprised with Grassy Mountain Mine sale, annexation plans. Nanton News 11 Jan <http://www.nantonnews.com/2013/01/11/ranchland-surprised-with-grassy-mountain-mine-sale-annexation-plans>.
- Reice, S. R., and M. Wohlenberg. 1993. Monitoring freshwater benthic macroinvertebrate and benthic processes: measures for assessment of ecosystem health. pp. 287-305. in D. M. Rosenberg, and V. H. Resh, editors. Freshwater biomonitoring and benthic macroinvertebrates. Routledge, Chapman & Hall, Inc., New York, NY. .
- Ripley, T., G. Scrimgeour, and M. S. Boyce. 2005. Bull trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed. Canadian Journal of Fisheries and Aquatic Sciences 62:2431-2442.
- Sauchyn, D., and S. Kulshreshtha. 2008. Prairies. pp. 278-328. in D. S. Lemmen, S. J. Warren, J. Lacroix, and E. Bush, editors. From impacts to adaptation: Canada in a changing climate 2007. Government of Canada, Ottawa, Ontario.
- Sawyer, M. D., and D. W. Mayhood. 1998a. Cumulative effects analysis of land-use in the Carbondale River catchment: implications for fish management. pp. 429-444. in M. K. Brewin, and D. M. A. Monita, editors. Forest-fish conference: land management practices affecting aquatic ecosystems. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-356..
- Sawyer, M. D., and D. W. Mayhood. 1998b. Cumulative effects of human activity in the Yellowstone to Yukon. pp. 61-63. in L. Willcox, B. Robinson, and A. Harvey, editors. A sense of place: issues, attitudes and resources in the Yellowstone to Yukon Ecoregion. Yellowstone to Yukon Conservation Initiative, 710 Ninth Street, Studio B, Canmore, Alberta T1W 2V7. .
- Silins, U., K. Bladon, M. Stone, M. Emelko, S. Boon, C. Williams, M. J. Wagner, and J. Howery. 2009. Southern Rockies Watershed Project: Impact of natural disturbance by wildfire on hydrology, water quality, and aquatic ecology of Rocky Mountain watersheds. Alberta Sustainable Resource Development and 3 others, Edmonton, Alberta..
- Silins, U., K. J. Devito, D. W. Schindler, V. St. Louis, S. Quideau, A. Curry, J. Culp, and C. Mendoza. 2005. Southern Rockies Watershed Project annual report - 2004. First year study results. Alberta Sustainable Resource Development and 5 others. Alberta.

SSRAC. no date. Advice to the government for the South Saskatchewan Regional Plan. South Saskatchewan Regional Advisory Committee. ii+65 p. <https://www.landuse.alberta.ca/ResultsResources/Pages/PublicationsandForms.aspx>

Stephanson, A. 2013. New coal mine proposed for Crowsnest Pass. Calgary Herald 8 Jan <http://www.insightwest.ca/news/mining-insight/coal-insight/new-coal-mine-proposed-for-crowsnest-pass/>.

Taylor, E. B. 2013. Changes to the Fisheries Act and what it means for freshwater biodiversity. Discovery May-June (In press).

The Forestry Corp. 2006. FMU C5 Forest Management Plan: Development of the preferred forest management scenario. Appendix 6B to the C5 Forest Management Plan 2006-2026. The Forestry Corp., Edmonton, Alberta.

Valdal, E. J., and M. S. Quinn. 2011. Spatial analysis of forestry related disturbance on westslope cutthroat trout (*Oncorhynchus clarkii lewisi*): implications for policy and management. Applied Spatial Analysis and Policy 4:95-111.

Winberg, G. G. 1956. Metabolism and food requirements of fishes. Fisheries Research Board of Canada Translation Series 194:1-239.

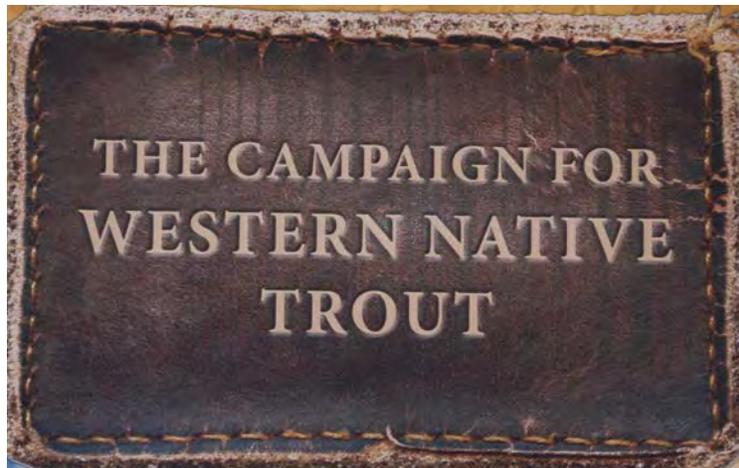


Photo courtesy of Eric Stark.

# Supplement

In 2013, there was a government furlough that closed all National Parks. This session includes papers from authors who intended to speak in 2013, but could not make it in 2014.





# THE *GYRODACTYLUS SALARIS* INVASION IN NORWEGIAN ATLANTIC SALMON RIVERS AND THE ERADICATION STRATEGY: LESSONS LEARNED

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**Abstract**—The monogenean ectoparasite *Gyrodactylus salaris* was unintentionally introduced to Norwegian Atlantic Salmon *Salmo salar* rivers with Baltic Atlantic Salmon in the mid-1970s. While Baltic Salmon have a normal host-parasite relation with *G. salaris*, salmon parr from rivers entering the Atlantic Ocean experience unusually high mortality, and wild stocks are within a few years of infection generally reduced to only 10 - 20 % of normal. This invasive parasite has represented one of the most serious threats to conservation of wild salmon in Norway. In addition, the costs in terms of loss of income from fishing to river owners, netsmen, and local communities have been significant. Norwegian authorities and scientific institutions have during the 40-year history gathered knowledge and experiences on a range of areas. In this presentation, we go through some of the key lessons, with emphasis on treatment strategies and alternatives, and the underlying scholarly debate whether or not the official "eradication strategy" is at all feasible. Extensive use of rotenone in rivers, but also development of parasite-specific treatment by use of acidic aluminum and hypochlorite has led to successes as well as failures. The relevance of these lessons for other challenges related to invasive species is discussed.

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## BACKGROUND

The monogenean ectoparasite *Gyrodactylus salaris*, which is restricted to freshwater, was originally collected from Baltic Salmon at the Hölle laboratory near the river Indalsälven, Sweden in 1952 (Malmberg 1957). It was at this time no suggestion that this species was or could be a pathogen (Harris et al. 2011). The parasite was then unintentionally introduced to Norwegian rivers and Atlantic Salmon *Salmo salar* with Baltic Atlantic Salmon in the mid-1970s. As part of a smolt transfer from Sweden to Norway, the parasite was without any knowledge about its devastating effects, transferred to a Norwegian hatchery near the river Driva. From here, it was subsequently distributed to a number of regulated rivers which were provided with parr and smolt from this hatchery, as well as to other hatcheries. Also, other, mostly nearby rivers were infected by migrating infected fish. Most infected rivers have been infected by fish stocked from an infected hatchery, happening

before the lethal effect of the parasite was known and subsequent migrations of infected fish. However, in a few cases (for instance in the river Beiarn (1981) and in the river Lærdal (1996)), no obvious, documentable source of infection has been identified. Overall, *G. salaris* has been found in 48 wild Atlantic Salmon populations and several Arctic Charr *Salvelinus alpinus* L. populations in Norway, and in approximately 40 hatcheries and fish farms (with Atlantic Salmon and/or Rainbow Trout *Oncorhynchus mykiss*). Among the infected rivers there are highly valuable (from a biological as well from a societal and economic perspective) salmon rivers like the Drammen, Lærdal, Rauma, Driva, Vefsna and Rana.

*Gyrodactylus salaris* has turned out to be the most important pathogen of natural Atlantic Salmon parr populations in fresh water, and is considered one of the most severe threats to sustainable management and long term conservation of Atlantic Salmon in Norway. According to Harris et al. (2011) it has also "rewritten paradigms of wild disease epidemiology" (p. 230).

<sup>1</sup> Atlantic Salmon is generally an anadromous, migratory species, which reproduce and have its juvenile stages in freshwater, before migrating to the sea where it feeds for 1 – 3 years before maturing and returning to its native river. It is naturally distributed around the North Atlantic Ocean from Maine, USA in the southwest to Labrador in northwest, and to northwest Russia in northeast down to the northern coast of Spain and Portugal in southeast. The Baltic Salmon, sometimes considered a subspecies of Atlantic salmon, generally conducts its full lifecycle within the Baltic Sea and rivers draining to this Mediterranean sea between Sweden, Finland, Russia and the Baltic states, Poland, Germany, and Denmark. In this paper we use the term Baltic Salmon for Atlantic Salmon native to the Baltic area, and Atlantic Salmon for salmon native to rivers which drain to, and who migrate to, the North Atlantic Ocean.

While a range of issues regarding the pathogenicity of the parasite is not fully understood, there is agreement that the parasite is a major and severe mortality factor for Norwegian and Russian White Sea populations, it is not for Baltic Salmon, while for Swedish west coast populations (draining to Skagerak and the North Sea) the situation is confusing. There is also general agreement that the reasons for the varying effect are to be found in the interplay between the agent (*G. salaris* genotype), the host (the salmon genotype) and the physiochemical environment in the rivers (Harris et al. 2011).

Efforts to eradicate or to control unwanted and uneconomic species or alien pathogenic organisms in aquatic environments have been relatively common in fisheries management since 1945 (Finlayson 2008). Both regarding pathogens as well as unwanted fish species, the major approach has been to remove (eradicate) fish from a given water body. A range of measures including physical removal (barriers, fishing, explosives), physical alteration (dewatering) and biological control have been used, but most used has been piscicides, especially rotenone (Finlayson 2000). Also in Norway, rotenone was known before the parasite established, but it was mostly used in smaller lakes and ponds to eradicate or reduce the abundance of unwanted fish species. However, use of rotenone was, together with a few fish barriers, the main strategy for removing the parasite. As of today, all previously infected farms and hatcheries are considered free of the parasite. Of the rivers, 20 previously infected rivers are free of the parasite, 14 are treated and are under monitoring awaiting the results of the treatment, while 14 rivers are still infected.

In a time when invasive or nonnative organisms spread at an “alarming rate” (Finlayson 2008) across the globe, the lessons from the Norwegian *Gyrodactylus* program should be of interest also to others. The purpose of this paper is to provide a brief overview of the Norwegian experiences in combating the “Gyro” parasite. This short overview is partly based on a review of scientific papers, and partly on Norwegian evaluations and summary reports. In

addition, the authors provide some comments and reflections.

### Economic Costs and Benefits

Several of the best, most profitable and prestigious Norwegian salmon rivers have been infected and had their fisheries closed down or significantly reduced following the introduction of the parasite. The loss of income in these mostly rural river valleys to river owners and local businesses in tourism and trade is not estimated in full, but will reach NOK 150 - 250 mill (approx. US\$25 mill) per year (2013), capitalized to NOK 3.75 – 6.25 billion (US\$625 – 1,005 mill). In addition to these losses in local economic impacts, nonmarket economic values from reduced recreational fishing and non-use values come in addition and are probably larger.

Norwegian salmon authorities have worked to reduce and ideally eradicate the parasite from Norway, and these efforts have been funded over the budget of the Ministry of Environment and their agency The Norwegian Environmental Directorate, which are responsible for carrying out wild salmon conservation and management. Until year 2003, the annual budget was on average less than NOK 5 mill (US\$1 mill) except for the period 1989 – 1992 when it averaged NOK 10 mill/year. Several unsuccessful treatments and disagreement and protests against treatment plans kept the funding down. Since 2004 the budget for what is now labeled the “*Gyrodactylus* project” has risen significantly, and reached NOK 20 mill in 2004, 50 mill in 2007 and 60 in 2008 – 2010. In 2011 and 2012 the annual budgets have reached nearly 120 and 140 mill, while for 2013 the costs budget are again NOK 60 mill. The high costs of 2011-2012 were related to treatment of the Vefsna region, including three rivers and several larger lakes. Overall, Norwegian salmon authorities have spent NOK 670 mill (US\$110 mill) during the three decades 1982 – 2012 fighting the parasite.

Case specific economic cost benefit estimates indicate overall that the economic benefits clearly are significantly larger than the costs (Mørkved-Rinnan and Krokan 2000; Magnussen 2011), also at the national level (Krokan and Mørkved-Rinnan 1994).

<sup>2</sup> Since the hatchery that originally imported the parasite to Norway was also a research station under the Ministry of Agriculture, and the introduction was unintentional, there has been little debate if the Government should fund the mitigation and conservation measures or if private fishery right holders should fund it. In a few of the rivers, especially on the Lærdal, some private funding has also been donated, from anglers as well as from river owners.

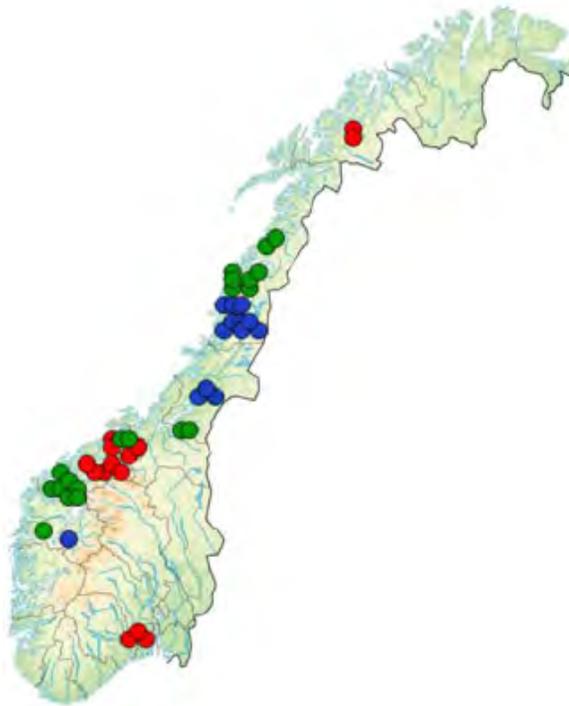
### Public and Political Support?

Public and stakeholder beliefs and opinions, and their support or opposition regarding natural resources management are increasingly becoming an important dimension, influencing on political and economic priorities within natural resource management (Vaske 2008). This has clearly been the case in the Norwegian discourse over how to deal with the “Gyro” parasite (Figure 1). Generally, the issue has not been high on the political agenda at the national level, but local politicians have engaged strongly, as have NGOs. While the Environmental Directorate (Agency) as well as the two major NGOs (the Norwegian Anglers’ Association and the River-owners’ Association) has all stood firmly behind the eradication strategy, and wholeheartedly supported the use of piscicides, environmental NGOs have either been negligent or opposed this strategy. Also the Norwegian Pollution Authority has, especially during the 1990s, been somewhat critical of the treatment strategy.

The major substantial concern in the discourse has been potentially detrimental effects on the environment and biodiversity from treatment with rotenone. Especially, the effect on other aquatic organisms has been discussed, considered, and monitored (Ugedal 1986). Also, pollution from the rotenone solution (including components other than the rotenone itself) has been debated. Especially some radical environmental NGOs have opposed the use of rotenone, without pointing to alternatives other than development of resistance (see below). It is also very clear from the Norwegian experiences that in periods of many unsuccessful treatment efforts, politicians have been less willing to support and fund the treatment plans as proposed from the Directorate.

### Management Lessons from Treatment and Conservation Measures

The lethal effect of *G. salaris* was gradually discovered towards 1980, and Norwegian salmon and



**Figure 1: Salmon rivers in Norway with *Gyrodactylus salaris*. Red dots: Infected rivers. Blue dots: Infected rivers treated with rotenone or acidic aluminum under monitoring awaiting decision. Green dots: Infected, treated and recovered rivers. Source: Directorate of Environment. (Up to date as of January 2014)**

fish disease authorities soon took measures against the parasite. The first rotenone treatment was conducted in 1981 and 1982 (once in the autumn, 1981, repeated in spring 1982) in the rivers Vikja, Sogn and Fjordane. At this time, full-scale treatment of rivers was uncommon and there was little experience with this, but the treatment of Vikja proved to be successful. In hindsight, it was also interesting that until the new strategy established in 2002, this was the only double, full scale treatment. Double treatment is now obligatory (see more below).

Other major efforts that were established included measures and actions to stop and prevent further spreading of the parasite, which in the first years had continued to spread since no one knew of its dramatic effects. In addition, already in 1982, three live gene banks for wild Atlantic Salmon stocks were established and priority was given to secure native stocks from the rivers infected by *G. salaris*. Also, programs to monitor the parasite, inform the public (see Figure 2) and target groups such as anglers, fish farmers and whitewater river rafters and kayakers, and establish stations for disinfection of gear and boats have been part of the multiple measures and actions all aiming to prevent and reduce the negative impacts of the parasite.

To eradicate a parasite from a natural area is known to be a highly challenging task, and there are very few examples of successful eradication programs globally (Finlayson 2008). However, when the devastating effects of the parasite was documented, Norwegian authorities considered the parasite a nonnative, alien species and established a goal to eradicate the parasite from Norway. Despite that the feasibility of this goal over the years has been challenged, from scientific as well as from political and economic perspectives, it has sustained as the main goal for Norwegian salmon authorities. It has sustained over three decades with highly mixed results. It is possible to identify at least three different periods in the use of rotenone in Norwegian salmon rivers. In addition, new chemicals have been identified, with the potential of targeting the parasite specifically.

### Period 1: the 1980s

This period, which followed immediately after the detrimental effects of the parasite became clear, included the first efforts to use rotenone in rivers. The Vikja was the first, probably because it was the only

river in a region with other, highly valuable rivers (such as the Lærdal), and also because the river was not large and the flow was partly controllable since it was regulated. Also, during 1986 – 1990 several rivers in the region of Sunnfjord, mostly smaller rivers (catchment area < 100 km<sup>2</sup>) were successfully treated. However, also medium-sized rivers such as the rivers Vallidal (catchment area 358 km<sup>2</sup> average runoff 24 m<sup>3</sup>/s) and Tafjord (300 km<sup>2</sup>) got rid of the parasite. Unlike the Vikja, all these rivers were treated only once, most often at low water in September or October. These first treatments were done with enthusiasm, and lead by experienced regional fishery managers, and the dose of rotenone seem to have been “sufficient”.

### Period 2: the 1990s

During the 1980s, the distribution of the parasite was cautiously investigated, and already from around 1980 - 1985 in accordance with what we now know. Several larger and highly important rivers were confirmed as infected, including the Vefsna, Rana, Rauma and Driva, yet there were no plans to treat them before the authorities had gained more experience with treating larger rivers. In 1993 and 1994 the first two efforts to treat bigger rivers were conducted. The rivers in Steinkjer (infected probably in 1977, confirmed in 1980), central Norway were located in a region with several of the most important Norwegian rivers such as Gaula, Orkla and Namsen and it was important to reduce the potential for contaminating these nearby rivers. These rivers (including the Steinkjer with a catchment of 2,122 km<sup>2</sup>) was treated with rotenone in 1993; however, the parasite was confirmed again in 1997. The river Beiarn (catchment 1,070 km<sup>2</sup>, salmon bearing over 30 km) in Northern Norway (*G. salaris* documented in 1981) was the second attempt to treat a somewhat bigger river and it was treated with rotenone in 1994. Despite concern that the parasite had survived because a salmon parr with the parasite was found during monitoring in 1996, the parasite was never again found, and the river was declared parasite-free in 2001, and has recovered completely.

Except for the success in river Beiarn, the 1990s was a depressing decade for those worrying over the parasite. In addition to the failure in Steinkjer, the parasite was observed and confirmed in the river Lærdal (maybe the most legendary of all Norwegian salmon rivers, in addition to the Alta) in 1996. This was a shock, also since how the parasite came there

# ADVARSEL! WARNING! ACHTUNG!

## GYRODACTYLUS SALARIS

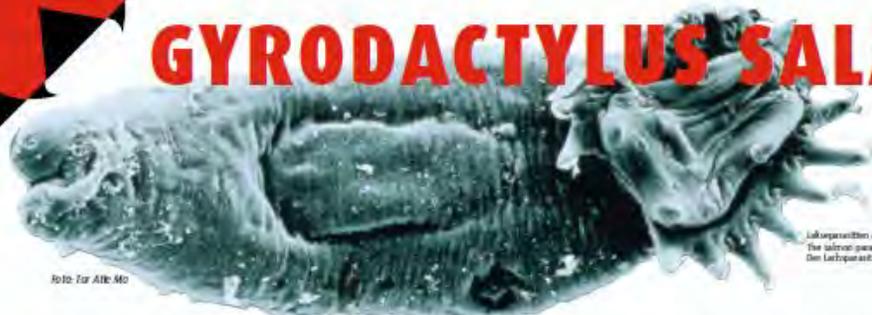


Foto: Tor Arne Mo

Lakseparasitten Gyrodactylus salaris (størrelse = 0,5 mm).  
The salmon parasite Gyrodactylus salaris (size = 0,5 mm).  
Der Lachsparasit Gyrodactylus salaris (Größe = 0,5 mm).

**🇳🇴 VÆR PÅ VAKT! SMITTSOM LAKSEPARASITT**

I Møre og Romsdal finnes lakseparasitten *Gyrodactylus salaris* i elvene Driva, Usma, Litjådal-elva, Batnfjordselva, Rauma, Istra, Hensvassdraget (Isa og Glutra) Innfjordelva og Skorga. I Trøndelag finnes parasitten i Driva, mens forekomsten i Steinkjerelva, Byaelva, Ogna og Figga forhåpentligvis er fjernet ved behandling foretatt i 2001 og 2002. Ingen av disse elvene er friskmeldt og krav om desinfeksjon er opprettholdt.

Parasittene *G. salaris* tar livet av lakseungene. All transport av fisk mellom vassdrag er forbudt. All transport av vann, fisk og utstyr mellom vassdrag fører til stor risiko for smittespredning. Det er påbudt å desinfisere utstyr som har vært brukt i smitta vassdrag.

Hjelp oss å stoppe spredningen av *G. salaris*:

- Ikke vask og sløy fisk andre steder enn på fangststedet.
- Ikke tøm vann i andre vassdrag enn der det ble henta.
- Desinfiser eller tørk fullstendig alt utstyr som har vært i kontakt med vann fra ei elv før det brukes i andre vassdrag. Dette gjelder fottøy, klær, fiskeutstyr, båter, pøhængsmotorene, beholdere med vann osv.

**🇳🇴 WARNING! CONTAGIOUS SALMON PARASITE**

Rivers infected with the salmon parasite *Gyrodactylus salaris* in Møre and Romsdal County include Driva, Usma, Litjådal-elva, Batnfjordelva, Rauma, Istra, Hensvassdraget (Isa & Glutra) Innfjordelva and Skorga. In Trøndelag County the river Driva is infected, whilst infections in Steinkjerelva, Byaelva, Ogna and Figga have hopefully been eradicated through treatments carried out in 2001 and 2002. None of the rivers have been awarded a clean bill of health and disinfection procedures must be maintained.

The parasite *G. salaris* kills salmon juveniles. All transport of fish between waterways is prohibited. All movement of water, fish and equipment between waterways constitutes a real risk of transmission. Disinfection of equipment that has been used in an infected waterway is mandatory by Norwegian law.

Help us stop the spread of *G. salaris*:

- Only wash or gut fish in the place of capture.
- Only pour out water where it was collected.
- Disinfect or dry out completely all equipment that has been in touch with water from a river before use in other waterways. This includes footwear, clothing, fishing gear, boats, engines, water canisters, etc.

**🇩🇪 SEI VORSICHTIG! GEFÄRLICHER LACHSPARASIT**

Der Lachsparasit *Gyrodactylus salaris* kommt in der Region Møre und Romsdal in den Flüssen Driva, Usma, Litjådal-elva, Batnfjordelva, Rauma, Istra, Hensvassdraget (Isa und Glutra) Innfjordelva und Skorga vor. In Trøndelag kommt der Parasit noch in der Driva vor, während er hoffentlich durch die 2001 und 2002 durchgeführten Bekämpfungsmassnahmen aus den Flüssen Steinkjerelva, Byaelva, Ogna und Figga entfernt wurde. Keiner dieser Flüsse hat bisher offiziell den Status „*G. salaris* frei“ erhalten, so dass eine Desinfektionspflicht auch weiterhin bestehen bleibt!

*G. salaris* tötet junge Lachse!  
Es ist verboten Fische von einem Gewässer in ein anderes zu verbringen!  
Jediges Überführen von Wasser oder Fischen von einem Fluss in einen anderen birgt ein hohes Risiko der Krankheitsverbreitung in sich!  
Jeder der Ausrüstung in einem der genannten befallenen Flüsse verwendet hat, ist gesetzlich verpflichtet diese zu desinfizieren!

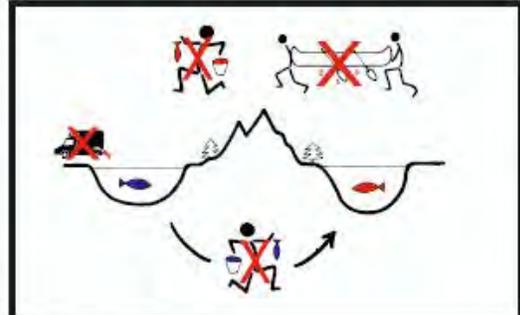
Bitte helfen Sie uns die Verbreitung von *G. salaris* zu verhindern.

- Reinigung und Auswaschen der Fische ausschließlich in den Gewässern wo sie gefangen wurden.
- Entleeren von Wasser ausschließlich in das Gewässer aus dem es ursprünglich stammt.
- Alle Teile der Ausrüstung die Kontakt zu Wasser hatten müssen sorgsam abgetrocknet und desinfiziert werden bevor sie in einem anderen Gewässer benutzt werden können. Bedenken Sie bitte, dass die Ausrüstung auch Stiefel, Kleider, Boot, Außenbordmotor, Trailer usw. umfasst.



Smittet, contaminated, befallen  
Friske, spesielt truede vassdrag, not contaminated, nicht befallen  
Behandlet, under overvåking, Treated, under surveillance, Behandelt, verdächtig.

Utbredelse av *G. salaris* i Midt-Norge.  
The occurrence of *G. salaris* in Mid-Norway.  
Die Ausbreitung von *G. salaris* im Mittel Norwegen.



Unngå transport av vann og fisk mellom vassdrag.  
Prevent transport of water and fish between watercourses.  
Vermeide transport von Wasser und Fischen.

**Fylkesmannens Miljøvernavdeling**

Sør-Trøndelag ☎ 73 19 90 00  
Nord-Trøndelag ☎ 74 16 80 55  
Møre og Romsdal ☎ 71 25 84 43

Mattilsynet (ditt distriktkontor) ☎ 06040



Tilbakemelding til NSD: brukstid 4 77 58 07 27, T-Net: Wiesberg-InDAS 4 77 58 08 00, 08/21/2008

Figure 2. Example of information board about the parasite issued by Norwegian Veterinary Authorities.

has never been clarified (Johnsen et al. 2008). Costly eradication efforts that proved to not be successful was also, in addition to Steinkjer, conducted in the major river Rauma including nearby smaller rivers, western Norway in 1993 and in Skibotn in northern Norway in 1995.

### Period 3: the 2000s until 2014

The last decade has in many ways become a new start for the work to reduce the negative impacts from the parasite, maybe even remove the parasite. There are several reasons for this. The disappointments and critique against the eradication strategy during the 1990s, as well as research progress gradually paved the way for more systematic evaluation and critique of successful as well as unsuccessful treatments. This led to (1) more systematic analysis and evaluation of rotenone treatments (Haukebø et al. 2000; Hjeltnes et al. 2006), including a more thorough look at international practice and guidelines (Johnsen et al. 2008; Finlayson 2008), (2) a closer assessment of the use of, and alternative types of fish barriers in the campaign against “gyro” (Thorstad et al. 2001), and (3) the discovery of alternative chemicals to rotenone, especially acidic aluminum, a parasite specific chemical (see more below), not only provided a highly interesting alternative to rotenone in itself but also most likely sparked increased political support and better funding for fighting the parasite in general.

An expert group concluded in 2008 (Johnsen et al. 2008) and provided recommendations for future treatments with rotenone as well as with acidic aluminum. The group highlighted five partly related constraining factors that might cause unsuccessful treatments aiming to eradicate the host and/or the parasite:

- Poor planning
- Insufficient mapping
- Insufficient treatment
- Lack of sufficient situational/local knowledge
- Challenges related to the size and complexity of the watercourse

In addition, the group pointed to that, generally, the rotenone concentration used during the 1990s was lower than during the 1980s, because of stricter regulations from the Pollution Authorities. While not being conclusive, they did not rule out that this fact

can have contributed to some of the unsuccessful treatments (Johnsen et al. 2008, p. 100-101). However, the main challenges related to the five bullet points above seem to be related especially to (1) difficult hydrological areas where groundwater influx can create refuges for fish during chemical treatment and (2) to uncertainty about which hosts are present where, especially regarding Arctic Charr and Rainbow Trout, two of the important host species for *G. salaris* in addition to Atlantic Salmon.

In 2003 – 2004 the Rana region in northern Norway (consisting of the Rana river and several nearby rivers) was treated with rotenone. This was so far the largest and most complex system treated. The Rana river has a watershed of 3,790 km<sup>2</sup> and an annual average runoff of 195 m<sup>3</sup>/s. Originally, the river held salmon in a reach longer than 60 km, but a fish ladder was closed in 1985, making treatment necessary over 13 km in the main river. Despite this, treatment was conducted before the recent guidelines which demand two full treatments, the system was treated several times. In autumn 2003 and spring 2004, different parts were treated with rotenone with the aim to reduce the occurrence of hosts. Then, in a well-planned and coordinated action during August, 2004, all infected rivers were treated with the goal of eradicating all hosts. This ambitious effort turned out to be successful and in 2009 the Veterinary authorities declared the region free of the parasite. Since then, the important but challenging Steinkjer (2008 and 2009), Lærdal (2011 and 2012) and the Vefsn regions (2009 – 2012) have been treated, following the new guidelines based on several, consecutive treatments. The Steinkjer will likely be declared free of the parasite in 2014, while we must wait longer in the other two. Ambitious plans are underway for the establishment of a costly fish barrier in the Driva, and to treat the Rauma again with rotenone in 2014.

Overall, it is now possible to assess more than 30 rivers that have been subject to treatment with rotenone aiming to eradicate the pathogenic parasite (Table 1). Summarizing the experiences clearly show that the success so far has been much larger in smaller (< 100 km<sup>2</sup> watershed) and medium-sized (100 – 500 km<sup>2</sup>) rivers than in larger (> 500 km<sup>2</sup>) rivers. In the larger rivers, three (Beiarn, Rana and Røssåga) of nine efforts have so far proven successful.

## Scientific Progress and Challenges

### The Discovery of New, Parasite-Specific Chemicals

The major alternative to rotenone treatment has been construction of migration barriers. Although a physical rather than chemical approach, the principal is the same as for rotenone: removing the parasite being a secondary effect of removing the host. Both rotenone and migration-barriers are controversial alternatives; rotenone due to its lack of specificity (killing most gill-breeding organisms) and migration barriers due to the long time span over which salmon will be absent from the river. Alternative chemicals have been sought with a therapeutic margin (parasite sensitivity to the chemical versus host sensitivity to the chemical) aiming at removing the parasite without harming the host. From research on acid precipitation and Atlantic Salmon, it was discovered that *G. salaris* has a lower tolerance for acidic aluminum-enriched solutions than Atlantic Salmon (Soleng et al. 1999). In 2001, a process was therefore initiated aiming to develop a new treatment method with acidic aluminum as the main remedy (rotenone still being used in peripheral standing or slow-running water), formally named “The combination method”. After 10 years of development and a few failed attempts to eradicate *G. salaris* from whole river-systems, the method is today under evaluation after a double treatment of the River Lærdalselva in 2011 and 2012. Provided successful treatment, the river is expected to be declared free from the parasite in the autumn 2017.

Another chemical with an apparent promising therapeutic margin is hypochlorite (Hagen, Hytterød and Olstad in prep.). Being a highly potential chemical, the logistics (including the costs) during

treatment using hypochlorite would be significantly reduced compared to acidic aluminum. However, this chemical has only recently been addressed in research aiming to develop alternative treatments against *G. salaris*. More tests and a more thorough evaluation of potential unwanted effects will be required before considering it in full-scale treatment.

### Taxonomic and Pathogenic Challenges: In the Middle of a Speciation Process?

*Gyrodactylus* is one of several hyperdiverse monogenean genera. *Gyrodactylus salaris* belongs to a group consisting of what is being regarded as several different rapidly evolving species, although the systematics and taxonomy among species and strains has not been fully resolved. With the exception of the pathogenic *G. salaris*, most of the other species and strains in the group are benign. However, also within *G. salaris* benign strains have been described. In Norway, one such nonpathogenic strain has been found parasitizing Arctic Charr in a number of lakes upstream of natural salmon migration barriers in the River Numedalslågen (Olstad et al. 2007; Robertsen et al. 2007). Despite extensive research on the *G. salaris* – Atlantic Salmon parasite – host relationship over the past 30 years, mechanisms of pathogenicity and resistance are not yet fully understood (For a thorough scientific review on the biology of *G. salaris*, see e.g. Bakke et al. 2007). Consequently, the evolution of these traits in this otherwise rapidly evolving group poses some important questions for further focus. A key aspect in a management context is the apparent ease with which species and strains closely related to *G. salaris* undergo host switching with subsequent reproduction. Frequent host switches could ultimately be an avenue for a significant

**Table 1. Overview over all rotenone treatments aiming at eradicating the parasite *Gyrodactylus salaris* in Norway and whether they have been successful or not. (adapted and updated per January 2014 from Johnsen et al. 2008).**

	Size of watershed	Number of treatments possible to evaluate	Number of successful treatments	Number of unsuccessful or undecided treatments	% Successful
Small	< 100 km <sup>2</sup>	14	12	2	86 %
Medium size	100 – 500 km <sup>2</sup>	11	9	2	82 %
Large	> 500 km <sup>2</sup>	9	3	6	33 %
<b>Sum</b>		<b>34</b>	<b>24</b>	<b>10</b>	<b>71 %</b>

expansion of the geographical range of pathogenic variants of *G. salaris*. Of paramount importance in this matter is that the identification of *G. salaris* based on any presently used molecular markers, because morphology alone is not sufficient for a diagnosis of the disease gyrodactylosis. Such diagnosis would therefore require experimental infections with the particular *G. salaris* strain on the relevant population of Atlantic Salmon, and with good control of the water quality. The EU (and Norwegian) legislation and the World Organisation for Animal Health (OIE) Manual of Diagnostic Tests for Aquatic Animals do not differ between pathogenic and nonpathogenic strains of *G. salaris*. According to the legislation, strict regulations apply when moving fish from an area with infections to an area that is declared free from infection. However, there are no such restrictions when moving fish from an area with a pathogenic strain of *G. salaris* to an area in which only a nonpathogenic strain is found. The lack of differentiation between strains thus poses a paradox in that it fails to protect areas that for practical reasons do not hold infections with a pathogen from introduction of the true salmon killer.

### **Eradication Versus Adaption and Resistance**

A growing number of researchers have pointed out the fact that variation in resistance, like in Baltic Salmon, also can be found in populations of Atlantic Salmon. In later years, the heritability of resistance in Atlantic Salmon towards *G. salaris* has been confirmed experimentally (Salte et al. 2010). Accordingly, a range of alternatives related to development of resistance has been forwarded; from leaving the systems untouched to large-scale breeding programs. As stated previously, for Norwegian authorities the main strategy during the three decades has been to remove and ideally eradicate the alien parasite from Norway. The authorities, NGOs, and scholars have pointed to the characteristic population structure of Atlantic Salmon where each population is genetically distinct. In such a perspective, systematic large scale breeding programs to enhance resistance can corrupt overall conservation of Atlantic Salmon. Development of resistance would be a disease control measure as it would improve the genetic capacity to survive the infection but not eradicate the parasite.

Such a strategy might therefore increase disease exposure and likely gradually spread the parasite across Norway.

Alternative strategies to the established eradication goal are to a large degree rooted in the challenges in the infected Drammen region, southern Norway. This region, while distant from other infected regions, is nearby one of the most productive salmon rivers in Norway, the river Numedal. The Drammen is one of the most water-rich rivers in Norway, and it empties into a large brackish fjord. Chemical treatment of this system has been considered unrealistic, and instead a significant fishery is upheld by a major cultivation program, which stock salmon parr above the infected sections of the river. The social and economic values this fishery represent, combined with the likelihood that removing the parasite will be a huge challenge remains unsolved and represents a special challenge in the Norwegian *Gyrodactylus* project.

## **CONCLUSION: LESSONS LEARNED AND IMPLICATIONS**

The spreading of *G. salaris* in Norway has slowed down since the parasite has not been detected in new, previously uninfected regions since it was discovered in the river Lærdal in 1996. However, while we also see promising results in eradicating the parasite in recent treatments, the parasite is still considered one of the most severe threats against conservation of wild Atlantic Salmon in Norway (Vitenskapsradet 2013), as well as a major barrier for sustainable salmon angling in several rural districts in Norway. Nevertheless, the lessons and experiences in Norway should also be of interest to a wider audience concerned about the challenges of “alien” versus native aquatic species.

Overall and in hindsight, the major lessons of the fight against the “gyro” parasite in Norway are in our opinion

1. The emphasis and benefits of paralleling active treatment and long-term conservation measures, especially the gene bank,
2. The need to carefully plan, conduct, and monitor every treatment, using the best available guidelines and literature,
3. In hindsight, it is highly likely that earlier and more active use of fish barriers could have reduced the challenge that the parasite currently represents,

4. Research has played a major role in understanding infection, pathogenicity, and spreading of the parasite and in improving and adding to the mitigations available, and
5. Having several groups of managers, scientists, and institutions, with differing tasks and views on the parasite have been a strength and not a constraint. The multiple groups and institutions involved might have felt unnecessary and maybe as a burden for the agency responsible for the treatment, yet it has definitely contributed to an open and transparent debate about alternatives, have triggered good science and the development of new treatment measures.

## REFERENCES

- Bakke, T. A., J. Cable, and P. D. Harris. 2007. The biology of gyrodactylid monogeneans: The "Russian-doll killers". *Advances in Parasitology* 64:161–376.
- Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, C. W. Thompson, and G. J. Tichacek. 2000. Rotenone use in fisheries management: Administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.
- Finlayson, B. 2008. Alternatives for Fish Removal to Protect Atlantic Salmon *Salmo salar* from Monogenean Parasite *Gyrodactylus salaris*. Paper to the Norwegian Directorate for Nature Management.
- Hagen, A. J., S. Hytterød, and K. Olstad. Therapeutic margin in treatment against the Atlantic salmon (*Salmo salar* L.) killer *Gyrodactylus salaris* (Malmberg, 1957) using low concentrations of sodium hypochlorite. (in preparation).
- Harris, P. D., L. Bachmann, and T. A. Bakke. 2011. The parasites and pathogens of the Atlantic salmon: Lessons from the *Gyrodactylus salaris*. P. 221-252 in Aas, Ø., S. Einum, A. Klemetsen, and J. Skurdal (eds). *Atlantic Salmon Ecology*. Oxford: Blackwell-Wiley.
- Haukebø, T., O. Eide, B. Skjelstad, G. Bakkeli, K. Tønset, and J. H. Stensli. 2000. Rotenonbehandling som tiltak mot lakseparasitten *Gyrodactylus salaris*. En gjennomgang av metodikk, utstyr og rutiner med forslag til forbedringer. (*Rotenone treatment as measure against the parasite G. salaris. Evaluation of methods, equipment, routines and standards*). - Utredning for DN, nr. 2000 - 2: 1 - 80.
- Hjeltnes, B., T. A. Mo, P. A. Jansen, Å. Brabrand, B. O. Johnsen, J. H. Stensli, and T. A. Bakke. 2006. Ny påvisning av *Gyrodactylus salaris* i Steinkjervassdraget og Figgja i 2005: Mulige årsaker. (*G. salaris redetected in the river Steinkjer and river Figgja: Possible explanations*).- Veterinærinstituttet, rapport 2006: 1 - 22
- Johnsen, B.O., Å. Brabrand, P. A. Jansen, H-C. Teien, and G. Bremset. 2008. Evaluering av bekjempelsesmetoder for *Gyrodactylus salaris*. Rapport fra ekspertgruppe. (Evaluation of treatment against the parasite *G. salaris*. Report from expert group.) Utredning for DN 2008-7.
- Krokan, P.S. and O.J. Mørkved. 1994. Nytt-kostnadsanalyse av innsatsen for å bekjempe lakseparasitten *Gyrodactylus salaris* i perioden 1981-1998. Utredning for DN 1994-4.
- Magnussen, K. 2011. Samfunns- og lokaløkonomiske virkninger av fiskesperre og kjemisk behandling i Driva. (Economic cost-benefit analysis and local economic impacts of establishing a fish barrier and treating the Driva river with rotenone.) SWECO Report (in Norwegian).
- Malmberg, G. 1957. On the occurrence of *Gyrodactylus salaris* on Swedish fishes. Skrifter utgivna av Södra Sveriges Fiskeriförening. Årsskrift 1956, 19-76.
- Mørkved, O. J., and P.S. Krokan. 2000. Nytt-kostnadsanalyse av prosjektet rotenonbehandling av Steinkjervassdragene. (Cost-benefit analysis of rotenone-treatment of the Steinkjer watersheds). Utredning for DN 2000 – 3. Direktoratet for naturforvaltning.
- Olstad, K., G. Robertsen, L. Bachmann, and T. A. Bakke. 2007. Variation in host preference within *Gyrodactylus salaris* (Monogenea): an experimental approach. *Parasitology* 134:589–597.
- Robertsen, G., K. Olstad, L. Plaisance, L. Bachmann, and T. A. Bakke. 2008. *Gyrodactylus salaris* (Monogenea, Gyrodactylidae) infections on resident Arctic charr (*Salvelinus alpinus*) in southern Norway. *Environmental Biology of Fishes* 83, 99–105.
- Salte, R., H. B. Bentsen, T. Moen, S. Tripathy, T. A. Bakke, J. Ødegard, S. Omholt, and L. P. Hansen. 2010. Prospects for a genetic management strategy to control *Gyrodactylus salaris* infection in wild Atlantic salmon (*Salmo salar*) stocks. *Canadian Journal of Fisheries and Aquatic Sciences* 67:121–129.
- Soleng, A., A. B. S. Polø, N. E. W. Alstad, and T. A. Bakke. 1999. Aqueous aluminum eliminates *Gyrodactylus salaris* (Platyhelminthes, Monogenea) infections in Atlantic salmon. *Parasitology* 119, 19-25.
- Thorstad, E.B., B. O. Johnsen, T. Forseth, K. Alfredsen, O. K. Berg, G. Bremset, G., H-P. Fjeldstad, R. Grande, E. Lund, K. O. Myhre, and O. Ugedal. 2001. Fiskesperre som supplement eller alternativ til kjemisk behandling i vassdrag infisert med *Gyrodactylus salaris*. (*Fish barriers as supplement or alternative to chemical treatment in rivers infected with G. salaris*). - DN - utredning 2001-9: 1 - 66.

Ugedal, O. 1986. Litteraturstudie av rotenons virkning i ferskvannøkosystemer. (*Literature review of the effects of rotenone on aquatic fauna*). – Direktoratet for naturforvaltning, reguleringsundersøkelsene. Rapport 14 – 1986: 1 – 52.

Vitenskapsradet. 2013. Status for norske laksebestander 2013. Hovedrapport. (*Status for Norwegian salmon populations 2013*). Trondheim: Vitenskapsradet.

## USING COLLABORATIVE RESEARCH TO IMPROVE CONSERVATION AND RESTORATION PRACTICES OF NATIVE BROWN TROUT: A TWENTY-YEAR HISTORY IN HAUTE-SAVOIE AREA, FRANCE

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**Abstract**—Conservation processes need better working relationships between researchers and managers, and multidisciplinary approaches to carry out effective actions. This need for local efficient operations is particularly acute in the context of the generally limited funding available for conservation and restoration. We report an applied experience of a collaborative research involving fishery managers and scientists from different disciplines (ecology, fishery biology and genetics) in order to conserve the native Brown Trout *Salmo trutta*. This species is the most common native salmonid in Europe. It has a high level of intraspecific diversity that is threatened by human activities, and it is also of considerable economic value. In particular, native Brown Trout populations are strongly threatened by nonnative strains introduced by stocking for more than one century. This process developed in the Haute-Savoie area (4,500 km<sup>2</sup>) in Northern French Alps was implemented progressively from small to large scale since 1994 and includes several pivotal tasks: the assessment of the contributions of traditional stocking using nonnative Brown Trout (1994-2006), the assessment of the first conservation strategies (1999-2006), the definition of the conservation units according to the genetic structure and the prioritization of the conservation efforts (2002-2006). All the scientific information collected has been used to implement effective conservation planning (since 2005) involving scientists and practitioners. This formal structure enabled the development of closer working relationships between researchers and managers, the reciprocal exchange of information, delivery of scientific findings more closely applied to management and, finally, the implementation of more effective conservation measures. The two ongoing tasks attempt to develop together demographic and genetic modelling and temperature modelling approaches to better take into account the evolutionary biology and the climate change effects in the future conservation strategies.

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### BACKGROUND ABOUT FISHERIES MANAGEMENT AND NATIVE BROWN TROUT CONSERVATION IN HAUTE-SAVOIE AREA

The Haute-Savoie hydrographic network encompasses around 2,800 km of rivers, streams, and mountain creeks in an area of 4,400 km<sup>2</sup>. For the end of the 19th century, resource managers stock massively all the streams with nonnative Brown Trout in order to develop recreational fisheries. Research by scientists on Brown Trout populations started in 1980. Initially, fishery scientists developed their own research projects without working relationships with managers.

After the discovery of the first native population in 1985 (Guyomard 1989) and during 1990s, research on Brown Trout conservation increased with some direct interaction between scientists and managers. Progressively, the working relationship between stakeholders increased, and research and management were integrated more closely in collaborative research for the benefit of both parties (Figure 1). In 1990s, the first collaboration was limited in time and space to study punctually some case studies on Brown Trout conservation and restoration. Since 2000, working scales changed to provide findings at more relevant spatial and temporal scales upon which to build conservation plans. Scientists and

managers implemented common research programs merging both science and management key questions and working together. These collaborative projects established a joint scientist position shared among different institutions to develop lasting and dynamic collaborations and close working relationships. This position facilitated the collaboration among stakeholders throughout the research process and the integration of scientific findings into the decision-making procedures of conservation planning. During these twenty years of collaboration, five pivotal tasks were implemented and provided important applied outcomes, which were integrated into conservation practices (Figure 1).

## TASK 1: LOCATION AND STATUS OF NATIVE POPULATIONS

### Goal

In 2000, there was a severe shortage of scientific knowledge about the genetic and demographic status of the wild Brown Trout populations in the area, and this hindered the ability of local managers to plan efficient conservation and restoration programs. This task aimed to locate the remaining nearly-pure native populations, to define the genetic units (i.e. management units), and to determine the level of threat to the native populations.

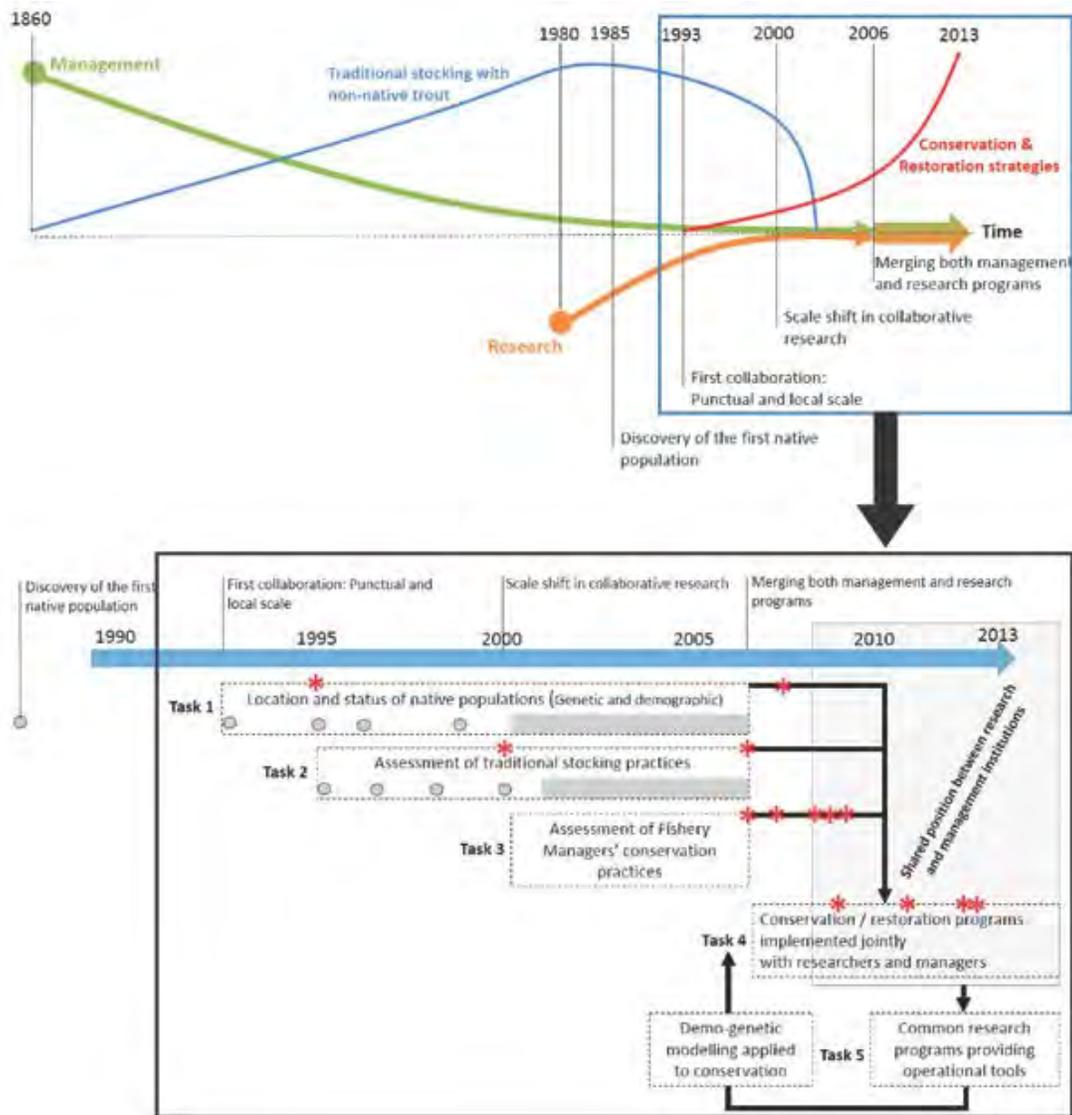


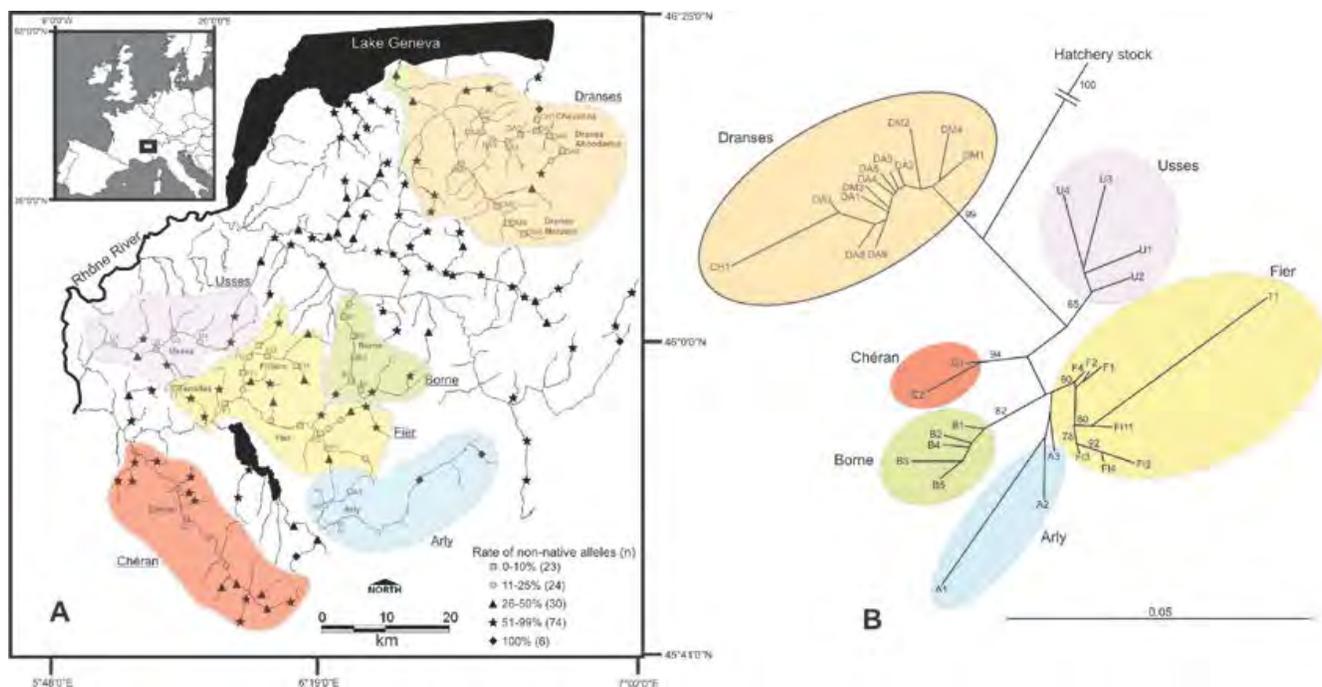
Figure 1. Timeline of the fisheries management and of the native Brown Trout conservation with the different tasks progressively implemented. \*Indicates the scientific papers published.

## Methods

Between 2000 and 2004, 6,590 Brown Trout were sampled in a total of 157 sectors. For each individual, a fin clip, scales, and the total length (measured to the nearest mm) were collected. The age of each individual was determined by scale analysis. A subsample of 1,800 adult trout ( $\geq 2+$ ) were genotyped using two microsatellite markers, Str541 and Str591, which have been shown to be diagnostic between both nonnative Atlantic and native Mediterranean strains (Estoup et al. 1999, 2000). We took the arbitrary choice of considering the populations with less than 25% of nonnative Atlantic alleles as native with a conservation interest. Then, in the conservation interest areas identified, additional genotyping was carried out with seven microsatellite loci. The genetic structure of the Mediterranean native populations and the Conservation Units were identified by using (i)  $F_{ST}$  values pair-wise, (ii) genetic distance between native populations, (iii) a Bayesian method carried out by the program STRUCTURE version 2.1 (Pritchard et al. 2000), and (iv) analysis of molecular variance (AMOVA, Excoffier et al. 1992).

## Main Findings and Management Implications

We identified the existence of extensive admixtures between native Mediterranean and nonnative Atlantic Brown Trout as a result of stocking. Indeed, in most of the area studied (70% of the 157 samples), the Atlantic allele rate was  $> 25\%$ . Six samples, all isolated and located in an upstream stretch of river, contained 100% Atlantic alleles (Figure 2). Only, 47 samples displayed a rate of native Mediterranean alleles higher than 75%, with less than 10% of Atlantic alleles in 23 of them. The findings confirmed the presence of two previously identified native populations: Chevenne (Guyomard 1989), Dranse d'Abondance (Largiadèr et al. 1996), and allowed us to discover eight new native populations (Dranse Morzine, Borne, Usses, Tenalles, Fillière, Fier, Chéran and Arly) with low admixture rates within six hydrographic catchment areas (of the Dranses, Borne, Fier, Usses, Chéran and Arly) (Figure 2). The sampling network allowed us to find the limits of the colonization of each native population, and to know their distribution at the microgeographical



**Figure 2.** Spatial distribution of the nonnative Atlantic allele and location of the six hydrographic catchments identified as Conservation Units (A) according to the genetic structure analyses displayed by the unrooted neighbor-joining tree, based on Cavalli-Sforza (1967) chord distance (B). Numbers at branch forks indicate bootstrap support.

scale in a large area. The analysis of genetic structure revealed seven groups, one corresponding to the Atlantic hatchery stock, and another six distinct groups with a Mediterranean origin corresponding to the hydrographic catchment of the area studied. This analysis grouped the sectors of the same basin in the same cluster. The AMOVA revealed highly significant genetic differentiation among the six groups corresponding to the hydrological catchments ( $F_{CT} = 0.16$ ,  $p < 0.0001$ ).

According to these results, scientist and managers decided to distinguish six genetically divergent Conservation Units. As a first conservation measure in these management units, they decided to stop the stocking with nonnative strains.

## TASK 2: ASSESSMENT OF TRADITIONAL STOCKING PRACTICES

### Goal

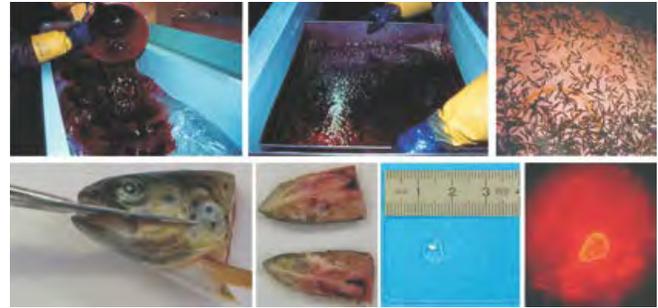
The objective of this task was to provide a full-scale assessment of the real contribution of traditional stocking practiced by fishery managers for more than a century to angler harvest of Brown Trout.

### Methods

For three consecutive years, in 2002, 2003, and 2004, all the trout alevins released, about 3 million annually, were marked by otolith fluoro-marking with alizarin red S (ARS) following the protocol described by Caudron and Champigneulle (2006) (Figure 3).

The contributions of stocking were investigated in standing populations at stage 0+ was studied by sampling a total of 5,187 0+ trout in 115 different stretches of rivers during the three years of the follow-up period. Each individual sample was sacrificed by an overdose of anesthetic (clove oil) and kept in the freezer. The age of each individual was estimated using scale analysis. Second, the contribution of the stocked fish to the anglers' catches was performed from 2004 and for three consecutive years, i.e. until 2006. To do this, volunteer anglers recorded data (date, exact position, size), and collected specimens (scales and heads) on a total of 2,700 trout.

For each individual the otoliths were removed, stuck to a glass slide, and examined under an epifluorescence microscope (Zeiss Axioskop 40) fitted with a mercury vapor lamp (HBO50) and an Alizarin filter (Zeiss n°15: BP546/12, FT 580, LP 590) (Figure 3).



**Figure 3.** Pictures showing fluoro-marking process with alizarin red S (above), the head dissection, an otolith bonded on a glass slide, and a view of a marked otolith under epifluorescence microscopy (below).

## Main Findings and Management Implications

The mean contributions of stocking are 40% and 33% at age-0 stage and in anglers' catches, respectively. However, the distribution of the contribution of stocking at age-0 stage can vary widely, ranging from 0 to 100%, just a few months after their release into the natural environment, but most of the sectors surveyed (60%) show a majority contribution of the natural recruitment.

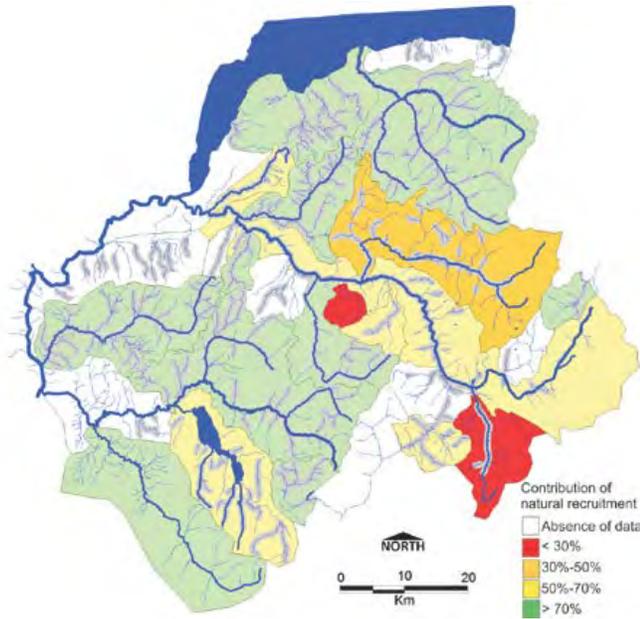
Finally, the spatial distribution of the contribution in the entire Haute-Savoie hydrographic network revealed a high contribution of the natural recruitment in most of the catchment (Figure 4).

According to these results and the results of the task 1, the traditional stocking practices have been reduced by fishery managers and progressively replaced by different actions for conserving and restoring native Brown Trout populations.

## TASK 3: ASSESSMENT OF CONSERVATION PRACTICES CARRIED OUT BY FISHERY MANAGERS

### Goal

Since 2000, fishery managers changed progressively their traditional practices, and then they implemented locally different actions in order to conserve persistent native Brown Trout populations or to restore new native populations. The goal of this task is to provide an objective assessment of the efficiency of these actions by a temporal genetic analysis.



**Figure 4. Spatial contribution of natural recruitment by catchment in the Haute-Savoie hydrographic network. The highlighting in grey indicates the parts of river stocked.**

## Methods

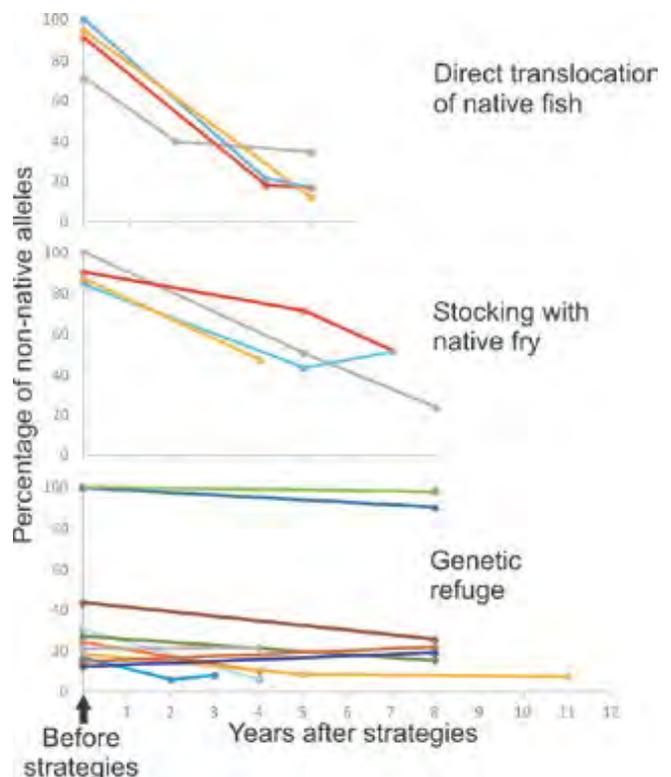
Between 2000 and 2006, three main conservation/restoration strategies have been assessed on 19 sectors of rivers: (i) genetic refuge area where stocking are banned, (ii) stocking with native fry, and (iii) direct translocation of wild native spawners. For each sector, individuals were sampled before and after the establishment of the conservation/restoration strategies and genetically analyzed with the same microsatellite markers and methods used in the task 1. The data analyses were focused to detect potential genetic effects (rate of hatchery introgression, proportion of individual genotype, deviation from Hardy-Wienberg equilibrium or linkage disequilibrium) of these strategies on the standing populations.

## Main Findings and Management Implications

The results showed that the three strategies had several detectable effects on the standing populations. They caused fast and significant decreases of the percentage of nonnative alleles in the wild population (Figure 5).

These decreases can be mostly explained by the disappearance of the pure nonnative trout after stopping the stocking with nonnative domesticated trout (Figure 6). Indeed, after this direct initial effect linked to the stopping of hatchery releases, the percentage of nonnative alleles remained stable over the monitored time.

The direct translocation of native spawners and the stocking with native fry resulted in significant increases of the native alleles in the wild population and in the establishment of a self-sustaining population. However, the results indicate that no strategy had been fully successful in restoring a nearly pure native population over the monitored time, except where no fish were present before implementing the strategies. This suggests that the restoration strategies appeared to be able to establish a new self-sustaining native population when there are no self-sustained nonnative populations inhabiting the stretch of river concerned.



**Figure 5. Evolution of the percentage of nonnative alleles in the standing population for the three strategies implemented.**

An important finding is that in all three situations monitored, the proportion of hybrid individuals between both nonnative and native trout increased showing that the introgression of the native gene pool by nonnative gene continued (Figure 6). The active strategies carried out by managers led to intraspecific introgression between both nonnative and native strains. The hybrid status of population is a common issue for the conservation programs of native salmonids (Allendorf et al. 2001 and 2004; Largiadèr 2007), and managers are confronted with the question, what is an acceptable level of introgression. Clearly, the knowledge is insufficient to assist managers in their decisions, and many additional studies are needed to monitor at long-term the efficiency of the programs for the genetic conservation and restoration of freshwater autochthonous trout populations.

### TASK 4: CONSERVATION/RESTORATION PROGRAMS AND LONG-TERM MONITORING

According to the results obtained in task 3, long-term monitoring of conservation and restoration plans are needed to improve the effectiveness of conservation actions. With this goal in mind,

collaborative research that merges both scientific and management interests was implemented on two catchments: the Chevenne Creek and the Borne River (for details see Caudron and Champigneulle 2011 and Caudron et al. 2012). The outcomes of the three first tasks were progressively used to build evidence-based programs of conservation where different strategies are implemented and assessed together by scientists and managers. The monitoring started in 1995 for the Chevenne and in 2005 for the Borne.

### TASK 5: DEVELOPING COMMON RESEARCH PROGRAMS TO PROVIDE OPERATIONAL TOOLS

Now, scientists and fishery managers are working in tight collaboration by co-supervising a PhD project in order to develop a demographic and genetic model applied to conservation issue of native salmonids. This demographic and genetic model takes into account ecological and evolutionary dynamics investigated by scientists and the needs and practices of managers. This tool will be used to simulate the demographic and genetic effects of conservation strategies on wild populations to help managers in their decision-making for implementing more effective actions (Figure 7).

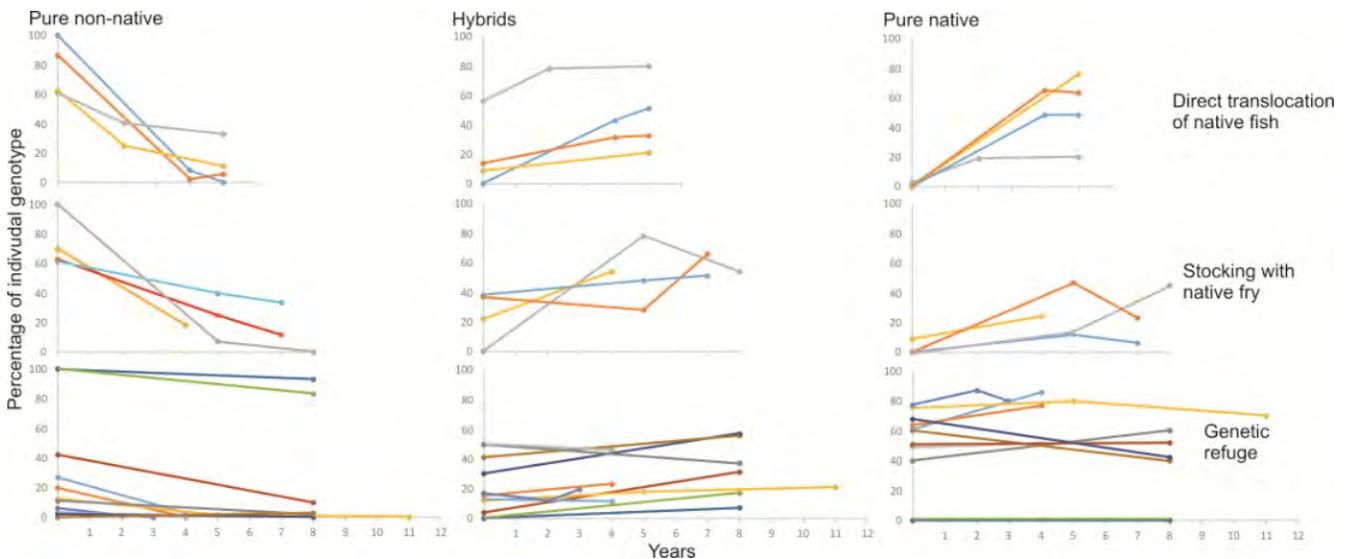


Figure 6. Evolution of the three individual genotypes (pure nonnative, hybrids, and native) in the standing population for the three strategies implemented.

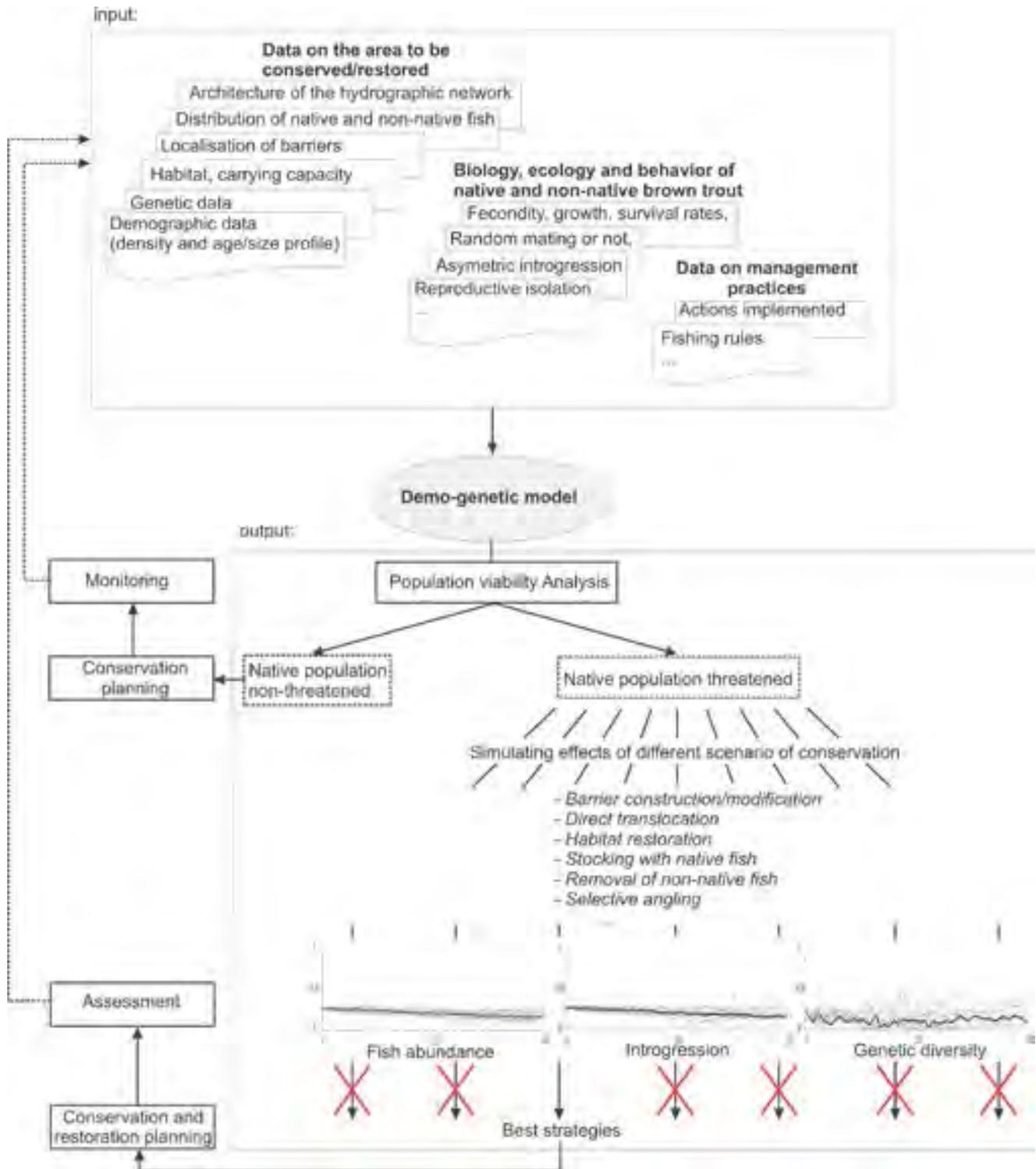


Figure 7. Flow diagram showing the principle of the demographic and genetic model developed to improve conservation strategies in practice.

## REFERENCES

- Allendorf, F.W., Leary, R.F., Spruell, P., and J.K. Wenburg. 2001. The problems with hybrids: setting conservation guidelines. *Trends in Ecology and Evolution* 16: 613-622.
- Caudron, A., and A. Champigneulle. 2006. Large-scale otolith fluoromarking of sac fry of brown trout (*Salmo trutta*) with alizarin red S. *Cybiurn* 30: 65-72 (In French).
- Caudron, A., Champigneulle, A., Vigier, L., Hamelet, V. and R. Guyomard. 2012. Early effects of the strategies of creating a genetic refuge and direct translocation for conserving and restoring populations of native brown trout. *Freshwater Biology* 57: 1702-1715.
- Caudron, A., and A. Champigneulle. 2011. Multiple electrofishing as a mitigate tool for removing nonnative Atlantic Brown trout (*Salmo trutta* L.) threatening a native Mediterranean brown trout. *European Journal of Wildlife Research* 57: 575-583.
- Cavalli-Sforza, L.L., and A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. *Evolution* 32:550-570.
- Estoup, A., Cornuet, J.M., Rousset, F. and R. Guyomard. 1999. Juxtaposed microsatellite systems as diagnostic markers for admixture: theoretical aspects. *Molecular Biology and Evolution* 16: 898-908.
- Estoup, A., Largiadèr, C.R., Cornuet, J.M., Gharbi, K., Presa, P. and R. Guyomard. 2000. Juxtaposed microsatellite systems as diagnostic markers for admixture: an empirical evaluation with brown trout (*Salmo trutta*) as model organism. *Molecular Ecology* 9: 1873-1886.
- Excoffier, L., Smouse, P., and J. Quattro. 1992. Analysis of molecular variance inferred from metric distances among DNA haplotypes: application to human mitochondrial DNA restriction data. *Genetics* 131:479-491.
- Guyomard, R. 1989. Diversité génétique de la truite commune. *Bulletin Français de Pêche et de Pisciculture* 314: 118-135.
- Largiadèr, C.R. 2007. Hybridization and introgression between native and alien species. Pages 275-292 in W. Nentwig editor. *Biological Invasions*. Springer, Berlin.
- Largiadèr, C.R., Scholl, A., and R. Guyomard. 1996. The role of natural and artificial propagation on the genetic diversity of brown trout (*Salmo trutta*) of the upper Rhône drainage. Pages 181-197 in A. Kirch-Hofer and D. Hefti, D. editors. *Conservation of endangered freshwater fish in Europe*. Birkhauser, Basel.
- Pritchard, J. K., Stephens, M. and P. Donnelly. 2000. Inference of population structure using multilocus genotype data. *Genetics* 155: 945-959.

## WHISTLERS OF THE WILD WEST: ASSESSING WYOMING'S MOUNTAIN WHITEFISH POPULATIONS.

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**Abstract**—Mountain Whitefish *Prosopium williamsoni* are a prominent salmonid of streams in the Rocky Mountains and native to all drainages west of the Continental Divide in Wyoming, as well as several east of the Divide. Adult whitefish feed primarily on invertebrates. They inhabit open channel habitats of cool to cold main-stem rivers and spawn in the fall. The sport-fishing popularity of whitefish is eclipsed by trout, which has afforded whitefish little attention from fish managers. Population declines in nearby states and some Wyoming waters, coupled with a scarcity of data, motivated the Wyoming Game and Fish Department to investigate sampling techniques, gather baseline population data, and assess the status of whitefish starting in 2009. Major main-stem streams were sampled with raft electrofishers, aiming to complete mark-recapture population estimates where possible. Post-sampling mortality was investigated for its potential to influence population estimate quality by collecting fish below sampling reaches ( $n \leq 40$ ) and retaining them in a live car (27 ft<sup>3</sup>) for up to 72 h. Threshold power delivery to illicit electro taxis of whitefish was generally lower than the power applied to collect trout (70% lower, on average). Survival of whitefish sampled with raft electrofishers was above 90% for most surveys, and highest when cautious handling protocols were followed and water temperature was < 60°F. Eight of ten population estimates were reliable and abundance ranged from 151 to 2,378 fish/mi (17 to 162 fish/acre). Catch per unit effort ranged from 18.3 to 304.9 fish/h, and was loosely related to abundance estimates in nonlinear regressions ( $R^2 = 0.38$  to 0.58). A report will follow the completion of large river surveys to provide recommendations for population monitoring and chart the next direction for whitefish research in Wyoming. Life history questions remain fruitful research territory.

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### INTRODUCTION

Mountain Whitefish *Prosopium williamsoni* (referred to as whitefish from here forward) are a prominent and widespread salmonid in large, deep, clear, cold rivers west of the North American Continental Divide in states of the central Rockies, including Montana, Wyoming, Idaho, Utah, and northwestern Colorado (Behnke 2002; Nature Reserve 2013; Figure 1). In Wyoming, whitefish are common in the Snake, Green, and Bear rivers west of the Continental Divide, and reside in the Madison, Yellowstone, Big Horn–Wind, and Tongue rivers east of the Divide (Baxter and Stone 1995), cohabiting with all four of Wyoming's cutthroat trout species. Although both whitefish and trout feed primarily on invertebrates, unlike trout, whitefish tend to inhabit open channel habitats without cover (Behnke 2002). Migrations of whitefish in large river systems are well documented among habitats used

for spring and summer feeding, fall congregating and spawning, and overwintering (Davies and Thompson 1976; Behnke 2002).

The sport fishing popularity of whitefish is eclipsed by trout, which has afforded whitefish little attention from fish managers until recently. The Wyoming Game and Fish Department (WGFD) initiated a project to assess the statewide population status of whitefish in 2009. Basic abundance data were not available for whitefish populations in Wyoming, and were generally lacking throughout North America (Meyer et al. 2009). Although most populations of whitefish appear robust in parts of the Rocky Mountain region, populations in Montana and Colorado declined recently for unknown reasons. Populations of whitefish in southern Idaho were deemed secure following an assessment tangential to a broad-scale cutthroat trout survey (Meyer et al. 2009), although Endangered Species Act protection

was solicited for one declining whitefish population in Idaho’s Big Lost River. The U.S. Fish and Wildlife Service ruled that listing this population was not warranted in 2010 and encouraged the continuation of local conservation efforts. A project was initiated by Montana State University in 2011 to address life-history characteristics of the whitefish population in the Madison River, which may help explain the population decline in this river. Population status and abundance trends for whitefish in Wyoming have been assumed stable and secure without being quantified. For this reason, the native species status (NSS) for whitefish was most recently designated as unknown, which defaulted whitefish to a species of greatest conservation need (NSS4; WGFD 2010). Improved information will be needed to revise the NSS for whitefish in 2015 and assist managers with tracking future population trends.

Objectives for the WGFD project on whitefish include (1) identifying whitefish sampling methods effective for monitoring, (2) establishing baseline data points at key sites for population monitoring, and (3) assessing population status. This manuscript was derived from a preliminary report, the intent of which was to update fish managers on project status and solicit input on project direction.

## METHODS

Surveys focused on large, non-wadeable rivers where the most abundant, core Mountain Whitefish populations were expected to reside (Sigler 1951; Behnke 2002; Meyer et al. 2009). Data for mark-recapture population estimate surveys were generally collected with three passes with raft electrofishing gear, two consecutive sampling days, a rest day to allow the fish to redistribute, followed by a final sampling day. Extra care was taken in collection, holding, and handling of whitefish during surveys, conforming to the general guidelines of Reynolds (1996). Fish were measured for total length (TL; in) and marked with a fin clip unique to the pass (including the final pass) during population estimate surveys and released.

During the first surveys in 2009, experimentation with power output settings aimed to maximize whitefish survival and identify threshold power delivery to illicit taxis. Settings began at 20 pulses per second (PPS) and 20% pulse-width (PW) and were increased as needed. Initial voltage was very low to minimize current at  $\leq 2$  amps, and increased until taxis was observed and whitefish were sampled effectively. Approximate power (watts) transferred to whitefish during surveys was derived with Ohm’s law using

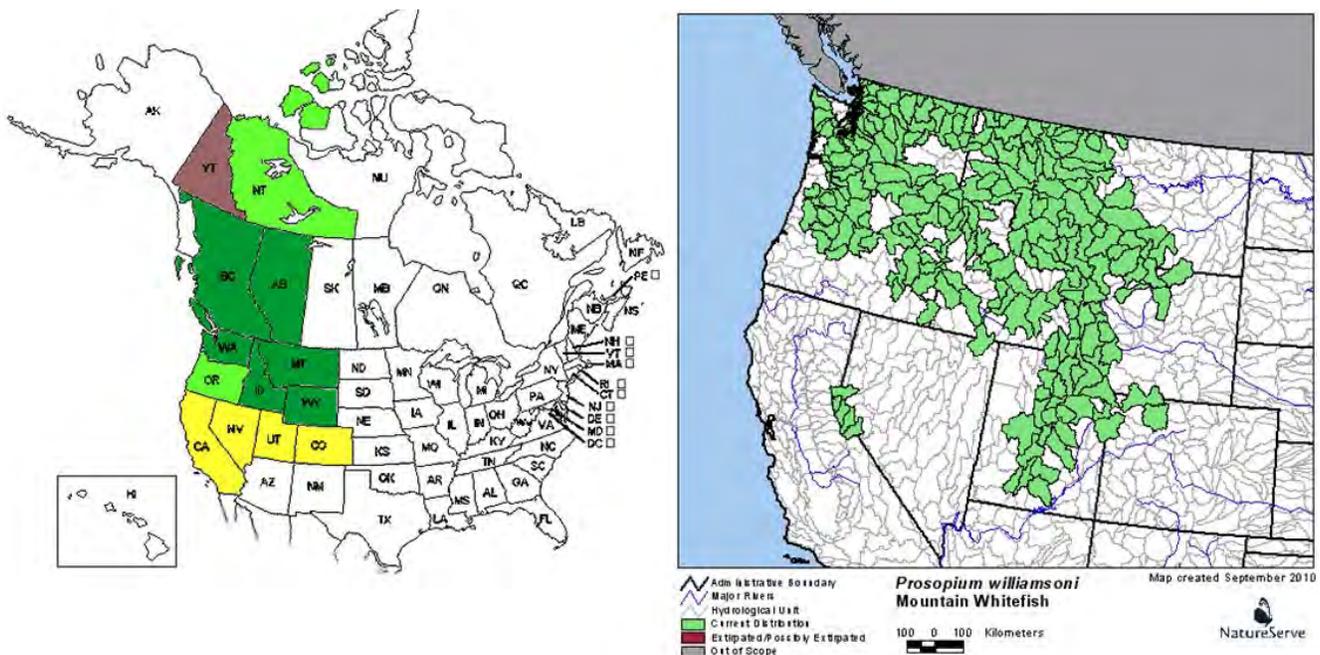


Figure 1. Mountain Whitefish distribution in North America by state or province (a) and its native range in the United States by 8-digit hydrologic unit, represented by green polygons in (b) (NatureServe 2013). Colors in (a) represent population status assigned by NatureServe as follows: yellow=vulnerable, light green=apparently secure, dark green=secure, and gray=not ranked/under review.

peak voltage, current, and a power correction factor based on ambient conductivity (Kolz 1989).

The survival of whitefish sampled with electrofishing gear was unknown. To estimate post-sampling survival, additional whitefish (target  $n=35$ ) were collected below some survey reaches, handled the same way as fish from the reach, and confined for observation up to 72 h in a 27-ft<sup>3</sup> live car. A subset of post-sampling survival data for whitefish was chosen for review where fish were observed for at least 48 h.

Population estimates were calculated for whitefish measuring  $\geq 6$  in TL using model  $M_t$  of the program CAPTURE (White et al. 1982). The mean probability of capture per pass and coefficient of variation for estimates were used to assign quality ratings to stream reach estimates using the criteria of White et al. (1982) and Otis et al. (1978). Abundance was expressed as the number of fish per mile and per acre. Field coordinates and electronic maps were used to calculate reach lengths.

Catch per unit effort (CPUE, fish/h of electrofishing time) was calculated using the combined catch from two rafts on the first pass, including

mortalities. Data from two rafts were reported as if from a single gear for CPUE.

Data for CPUE were analyzed using total CPUE (both boats combined) and catch per netter-hour, during the first pass of each population estimate survey. The relationships between CPUE data and estimates of true abundance (number/mile, number/acre) were plotted to evaluate variability, trends, and the reliability of whitefish CPUE data collected with raft-mounted electrofishing gear for monitoring. Data were also reported (CPUE, total numbers, population structure) for whitefish populations surveyed where abundance was too low (Little Snake River and Wind River below Boysen reservoir) to conduct mark-recapture population estimates.

## RESULTS

Through 2012, the WGFD project on whitefish gathered baseline abundance information for whitefish at 14 sites on 10 major, non-wadeable rivers (Table 1). The abundance of whitefish for reliable estimates ranged widely from 151 to 2,378 fish/mi at the

**Table 1. Mountain Whitefish surveys on Wyoming rivers. The number of netters is provided in parentheses. Population estimate quality rankings were VP=very poor, P=poor, A=acceptable, VG=very good, and E=excellent. Numbers of fish captured per hour of pedal time and 100 meters of the sampling reach were collected with two boats on the first pass (including mortalities).**

River and Location	Year	Number of Fish		Estimate Quality	Fish/h
		Mile	Acre		
Clarks Fork River near Clark (2)	2010	1,441	81	A	114.2
Shoshone River below Corbett div. (2)	2011	2,022	108	A - VG	210.9
Salt River at the Narrows (2)	2009	1,387	162	A - VG	128.0
Pacific Creek near Moran Junction (2)	2012	.	.	.	23.8
Greys River near Alpine (2)	2012	374	34	A - VG	70.6
Wind River above Dubois (2)	2009	324	40	VG	102.8
Wind River below Boysen dam (4)	2010	.	.	.	0.0
Popo Agie River near Lander (2)	2011	151	17	A	18.3
Green River below Green River Lake (2)	2012	.	.	.	122.2
Green River near Big Piney (4)	2011	2,378	119	A - E	304.9
Smiths Fork River near Cokeville (3)	2011	463	93	VG - E	86.8
Green River at Seedskaadee (4)	2011	3,155	118	VP	128.1
Little Snake River near Baggs (2)	2010	.	.	.	11.2
Little Snake River near Baggs (2)	2010	.	.	.	1.9

Popo Agie River and the Green River at Big Piney, respectively. The density of whitefish also varied greatly, from 17 to 162 fish/ac at the Popo Agie and Salt rivers, respectively. Catch per unit effort ranged from 0.0 fish/h to 304.9 fish/h on the Popo Agie and the Green River near Big Piney, respectively (Table 1). Population estimate quality was acceptable to excellent for eight of the nine reliable mark-recapture surveys.

Survival of sampled fish ranged from 83.6 to 100.0% prior to release (initial) and from 47.8 to 100% for fish that survived processing at 48 h after sampling (Table 2 and Figure 2). Approximate power transferred to fish ranged from 403 to 995 watts for surveys where

no equipment problems occurred (Table 2). Water temperatures varied from 50 to 68 °F (Table 2) and was most tightly related to post-sampling survival of Mountain whitefish in a non-linear fashion ( $R^2=0.99$ ; Figure 2). Survival of sampled fish was high (>90%) initially and 48 h post-sampling for surveys where water temperature was <60°F (Figure 2). Initial and 48 h post-sampling survival sharply declined when water temperatures exceeded 60°F (Figure 2).

Relationships between CPUE and abundance were weak, at best ( $R^2 = 0.38$  to  $0.58$ ; Figure 3). Number of fish per mile and the total number of fish per hour of electrofishing (pedal time) had the strongest association ( $R^2 = 0.58$ ) with CPUE.

**Table 2. Post-sampling survival of whitefish captured during surveys on large Wyoming streams with raft-mounted electrofishing gear. Specific conductivity ( $C_s$ ;  $\mu\text{S}/\text{cm}$ ) was metered with automatic temperature correction (standardized to 25°C). Peak volts ( $V_{\text{peak}}$ ) and amps ( $A_{\text{peak}}$ ) represent the highest readings recorded. Power transferred to sampled fish is an estimated peak in watts. PPS/PW represents settings for pulses per second and pulse-width. Time interval 0h represents mortalities that occurred immediately, during, or shortly after handling.**

River and location	Year	$C_s$	°F	$V_{\text{peak}}$	$A_{\text{peak}}$	Watts	PPS/PW	% Survival ( <i>n</i> )	
								0h	48h
Popo Agie near Lander	2011	360	64	250	4	734	25/25	96.2 (51)	90.9 (22)
Green at Seedskaadee	2011	220	68	225	3	601	25/25	83.6 (372)	47.8 (23)
Green near Big Piney	2011	250	61	200	3	656	25/25	97.5 (905)	100.0 (38)
Smiths Fork near Cokeville*	2011	360	46	250	2	403	25/25	94.8 (384)	100.0 (35)
Shoshone below Corbett div.	2011	351	55	150	4	780	25/25	99.5 (369)	97.1 (35)
Clarks Fork near Clark	2010	104	61	500	2	995	25/25	84.5 (323)	100.0 (34)
Green near Big Piney	2010	278	54	350	5	1,517	30/25	100.0 (135)	100.0 (11)
Wind above Dubois	2009	100	53	400	2	785	20/20	98.3 (115)	100.0 (28)
Salt at the Narrows	2009	410	54	200	3	438	20/20	98.6 (215)	100.0 (40)
Green near Big Piney	2009	220	50	500	5	2,119	25/25	97.8 (74)	94.7 (38)

\*Poor weather ended this study prematurely at 40 h.

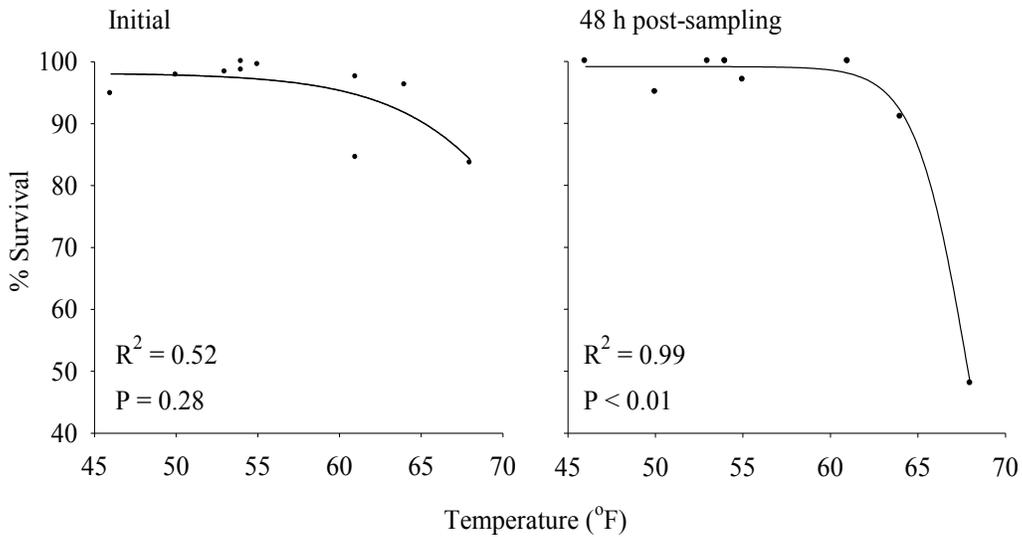


Figure 2. Percent initial survival (prior to release) and estimated post-sampling survival (48 h after release) of whitefish sampled with raft-mounted electrofishing gear on large Wyoming rivers from a subset of surveys during 2009-2011.

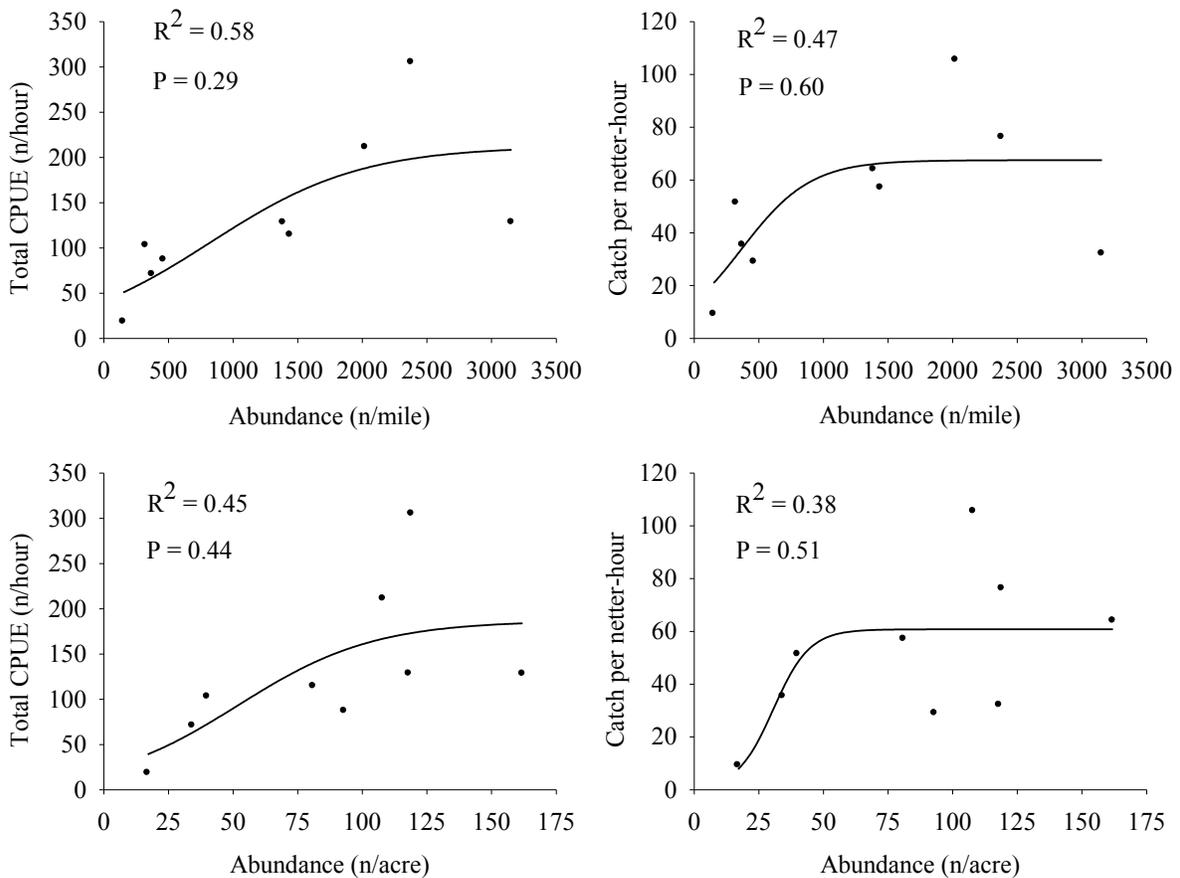


Figure 3. Abundance (number per mile, number per surface acre) as determined by mark-recapture population estimate techniques versus catch per unit effort (CPUE; total catch per hour and catch per netter-hour) for whitefish sampled in large Wyoming rivers with raft-mounted electrofishing gear from 2009 to 2012.

## DISCUSSION

Raft electrofishing gear is most commonly used to sample fish on many of Wyoming's large rivers where motorized boats are less effective or cannot operate. A primary research question was whether or not mark-recapture population estimates conducted with this gear were possible for whitefish. Potentially low post-sampling survival of whitefish created concern for the quality of mark-recapture population estimates. Historical experiences of biologists with whitefish during routine trout sampling with pulsed DC current and raft-mounted gear indicated that whitefish were more susceptible to capture by electrofishing than trout and prone to high sampling mortality. Trout sampling typically employed VVP (variable voltage pulsator) settings at 30-40 pulses per second (PPS) and 20-30% pulse width (PW) at a voltage that allowed 3-8 amps of current. This suggested that whitefish could be sampled effectively with VVP settings at far less power (voltage and/or current), lower PPS, and shorter PW than needed for sampling trout. Injury and mortality of whitefish reported during trout surveys was at least partially attributed to overpowered electrofishing conditions for whitefish.

Experimentation during early whitefish surveys obtained a threshold of effective power transfer for whitefish that was lower than necessary for trout. Effective power output during whitefish surveys was 70% lower, on average, than if settings had been used that were typically reported for trout surveys in Wyoming (targeted ceiling of 4 amps of current). Threshold power delivery occurs at the minimum power transferred to fish required to illicit a desired response such as taxis (Kolz 1989; Kolz and Reynolds 1989), which should allow capture and minimize harm (Reynolds 1996). Effective VVP settings for whitefish were at 20-25 PPS and 20-25% PW using a voltage that allowed  $\leq 2$  amps of current. Power transfer analysis showed that the threshold power transferred to whitefish ranged from 403 to 995 watts during successful surveys. Whitefish exhibited desirable taxis towards anodes using these "low-powered" settings while trout did not and were rarely captured. In fact, trout were seldom seen or exhibited fright and flight behavior during whitefish surveys. Power transferred to whitefish was dramatically higher during surveys where equipment malfunctions occurred (1,517-2,119 watts) or when sparse whitefish populations were

sampled during "reconnaissance" surveys (1,414-2,731 watts). This phenomenon reflected the nature of biologists to gradually default to routine VVP settings to improve confidence in sampling efficiency under unfamiliar circumstances.

The survival of whitefish sampled during surveys was acceptable when procedures were properly followed and sampling conditions were conducive to recovery of sampled fish. Survival rates were above 90% for most surveys – when water temperatures were near or below 60° F. Initial survival of sampled fish during first passes was affected by the adherence to procedures as much as water temperature. Maintaining low densities of whitefish in each live well ( $n \leq 30$ ) and minimizing the time whitefish were confined prior to processing were both major factors that influenced initial and delayed survival. The highest live well densities occurred during the Green River survey near Big Piney in 2011, yet survival rates were high. This was a likely result of adherence to procedures, even in light of moderate water temperature (61° F). Initial survival of whitefish sampled from the upper Green River, below Green River Lake, in 2012 was low (82.6%) due to high water temperature (66.4° F), despite careful adherence to procedures. Sampling whitefish when water temperature was below 60° F was preferred and below 65° F was critical, to maximize survival and data quality. The nonlinear negative relationship between water temperature and 48 h post-sampling survival was strong.

Eight out of ten surveys where population estimates were obtained for Mountain Whitefish resulted in reliable estimates of absolute abundance (quality rankings of acceptable or better). All surveys also acquired catch per unit effort (CPUE) data on the first pass, which provided another baseline for basic population monitoring. Comparison of CPUE data among repeated surveys may introduce more uncertainty than thorough population estimates of true abundance, but collecting CPUE data requires much less effort than population estimates. Population estimates are not possible where abundance is too low for mark recapture techniques and multiple passes may be too difficult or cost- or manpower-prohibitive.

Thorough whitefish monitoring was incompatible with routine trout monitoring. The disparity between power levels necessary to effectively sample trout versus whitefish prohibited a unified effort to simultaneously collect quality data for both. These

circumstances were additive to the overwhelming numbers of fish that would be collected during a unified effort and hinder positive results for both efforts. Stream access, streamflow, and other logistical constraints often provide for limited sampling opportunities. Fortunately, most trout monitoring is not annual, allowing opportunities to monitor whitefish populations in overlapping reaches during off years.

Monitoring of whitefish populations may employ a combination of periodic abundance estimates and more frequent single-pass measurement of relative abundance, or CPUE. However, the ability of CPUE data to reflect actual abundance of whitefish was unknown and appears less definitive thus far for detecting abundance changes than reliable population estimates. However, there were few reliable data points ( $n=9$ ) available and considerable variability associated with both measures. Concern was expressed for the densest whitefish populations where the sheer volume of fish encountered during sampling was feared to exceed the capacity for biologists to collect them, and undermine CPUE precision. This has not yet been the case, as the relationships between CPUE and true abundance estimates do not exhibit a ceiling for CPUE. However, further data collection may help improve the utility of CPUE and population estimate data.

Methods developed to target whitefish and an emphasis on cautious handling procedures proved effective for collecting reliable data on this native sport fish. These procedures will enable fisheries managers to confidently move forward with research questions to better understand whitefish life history and monitor population status. Effects of climate change are likely to affect migratory species that inhabit thermal transition zones, which includes the foothill and main-stem habitats of whitefish. Detailed research of whitefish life history in a Wyoming

drainage such as the upper Green River would help fill many research gaps. A next logical step for the WGFD project may be to explore sampling methods and obtain abundance information for whitefish in smaller, more headwater habitats, as well as collect age and growth data from all populations.

## LITERATURE CITED

- Behnke, R. J. 2002. Trout and salmon of North America. Free Press, New York.
- Kolz, A. L. 1989. A power transfer theory for electrofishing. U.S. Fish and Wildlife Service Technical Report 22, Washington, D.C.
- Kolz, A. L., and J. B. Reynolds. 1989. Determination of power threshold response curves. U.S. Fish and Wildlife Service, Technical Report 22, Washington, D.C.
- McMichael, G. A., A. L. Fritts, and T. N. Pearsons. 1998. Electrofishing injury to stream salmonids; injury assessment at the sample, reach, and stream scales. *North American Journal of Fisheries Management* 18:894-904.
- Meyer, K. A., F. S. Elle, and J. A. Lamansky, Jr. 2009. Environmental factors related to the distribution, abundance, and life history characteristics of whitefish in Idaho. *North American Journal of Fisheries Management* 29:453-767.
- NatureServe. 2013. NatureServe Explorer: an online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available <http://www.natureserve.org/explorer>. (Accessed: July 31, 2013).
- Reynolds, J. B. 1996. Electrofishing. Pages 221-253 in B. R. Murphy and D. W. Willis, editors. *Fisheries Techniques*. American Fisheries Society, Bethesda, Maryland.
- Sigler, W. F. 1951. The life history and management of *Prosopium williamsoni* in the Logan River, Utah. State Agricultural College, Bulletin 374, Logan, Utah.
- WGFD. 2010. Strategic Wildlife Action Plan. Wyoming Game and Fish Department, Cheyenne.

## GROWTH VARIATION IN A MID-ATLANTIC BROOK TROUT POPULATION

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**Abstract**—We used recapture data from >2,200 individually marked Brook Trout *Salvelinus fontinalis* to quantify their growth rates in three western Maryland streams. Individual growth rates varied greatly among fish, ranging from 0 to 144 mm·year<sup>-1</sup>. More importantly, we found substantial growth differences among years, resulting in some fish in their second year being as long as four-year-old fish. Although hooking injuries and conspecific density were not important drivers of individual growth, we found sex-specific differences in growth, as males grew 10.5 mm·year<sup>-1</sup> faster than females. We also found significant growth differences among reaches, highlighting the importance of downstream areas for Brook Trout growth. Strong inter-annual and sex-specific growth variation have major implications for population management, and have forced us to reassess our understanding of population dynamics because of the strong relationship between fish length and fecundity, our inability to confidently determine age from length-frequency plots, and the dominant, and largely uncontrollable, drivers of Brook Trout growth in these streams.

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### INTRODUCTION

Brook Trout *Salvelinus fontinalis* are a highly plastic and variable species whose life history, habitat use, movement patterns, morphology, and genetics may all vary markedly among and within populations (Power 1980; Perkins et al. 1993). In turn, growth and longevity in Brook Trout are also highly variable within and among populations, resulting in considerable differences in population size structure and reproductive outputs (Hutchings 1993; Ficke et al. 2009). Brook Trout populations may be dominated by young and fast growing individuals, long-lived and slow growing fish, or represent an aggregation of individuals exhibiting disparate life history strategies (Dutil and Power 1980; Power 1980). Because size and reproductive output are closely linked (Hutchings 1993), growth rates have a strong influence on the dynamics of a population. If we can identify factors that are important controls of growth, we may be able to identify opportunities for managers to enhance wild trout populations.

Given the high variability observed in Brook Trout life history, local information is critical for effective management. The objectives of this study were to (1) describe growth variability in the Savage River watershed and (2) explore intrinsic, biotic, and abiotic factors that influence individual growth rates.

We used observed growth at size to (3) calculate Von Bertalanffy growth trajectories for two years to highlight the importance of inter-annual variation of growth rates.

### METHODS

We conducted our study on two streams in the Savage River watershed of western Maryland (Figure 1). The Savage River watershed contains >90 km of interconnected coldwater streams and has been identified as a regionally important stronghold for wild Brook Trout. Within this drainage, our efforts focused on segments of two tributaries: Big Run (4.5 km) and Middle Fork (0.5 km). Both streams are the focus of a large-scale tagging project and have been divided into contiguous 50-m study sections.

Fish were collected annually during early summer using three-pass backpack electrofishing surveys throughout each of the study sections. All fish were chemically anesthetized (80 mg·L<sup>-1</sup> tricaine methanesulfonate buffered with 0.2 mM NaHCO<sub>3</sub>, pH = 7) prior to handling. Total length (mm) was measured and each individual was examined for hooking injuries. All individuals that had not been previously captured were surgically implanted with a 12-mm passive integrated transponder (PIT) tag (134.2 kHz ISO tag, Digital Angel Co., TX1411SST). Sex

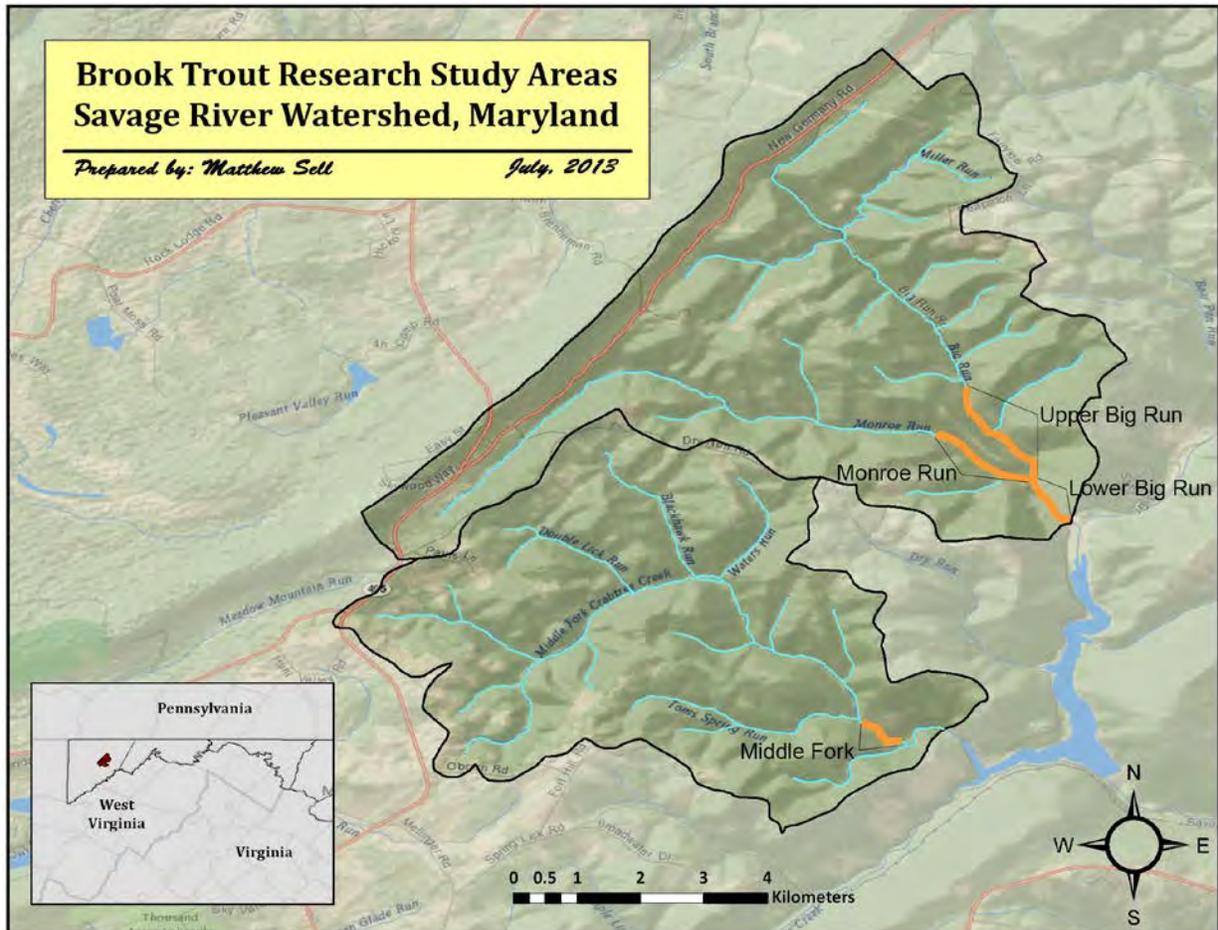


Figure 1. Location of study reaches with the Middle Fork and Big Run watersheds.

was determined for a subset of the tagged individuals during fall electrofishing samples conducted shortly before the peak of spawning. For all captured individuals, manual expression of gametes was attempted. For those individuals that did not express gametes, rapid visual assessment (Kazyak et al. 2013) was used to assign sex.

For the purposes of this study, we used absolute growth rate as our response variable (Eq. 1). This metric of growth was selected because it is easy to interpret scales linearly with individual length (Figure 2), and is directly compatible with the Fabens (1965) modification of the von Bertalanffy Growth model.

$$\text{Equation 1. Absolute growth} = \frac{L_1 - L_0}{t_1 - t_0}$$

To determine if conspecific density promotes spatial variability in growth rates, we derived Brook Trout biomass and adult counts from three-pass

electrofishing surveys. Because our overall sampling efficiency was generally in excess of 95%, we used the abundance and biomass of our catch to represent Brook Trout density. The vast majority of recaptured individuals were found in the same section one year later. Consequently, we used an individual's location at the start of a growth interval to assign place-based covariates.

Using field data, we created a suite of *a priori* linear models using Program R (R Core Team 2012) to explain individual growth rates as a function of intrinsic, biotic, and abiotic factors (Table 1). Candidate variables included total length (mm), year, adult count, reach, sex, and hooking injuries. All predictor variables represent data collected at the start of the growth interval. Adult count equals the total number of adult Brook Trout (>100 mm TL) encountered in the study section at the start of the period at large. For the purposes of this analysis, the study area was divided into four reaches: Middle Fork,

Monroe Run, Lower Big Run and Upper Big Run. We used Akaike Information Criterion as a guide to identify top candidates for model selection. Among these models, we used the overall variance explained ( $R^2$ ) and model complexity ( $k$ ) to select a model which was best suited to elucidating key drivers of individual growth variation in our area.

We used the Fabens (1965) modification of the von Bertalanffy growth model to project size-at-age trajectories using data from each of the two years.

Model outputs were used to calculate expected fecundity-at-age based on the length-fecundity relationship reported by Halfyard et al. (2008) for lotic Brook Trout, assuming fish mature in their second fall.

## RESULTS

We PIT tagged >2,200 individual Brook Trout during the summers of 2010 and 2011. These efforts yielded 681 recapture events during 2011 (21 male,

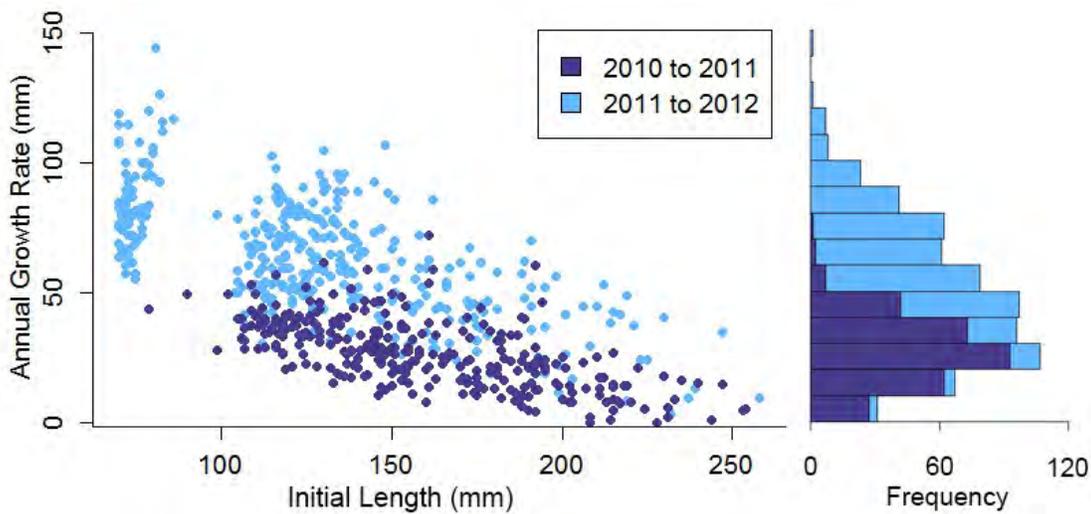


Figure 2. Observed annual growth rates versus initial length for two years. Growth rates generally slowed with individual size, but were markedly faster during the second year of the study.

Table 1. Comparison of the structure and efficacy of a suite of a priori models developed to explain individual growth rates as a function of size, year, location, hooking injuries, sex, and competition. All place-based variables correspond to the section where an individual was captured at the start of the growth interval. The model favored by the authors is shown in bold. The number of estimated parameters is represented by  $k$ .

Model	Structure	$k$	AIC <sub>c</sub>	ΔAIC <sub>c</sub>	Adj. $R^2$
A	Length * Year + Adult Count * Year + Reach * Year + Sex	14	5203.58	0.00	82.4
B	Length * Year + Adult Count * Year + Reach * Year + Sex + Hooking Injury	15	5205.57	-1.99	82.4
<b>C</b>	<b>Length * Year + Reach * Year + Sex</b>	<b>12</b>	<b>5210.20</b>	<b>-6.62</b>	<b>82.2</b>
D	Length * Year + Reach * Year	10	5255.10	-51.52	81.0
E	Length * Year + Sex	6	5492.09	-288.51	72.9
F	Length * Year	4	5551.56	-347.98	70.4
G	Length	2	5957.11	-753.53	46.2

24 female, 267 unknown sex) and 2012 (66 male, 111 female, 198 unknown sex). The vast majority of recaptured individuals remained in the same section, although a few individuals made more extensive movements (Figure 3). Individual growth rates varied widely, ranging from 0 to 144 mm·year<sup>-1</sup> (Figure 2). Hooking injuries were detected in 3.2% of the tagged individuals that were subsequently recaptured and represented in the model.

The best model (Model C; Table 1) explained 82% of the variation in growth (Figure 4) and was comprised of individual length and stream reach, the effects of which vary by year, and also sex. Growth rates were significantly lower in the first year ( $\bar{x} = 26.57$  mm·year<sup>-1</sup>) relative to the second year ( $\bar{x} = 63.32$  mm·year<sup>-1</sup>). This was reflected in the parameter estimates generated by our model, where individual growth rates varied considerably between

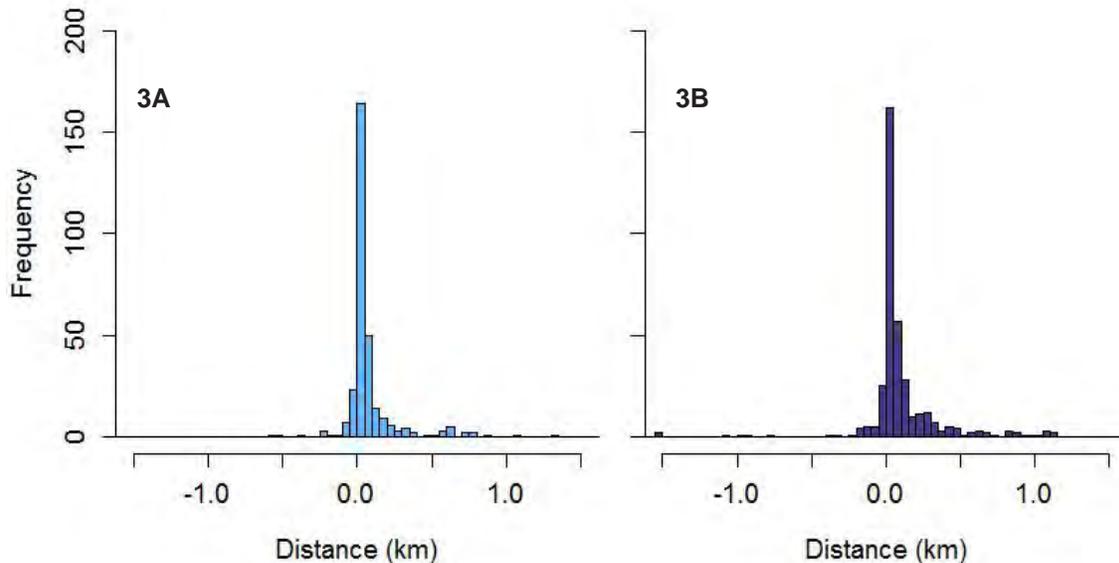


Figure 3. Histogram of observed distances between recaptures (June to June) for Brook Trout in the Savage River watershed, MD. Dispersal distances were similar between the first (3A) and second (3B) years of the study. Six outliers are omitted from plot 2B, and their dispersal distances were as follows: -1.55, 1.75, 1.90, 2.35, 2.65, and 2.70 km.

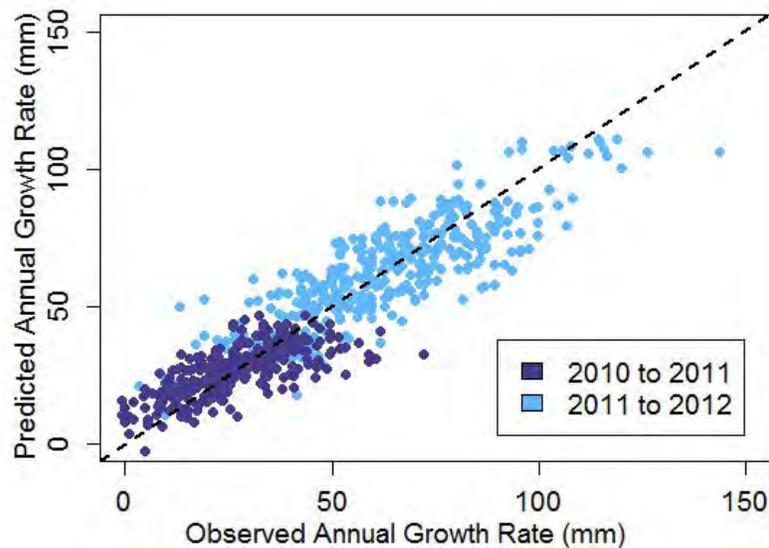


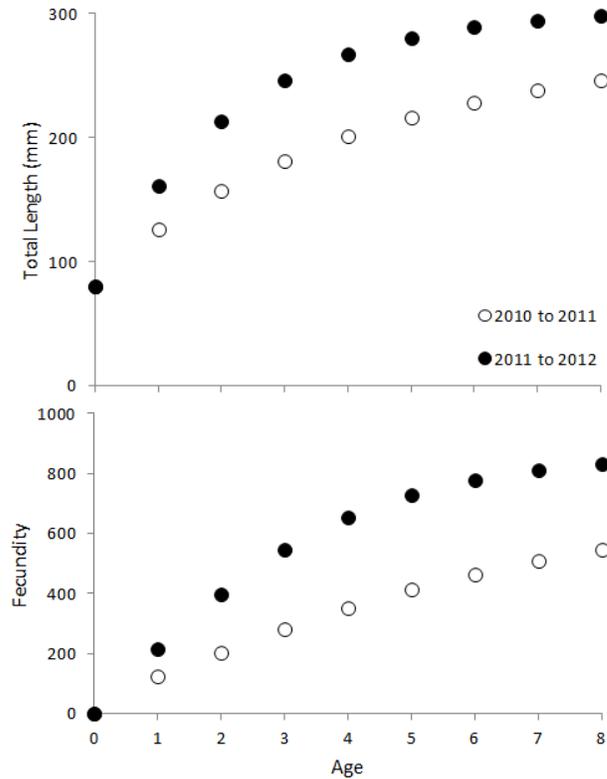
Figure 4. Observed versus predicted annual growth rates for individual Brook Trout. Predicted growth rates were derived using parameter estimates from model C.

the two years and to a lesser extent among stream reaches (Table 2). The negative effect of individual size on growth was also more pronounced during the second year (-0.40 mm·year<sup>-1</sup>·mm<sup>-1</sup>) compared to the first (-0.26 mm·year<sup>-1</sup>·mm<sup>-1</sup>; Table 2). Mean annual growth for male Brook Trout was 10.49 mm·year<sup>-1</sup> greater than for females, while the growth rate for those fish where sex was unknown was intermediate (Table 2).

Von Bertalanffy growth trajectories observed during the first year of the study (2010 to 2011) resulted in much reduced size-at-age and fecundity-at-age when compared to projections using data from the second year (2011 to 2012; Figure 5). Based on the first growth interval, our modeled growth trajectory predicted an age-3 fish would be 182 mm and produce 280 eggs. For comparison, the rapid growth rates observed during the second year of the study yielded a predicted size of 246 mm for the same age, with females of this size expected to produce 545 eggs (Halfyard et al. 2008) – nearly double the predicted age-3 fecundity from the first year.

## DISCUSSION

Our results show that size is a poor proxy for age, and consequently, we do not expect length-frequency histograms to provide accurate results if growth rate varies among years. Spatial, temporal, and sex-specific variation in growth rates are more than sufficient to confound the relationship between



**Figure 5.** Mean length at age predictions based on the Von Bertalanffy growth model using data from two separate years (5A). Initial length at age-0 was fixed at 80 mm and reflects the typical length of new recruits during the electrofishing surveys. Expected fecundity based on projected growth trajectories and the length-fecundity relationship reported by Halfyard et al. (2008) for lotic Brook Trout, assuming fish mature in their second fall (5B).

**Table 2.** Estimated parameters derived from the selected model (C). All units are mm·y<sup>-1</sup>

Variable	Observed Condition	Estimate ± SE	
		2010	2011
Reach	Monroe Run	62.43 ± 4.64	101.00 ± 10.23
	Lower Big Run	71.10 ± 4.94	128.33 ± 11.30
	Upper Big Run	63.75 ± 3.09	113.57 ± 6.70
	Middle Fork	65.93 ± 4.98	104.50 ± 10.57
Length	mm <sup>-1</sup>	-0.26 ± 0.02	-0.40 ± 0.04
Sex	Female	0.00 ± 0.00	
	Male	10.68 ± 1.52	
	Unknown	3.75 ± 1.16	

size and age. Differences among stream sections also suggest that some areas within riverine networks have greater Brook Trout growth than others. In both years, the highest growth rates were observed in the lower portion of Big Run. This is consistent with the idea that downstream reaches may be important feeding habitats for Brook Trout (Utz and Hartman 2006). Thus, management should strive to maintain these downstream, interconnected reaches because of their biological significance.

Hooking injuries did not influence individual growth rates, even though some fish had significant jaw deformities. Although simulations (Meka and Margraf 2007) have suggested there may be sublethal impacts of angling on salmonid growth, our field results are consistent with laboratory studies using live fish (Pope et al. 2007). However, our result should be viewed as preliminary, because our sample size of fish with hooking injuries was quite small.

The significantly lower growth of female Brook Trout has important implications for population dynamics and fisheries management. Since fecundity is tightly correlated with size in fishes (Blueweiss et al. 1978), slower female growth implies that actual reproductive output may be much lower than expected based on models lacking sex-specific data. We also expect males to dominate the largest size classes within the population, assuming equal life span between sexes. Future work may consider examining sex ratios across a range of size classes within a Brook Trout population.

Habitat quality has sometimes been associated with variation in growth rates in salmonids (Hayes et al. 1996). A preliminary examination of the direct effects of habitat quality did not show any strong signals, but missing data precluded a formal analysis. We used conspecific density as a surrogate for habitat quality and found it was not a useful predictor of individual growth rates despite density-dependent growth rates in other Brook Trout populations (Utz and Hartman 2006).

We documented clear differences in size- and fecundity-at-age trajectories between two years of the study. Additional years of data may help us understand the complete distribution of growth rates exhibited in our study populations. However, it is clear that population projections and management decisions based on a single year of data may be considerably different than those based on multiple years of data,

which are required to capture the inherent variability within the population. Taken as a whole, our study highlights the importance of high-resolution, multi-year data when using science to inform management. Projected increases in environmental variability will only increase the importance of longer-term datasets.

## ACKNOWLEDGEMENTS

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## LITERATURE CITED

- Blueweiss, L., H. Fox, V. Kudzma, D. Nakashima, R. Peters, and S. Sams. Relationships between body size and some life history parameters. *Oecologia* 37:257-272.
- Dutil, J.D., and G. Power. 1980. Coastal populations of brook trout, *Salvelinus fontinalis*, in Lac Guillaume-Delisle (Richmond Gulf) Quebec. *Canadian Journal of Zoology* 58: 1828-1835.
- Fabens, A.J. 1965. Properties and fitting of the von Bertalanffy growth curve. *Growth* 29:265-289.
- Ficke, A. D., D. P. Peterson, and W. A. Janowsky. 2009. Brook trout (*Salvelinus fontinalis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region, Golden, Colorado. Available: <http://www.fs.fed.us/r2/projects/scp/assessments/brooktrout.pdf>. (June 2013).
- Hayes, D.B., C.P. Ferreri, and W.W. Taylor. 1996. Linking fish habitat to their population dynamics. *Canadian Journal of Fisheries and Aquatic Sciences* 53:383-390.
- Halfyard, E.A., J.L. MacMillan, and R.J. Madden. 2008. Fecundity and Sexual Maturity in Select Nova Scotia Trout Populations. Unpublished report. Inland Fisheries Division, Nova Scotia Department of Fisheries and Aquaculture. Pictou, Nova Scotia.
- Hutchings, J.A. 1993. Adaptive life histories effected by age-specific survival and growth rate. *Ecology* 74:673-684.
- Kazyak, D.C., R.H. Hilderbrand, and A.E. Holloway. 2013. Rapid visual assessment to determine sex in

- Brook Trout. *North American Journal of Fisheries Management* 33:665-668.
- Meka, J.M., and F.J. Margraf. 2007. Using a bioenergetic model to assess growth reduction from catch-and-release fishing and hooking injury in rainbow trout, *Oncorhynchus mykiss*. *Fisheries Management and Ecology* 14:131-139.
- Perkins, D.L., C.C. Krueger, and B. May. 1993. Heritage brook trout in northeastern USA: genetic variability within and among populations. *Transactions of the American Fisheries Society* 122:515-532.
- Pope, K.L., G.R. Wilde, and D.W. Knabe. 2007. Effects of catch-and-release angling on growth and survival of rainbow trout, *Oncorhynchus mykiss*. *Fisheries Management and Ecology* 14:115-121.
- Power, G. 1980. The brook charr, *Salvelinus fontinalis*. pp. 141-203. *In*: Balon, E.K. (ed). *Charrs, salmonid fishes of the genus Salvelinus*. W. Junk, The Hague, Netherlands.
- R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>.
- Utz, R.M., and K.J. Hartman. 2006. Temporal and spatial variation in the energy intake of a brook trout (*Salvelinus fontinalis*) population in an Appalachian watershed. *Canadian Journal of Fisheries and Aquatic Sciences* 63:2675-2686.
- Utz, R.M., and K.J. Hartman. 2009. Density-dependent individual growth and size dynamics of central Appalachian brook trout (*Salvelinus fontinalis*). *Canadian Journal of Fisheries and Aquatic Sciences* 66:1072-1080.

## SHORT-TERM AND SEASONAL MOVEMENTS OF BROOK TROUT IN THE UPPER SAVAGE RIVER WATERSHED, GARRETT COUNTY, MARYLAND

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**Abstract**—We used radio telemetry to determine movement patterns of adult Brook Trout *Salvelinus fontinalis* in the upper Savage River, Garrett County, Maryland. The lower main-stem river is a stocked fishery (daily creel of 5 trout), whereas the rest of the watershed is managed as wild trout water, artificial lures only, with no harvest of Brook Trout. Our objective was to determine if fluvial Brook Trout use the lower reaches of the river seasonally, where they are susceptible to harvest. Sixteen large Brook Trout (> 240 mm total length) were implanted with radio tags and located regularly over the tag lifespan (~1 year). Most fish (10 of 16) migrated upstream (>100 m) to upper river reaches or tributaries in late spring as lower main-stem water temperatures neared 20°C. The mean upstream movement was 5.9 km, with one individual exceeding 11 km. Some fish (2 of 16) moved <100 m, remaining in relatively deep pools near their tagging location. All tagged Brook Trout were sedentary from late June into October, moving only slightly (<100 m) to spawn. After spawning all but two of the migratory fish quickly moved (within 7 d) back to the general areas in the main-stem river where they were tagged; many (7 of 10) returned to the same pool. Consequently, fluvial Brook Trout mobility and the timing of their movements make them susceptible to angling harvest in the lower main-stem Savage River.

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### INTRODUCTION

The upper Savage River (USR) is the only remaining Brook Trout *Salvelinus fontinalis* watershed in Maryland to allow unrestricted movement throughout the watershed. Due to declining populations, great measures have been taken to conserve the Brook Trout in the Savage River watershed (Heft et al. 2006), including a no-harvest, artificial-lure-only regulation, which began in 2007 for most of the watershed.

In addition to the more common stream resident fishes, we have recently discovered a population of large, fluvial Brook Trout that seasonally inhabit the lower reaches of the USR. This mobile component remains poorly characterized and seasonally inhabits the only reach that remains open to Brook Trout harvest – the Savage River Put and Take management area (SRPT) (Figure 1).

Prior to the new regulation (pre-2007), anglers rarely reported catching large Brook Trout (>200mm total length) in the SRPT. Since the regulation change,

there has been a substantial increase in angler reports of large Brook Trout being captured, supported by Maryland DNR sampling data which has shown an increase in the average and maximum size of Brook Trout in the system (Hilderbrand 2012). As the size and number of Brook Trout have increased, angler reports and current creel survey information (Sell et al. 2012) suggest that a relatively large number of adult Brook Trout are being harvested in the SRPT. Additionally, it is likely that Brook Trout harvest is particularly high during the spring months (March through May) when angling pressure is at its highest and surface water temperatures are best suited for Brook Trout habitation in the main-stem USR.

Our objectives were to determine the movement patterns of Brook Trout in the main-stem USR watershed using radio telemetry and determine their susceptibility to harvest in the SRPT. We tested the hypothesis that Brook Trout in the put-and-take section of the USR inhabit the area seasonally and migrate to thermal refugia when summer water temperatures exceed their thermal limitations.

## STUDY SITE

The USR is a large watershed located in east-central Garrett County, Maryland and is part of the larger North Branch of the Potomac River drainage. The watershed covers approximately 300 km<sup>2</sup> and ranges in elevation from 290 m at its mouth to over 850 m at its origin. Most (53%) of the watershed area is within state-owned property, including the Savage River State Forest and is mostly mixed deciduous and coniferous forest. Some low density residential homes (seasonal camps in the lower portion of the watershed and some residential homes in the upper third) and a moderate amount of agriculture in the headwaters comprise the remaining land cover (Figure 1).

The USR system consists of the main-stem upper Savage River from the Savage River Reservoir upstream to the headwaters, eight named tributaries, and many unnamed tributaries. Water chemistry and habitat are typical of freestone Appalachian streams. The main-stem USR experiences low summer flows and water temperatures that typically exceed 20° C (Figure 3), the upper temperature tolerance for Brook Trout (Fisher and Sullivan 1958; Power

1980; Hartman and Cox 2008). Upper Savage River tributaries have maximum water temperatures that rarely exceed 20° C and support fish assemblages representative of high gradient coldwater Appalachian streams, whereas main-stem USR assemblages are more diverse and representative of low to moderate gradient, Appalachian streams (MD DNR 2005). Brook Trout are the only wild salmonid species within the watershed. Stocked Rainbow Trout *Oncorhynchus mykiss* are typically confined to the main-stem USR, have negligible survival, and no reproduction. Brown Trout *Salmo trutta* stocking was discontinued in the mid-1980s, and they are now considered extirpated from the USR system.

## METHODS

Fifteen large (> 240mm) Brook Trout were collected by angling from the put-and-take management area on the USR during the period of February 2 through February 22, 2012. Additionally, one Brook Trout was collected during this same time period in a tributary stream (Poplar Lick) to investigate the possibility that there are stream resident “tributary fish” in the USR tributaries.

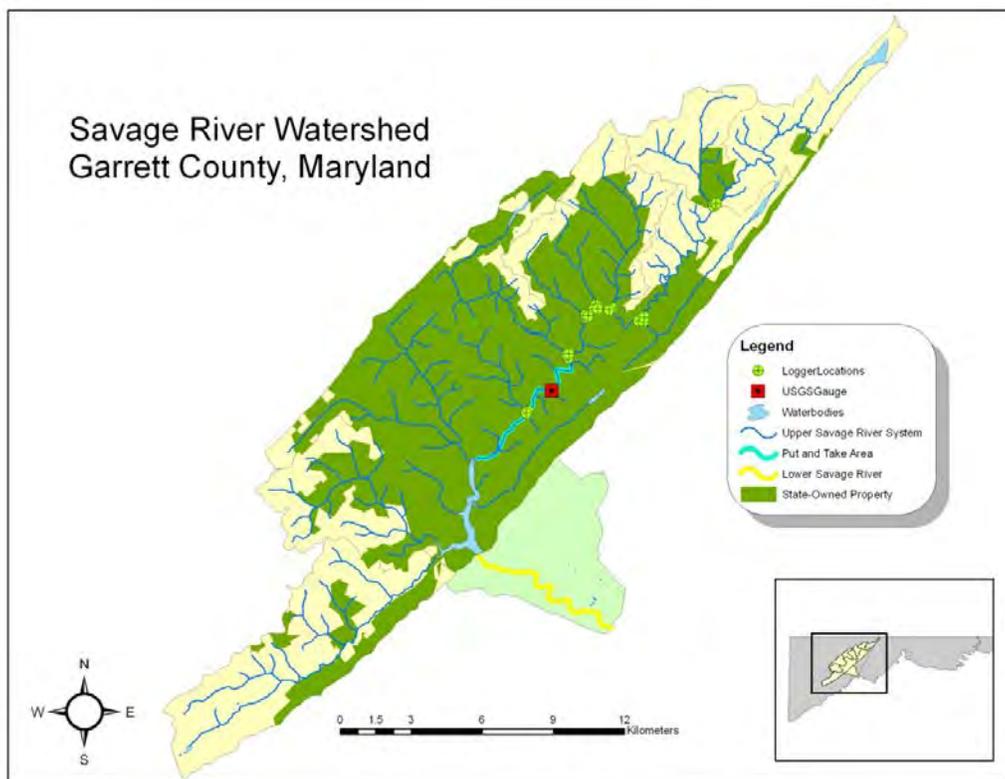


Figure 1. Study area, showing state-owned property and temperature logger locations.

Captured fish were immediately transported to an in-stream live well where they were measured. Fish  $\geq 240$  mm, total length (TL) were then tagged. The minimum size threshold of 240 mm was determined using long-term Brook Trout length-weight relationship developed by the MD DNR in the USR system. Tagging above this threshold ensured that the tag weight was always below 2.5% of the fish's total weight (Winter 1983; Swanberg 1997).

Brook Trout were anesthetized using a diluted (1 ml clove: 2 L water) clove oil solution (buffered with ethanol, 1:10), checked for injuries, and abdominally implanted with a radio tag (Advanced Telemetry Systems model F1170, 45 pulses per minute). Fish were allowed to recover in an in-stream live well for approximately 15 min and were returned to their place of capture.

Tracking was initiated on March 1, 2012 after the tagged trout were at large for at least 2 weeks and continued until the tags had expired (~1 year). We used a directional loop antenna along the entire main stem and eight major tributaries to the USR. Initially, tracking occurred at least once weekly, slowed to biweekly when fish movements slowed or stopped, and again resumed weekly when movements resumed. From late September through the end of November, tracking was conducted weekly to determine any movements associated with spawning activity.

The exact location of tagged fish was recorded using a hand-held GPS unit. The general habitat type where the fish was located was recorded (i.e. deep pool, run, riffle and whether woody debris or other gross instream habitat was present) and water temperature was measured at each location. Brook Trout locations were downloaded to ArcGIS (v. 10.0), where movement distances were calculated.

Continuous summer water temperature data were collected at 1-h intervals using HOBO brand in-stream devices in the eight tributaries of the USR as well as at multiple locations in the main-stem USR (Figure 1). Data were collected from June through August and were used to determine mean and maximum summer water temperatures. Annual main-stem water temperatures were obtained from the U.S. Geological Service (USGS) gauging station (gauge #01596500) located near the middle of the put-and-take section (J. Dillow, U.S. Geological Survey, personal communication) (Figure 1).

## RESULTS

### Trout Movements

We obtained long-term data (> 3 months) from 12 of the 16 tagged Brook Trout, but the four remaining trout disappeared by mid-May and were assumed to have been harvested. Of the 12 Brook Trout tracked long-term, eight made large-scale movements (>500 m) away from their capture locations, and two made moderate upstream movements (100-500 m). Movements by these 'mobile fish' all occurred during the early summer coincident with water temperatures approaching 20°C. Movements back into the main-stem river during the late fall were not temperature related, but rather, appear to be closely tied to the conclusion of spawning. Two of the 12 trout remained resident within 100 m of their capture location for the entire period, where they remained in large pools throughout the summer. The 'tributary fish' in Poplar Lick was sedentary throughout the study.

Migratory fish moved an average of 5.9 km upstream and into either the upper reaches of the main-stem river (n=4), into Poplar Lick (n=4), or the Little Savage River (n=2). After their initial migration, these trout exhibited sedentary tendencies throughout the summer months. During the fall spawning period, small movements upstream or downstream occurred. After spawning, most of the migratory fish (8 of 10) quickly returned to the area where they were tagged, seven of whom returned to the same pool where they were collected (Figure 2).

Localized movements for both migratory and resident trout were generally diurnal and restricted to the riffle areas immediately adjacent to the pools where they were tagged. These movements were typically less than 50 m and seemed to be related to feeding activity rather than directed movement.

The following is a summary of four representative and remarkable migratory fish movements.

Fish 041 was caught and tagged on February 21, 2012 in a large pool downstream of Westernport Road and was located on six separate occasions during the study period. This fish remained in the original pool for the majority of the spring and early summer until it was found in early July in the little Savage River, ~4.7 km from where it was tagged. It remained there until October 10, 2012, when it was found ~600 m upstream

in an area on the Little Savage River known locally as “Jacob’s Ladder”, and was observed building a redd. On November 20, 2012 this trout was found <50 m from the pool in which it was tagged.

Fish 280 was caught and tagged on February 7, 2012 in a large pool near the mouth of Bear Pen Run and was located on 10 separate occasions during the study . It remained in the pool where it was tagged until it was found in early July near the headwaters of Poplar Lick, ~11.1 km upstream. The trout remained there until November 6, 2012, when it was found in the pool where it was originally tagged. This trout moved the farthest of any migratory fish.

Fish 411 was caught and tagged on February 2, 2012 in a logjam near the USGS gauging station on the USR and was located on 11 separate occasions during the study . Initially the fish remained at its tagging location until July 5, 2012 when it was located ~6.3 km upstream in a large main stem pool. It remained there throughout the fall and was last found in the same location on November 26, 2012. This was one of

only two migratory fish that did not return to the area it was tagged after spawning.

Fish 421 was caught and tagged on February 2, 2012 in the Poplar Lick tributary and was located on 12 separate occasions during the study period. It remained in the same pool throughout the study period.

### Temperature

Temperatures in the main-stem USR were suitable for Brook Trout throughout most of the year (Figure 3). However, by mid-June daily maximum water temperatures regularly exceeded 20°C, and remained elevated until early September. Tributary water temperatures were elevated above those of previous years. The average and maximum monthly temperatures exceeded 20°C in many of the major tributaries, including Poplar Lick, but remained noticeably cooler than the main-stem USR, and only occasionally exceeded 20°C. Thus, we believe the tributaries provided adequate thermal refugia despite elevated temperatures.

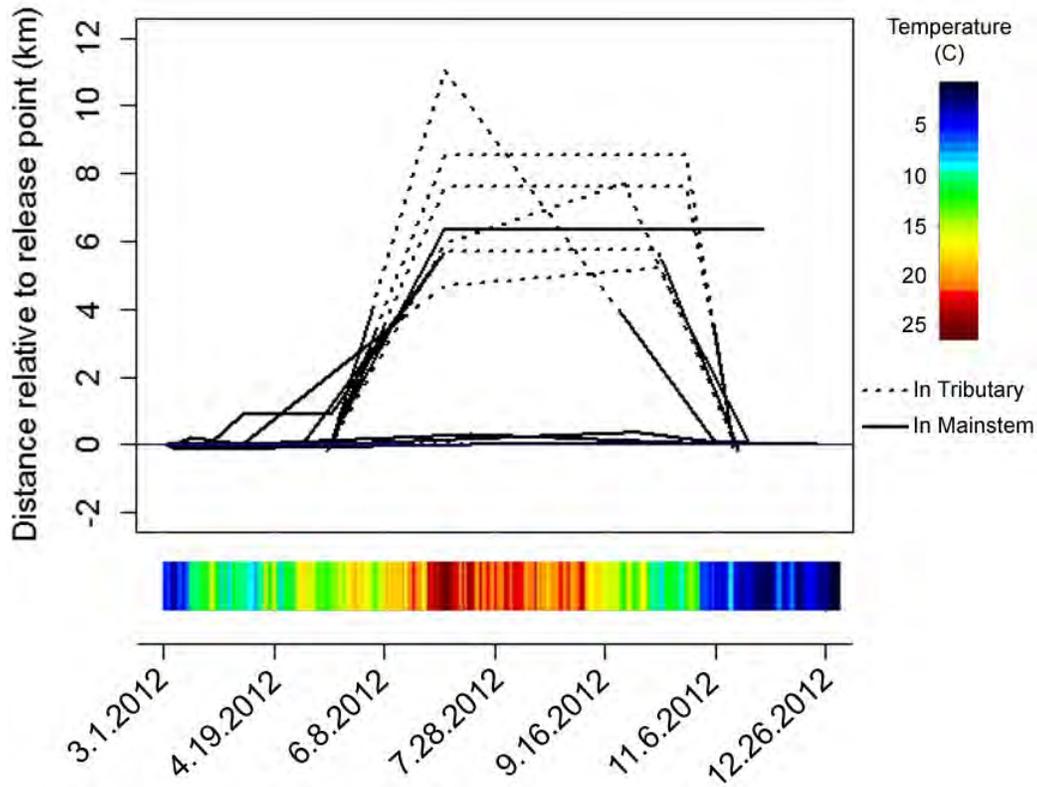


Figure 2. Movements of all tagged Brook Trout, relative to their point of release. Maximum daily temperatures shown in color bar.

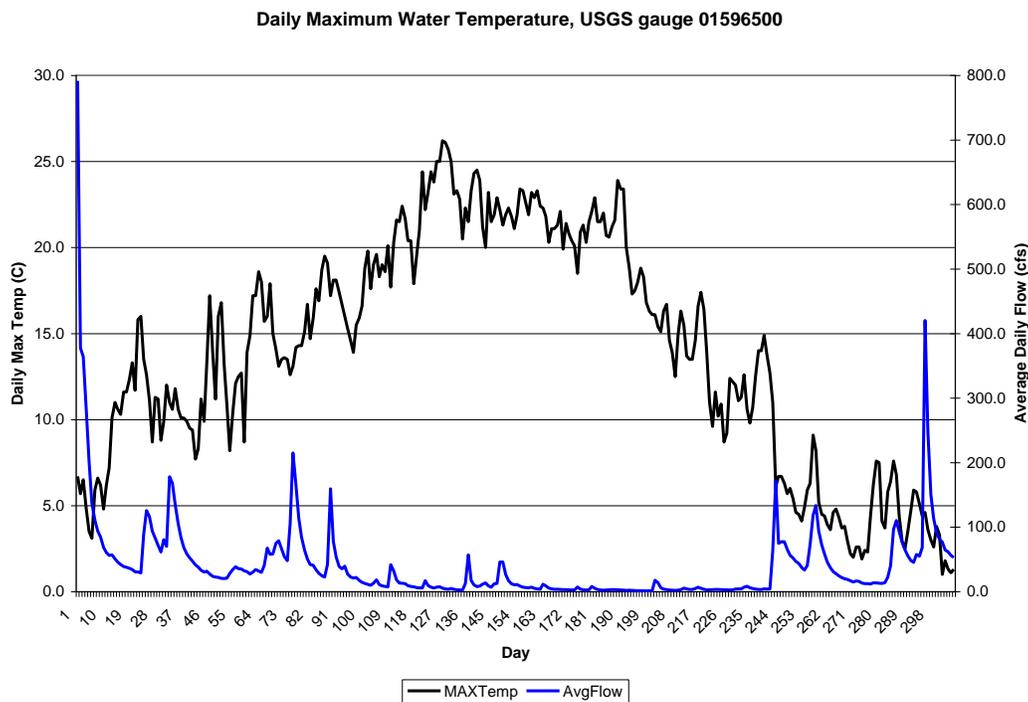
## CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Brook Trout in the USR main stem exhibited strong seasonal movements, often migrating long distances and frequently into tributaries. Migrations were coincident with increasing water temperature during late spring and at the conclusion of spawning during late fall. Our data suggests the USR population complex contains a continuum of movement strategists similar to salmonids elsewhere (Gowan et al. 1994; Hilderbrand and Kershner 2000; Curry et al. 2002; Petty et al. 2005 2012) with a mix of resident, semi-mobile, and highly mobile fish. However, the degree to which the various movement ‘strategists’ change behaviors or function as a single population, meta-population, or discrete populations is unknown and the subject of ongoing research.

The timing of residency in the USR main-stem suggests the fluvial Brook Trout are susceptible to harvest, as they reside in the put and take management area during the spring fishing season. Creel surveys confirm harvest of large Brook Trout, and include an

angler who reported harvesting a radio-tagged Brook Trout during the spring 2013. Regardless of whether these fluvial fish contribute genetically to the viability of the resident population in tributaries, they form an important part of the USR Brook Trout complex, as the large females may contribute disproportionately more to recruitment because fecundity scales non-linearly with length (Power 1980). Therefore, better information on susceptibility to harvest is needed to maintain a viable fluvial component for both the population and recreational angling.

The radio telemetry data have allowed a better understanding of how Brook Trout use the entire USR system, as well as identified critical reaches for growth, reproduction, and survival – a point further emphasized by the high site fidelity exhibited in the fluvial component of the population. We now realize the USR Brook Trout complex is a highly connected system that cannot be managed as independent reaches or tributaries without considering the responses of those actions cascading to influence other connected streams. Although a few of the tributaries to the USR are contained within state-owned property, many are



**Figure 3. Annual daily maximum water temperatures and average daily flows on the mainstem USR during the study period, as recorded at the USGS gauging station (01596500). Day 1 = March 1, 2012.**

not, but still have the potential to influence the entire fishery. Minimizing thermal gains in those areas by maintenance or establishment of riparian buffers and removal of heat sinks, such as small ponds, needs to occur. Likewise, two major tributaries are completely disconnected from the USR during low summer flows. This eliminates miles of potential thermal refugia during the summer months and could be rectified with habitat restoration. Such remediation and the subsequent cooling effects would help to maximize the amount of available habitat to the USR Brook Trout population, provide more reliable thermal refugia, and reduce main-stem temperatures during the summer.

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## REFERENCES

- Curry, R. A., D. Sparks, and J. van de Sande. 2002. Spatial and temporal movements of a riverine Brook Trout population. *Transactions of the American Fisheries Society* 131:551-560.
- Fisher, K. C., and C. M. Sullivan. 1958. The effect of temperature on the spontaneous activity of speckled trout before and after lesions of the brain. *Canadian Journal of Zoology* 36:49-63.
- Gowan, C. M., K. Young, K. D. Fausch, and S. C. Riley. 1994. Restricted movement in resident stream salmonids: a paradigm lost? *Canadian Journal of Fisheries and Aquatic Sciences* 51:2626-2635.
- Hartman, K. J., and M. K. Cox. 2008. Refinement and testing of a Brook Trout bioenergetics model. *Transactions of the American Fisheries Society* 137:357-363.
- Heft, A. A. 2006. Maryland Brook Trout Management Plan.
- Hilderbrand, R. H., and J. L. Kershner. 2000. Movement patterns of stream-resident cutthroat trout in Beaver Creek, Idaho-Utah. *Transactions of the American Fisheries Society* 129:1160-1170.
- Hilderbrand, R. H. 2012. Assessing the effectiveness of the Savage River Brook Trout regulations – sampling year 2012. Annual report to Maryland Department of Natural Resources Fisheries Service, unpublished.
- MD DNR (Maryland Department of Natural Resources). 2005. Survey and management of Maryland's fishery resources. Annual (2005) and final (2001-2005) performance report: 219-393.
- Petty, J. T., P. J. Lamothe, and P. M. Mazik. 2005. Spatial and seasonal dynamics of Brook Trout populations inhabiting a central Appalachian watershed. *Transactions of the American Fisheries Society* 134: 572-587.
- Petty, J. T., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook Trout movement in response to temperature, flow, and thermal refugia within a complex Appalachian riverscape. *Transactions of the American Fisheries Society* 141:1060-1073.
- Power, G. 1980. The brook charr, *Salvelinus fontinalis*. Pages 141-203 in E. K. Balon, editor. *Charrs, salmonid fishes of the genus Salvelinus*. Dr. W. Junk, The Hague, The Netherlands.
- Sell, M. T., and Heft, A. A. 2012. An evaluation of use, techniques, demographics, and fishing success by anglers in the Savage River put and take management area. Report to Maryland Department of Natural Resources Fisheries Service, unpublished.
- Swanberg T. R. 1997. Movements and habitat use by fluvial bull trout in the Blackfoot River, Montana. *Transactions of the American Fisheries Society* 126:735-746.
- Winter, J. D. 1983. Underwater biotelemetry. Pages 371-395 in L. A. Nielsen, D. L. Johnson, and S. S. Lampton, editors. *Fisheries techniques*. American Fisheries Society, Bethesda, Maryland.

## EXTENDED ABSTRACT: THE ROLE OF NORMS AND INFORMAL SANCTIONS IN A RAPIDLY GROWING CATCH-AND-RELEASE ATLANTIC SALMON FISHERY

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Catch-and-release (C&R) angling for Atlantic Salmon *Salmo salar* originated in the USA and Canada, and became part of formal regulations in the mid-1980s. Since the mid-1990s, Scotland, England, and Wales had significant increases in C&R (Aas 2007). From 2009 to 2012, C&R of Atlantic Salmon in Norwegian rivers grew from 7% to 16% of the total registered catch (Statistics Norway 2013), indicating a growing and emerging norm for C&R. The registered C&R rate in Norwegian rivers varies from 0 to more than 50%. Discussions in the media show opposition as well as support of C&R, suggesting norms for keeping as well as releasing fish.

For norms to be able to guide angler behavior, there must be associated sanctions, and especially self-sanctioning, for conforming or violating to the norm (Heywood 2011). This study aims to increase our understanding of the growth in C&R angling by studying angler perception of C&R obligations and self-sanctioning in an Atlantic Salmon fishery. Further, we investigate how self-sanctioning influence anglers' behavioral intention to voluntarily release fish.

Anglers might have different social standards for releasing or keeping fish. Standards are situational and could change for the individual depending on place, people, or species involved (Arlinghaus et al. 2007). Social standards are normative, if they have crystallized and have strong intensity. *Crystallization* is the level of agreement or consensus about a norm (e.g., releasing fish), whereas *intensity* is the relative strength or importance of a norm. The power of a norm to influence behavior is a function of the certainty of obligation (crystallization) and certainty of sanctions (intensity) implied when conforming to or violating that norm (Heywood 2002).

Many approaches to norms emphasize a sense of obligation by the individual and possible sanctions such as punishment for violating norms and reward for

following them (Heywood 2002). Social norms can be enforced through informal sanctions by other anglers who hold the norm, internalized by the angler in form of a personal norm, and then enforced by that person on oneself and on others (Heywood 2011).

Our study site, the Lakselva River salmon fishery in Northern Norway is known for big salmon and encouragement of voluntary release. It has among the highest release rates in Norway, increasing from 9% in 2007 to 40% in 2011 and 2012. In winter 2012, we sent anglers an e-mail survey which yielded 656 responses, a response rate of 68%. The questionnaire was available in Norwegian, Finnish, English, and German.

There was large variation within the angler sample on many of the C&R variables. One of four anglers was unlikely, and almost 50% were likely to voluntarily release a large salmon the next year they fished Lakselva. The personal norm to release all fish caught was held by only 19% of anglers. Almost half of the anglers were in opposition to releasing all fish they caught. However, the personal norm to keep all legal fish was held by only 9% of the anglers. Two thirds of all anglers were opposed to keeping all fish. The obligation ("what others should do") for Lakselva anglers to release or keep all fish caught, as expressed by the aggregation of individual angler response, showed similar trends with about equal proportions holding that social standard norm. Fewer anglers reported opposition to these two standards than to the personal norm.

The reward (positive feeling; such as pride, admired, guiltless, comfortable) was high and punishment (negative feeling; such as embarrassed, ashamed, guilty, uneasy) very low for releasing a large salmon as expressed by the intensity of self-sanctions. About two out of three anglers saw C&R as a rewarding experience. Most anglers saw keeping

a large salmon more as a rewarding experience than as a punishment. The power of the C&R norm was relatively high, and higher than the norm of keeping fish all fish.

A regression model showed that two variables, norm power of keeping all fish and norm power of C&R for all fish, explained 27% of the variation in angler intention to release a large legal salmon in the Lakselva River. While norm power of C&R had a positive influence on the intention to release, norm power of keeping all fish exerted a negative influence. Both norm powers contributed about the same to the model.

This study adds understanding to the growth in C&R angling by showing that norm power (self-sanctions and obligations) influences the intention to release fish. We further found that the personal norm, obligation, intensity of self-sanctions, and norm power to do C&R or keep fish differed among anglers. Our results support evidence for the existence of both a keep norm and a C&R norm in this fishery.

Arlinghaus et al.'s (2007) conceptual model of voluntary C&R pointed to personal and situational factors as the two main factors influencing behavior. Our study adds understanding to this model, and the work on C&R social norms by Stensland et al. (2013), since we investigate the self-sanction part of the C&R and keep norm concepts. We believe this is the first time these issues are studied empirically in the human dimensions literature.

The norm to do C&R only or Keep all fish was not highly crystalized in our sample, and there is an opposition by large parts of the sample towards these “extremes”. The results indicate the existence of agreement for a norm of releasing some fish, and a continuum of accepted C&R levels from 0 to 100% varying between anglers.

Studies addressing rivers with less C&R and especially local anglers should be conducted to compare with our results. In line with Heberlein (1974; p. 4-9, 2012) we suggest that encouragement of voluntary C&R must include a combination of cognitive (e.g., normative information) and structural (e.g., bag limits, awards for releasing fish) “fixes” or management actions.

## ACKNOWLEDGEMENTS

This work is part of the project *SALMONCHANGE* funded by the Research Council of Norway (project no. 208056), Directorate of Nature Management, the Agricultural Research Fund and Porsanger i utvikling. We thank Esten Sødal Skullerud, Egil Liberg, Katrin Daedlow, Timo P. Karjalainen and Jaakko Erkinaro for their contribution to data collection and translation work.

## REFERENCES

- Aas, Ø. 2007. The role of catch and release in wild Atlantic salmon conservation in Europe - possibilities and pitfalls. Pages 161–168 in R. F. Carline and C. LoSapio, editors. *Wild Trout IX: Sustaining wild trout in a changing world*. Wild Trout Symposium: Bozeman, Montana. Available [www.wildtrout Symposium.org](http://www.wildtrout Symposium.org). (July 2013).
- Arlinghaus, R., S. J. Cooke, J. Lyman, D. Policansky, A. Schwab, C. Suski, S. G. Sutton, and E. B. Thorstad. 2007. Understanding the complexity of catch-and-release in recreational fishing: An integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science* 15: 75–167.
- Heberlein, T. A. 1974. The three Fixes: Technological, cognitive and structural. Pages 279–296 in D. Field, J. C. Barren, and B. F. Long, editors. *Water and Community Development: Social and Economic Perspectives*. Science Publishers, Ann Arbor, Michigan.
- Heywood, J. L. 2002. The cognitive and emotional components of behavior norms in outdoor recreation. *Leisure Sciences* 24: 271–281.
- Heywood, J. L. 2011. Institutional norms and evaluative standards for parks and recreation resources research, planning, and management. *Leisure Sciences* 33: 441–449.
- Statistics Norway. 2013. Elvefiske etter laks, sjøaure og sjørøye, 2012 [River fishing for salmon, sea trout and sea run char, 2012]. Available <http://www.ssb.no/emner/10/05/elvefiske/>. (July 2013).
- Stensland, S., Ø. Aas and M. Mehmetoglu. 2013. The influence of norms and consequences on voluntary catch & release angling behavior. *Human Dimensions of Wildlife* 18:1–13.

# Poster Presentation

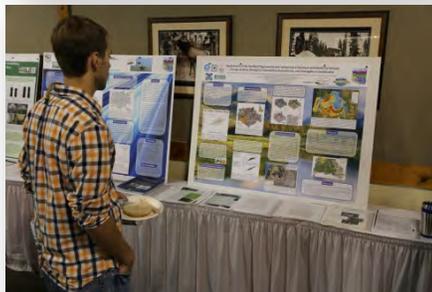
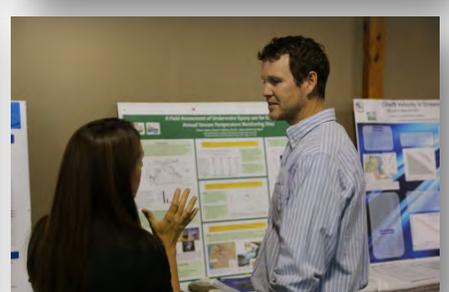
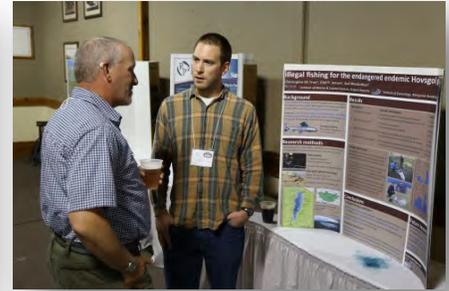




Photo courtesy of Mark Smith.

## Poster Presentations *(in alphabetical order)*

### Gila and Apache trout status in Arizona

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**Abstract:** Gila and Apache trout historically were found throughout the upper portions of the Little Colorado, Salt, Gila, and Verde rivers in Arizona. Both species were listed as endangered in 1973. Due to the efforts of state, federal, and tribal agencies as well as support from angling organizations, Apache trout were downlisted to threatened in 1975, while Gila trout were downlisted in 2006.

Threats to native trout in Arizona have increased considerably over the past 30 years, with non-native interactions and habitat loss being the major concern early in recovery efforts. While much of the ongoing effort remains focused on moderating interactions with non-native salmonids, monitoring barriers, and maintaining small, isolated populations, recent focus has also had to include the availability of suitable habitat across the historic range. Identification of watersheds able to support resilient populations on a long term basis will be an integral part of recovering these species. Over the last 10 years, drought has altered existing populations as well as decrease availability of suitable streams. Recovery of both Apache and Gila trout have also been plagued by stochastic events that have altered the landscape in the southwest. In 2011 and 2012 the Wallow and Whitewater Baldy wildfires impacted a significant number of populations of both species and also altered habitat conditions in several candidate watersheds. Each of these fires was the largest on record in both Arizona and New Mexico. While these events impacted populations over the short term, they also provide opportunity by removing non-native species from previously occupied streams which are now available for Apache and Gila trout. Continued recovery efforts will need to balance fundamental goals with the flexibility to respond to changing conditions in order to be successful at restoring these species across their historic range.

### New Fork River, Wyoming - interagency funded trout habitat restoration on private property

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**Abstract:** The New Fork River, near Pinedale Wyoming, is one of the most popular fisheries in the region. It is managed as a wild brown trout fishery, but rainbow trout and Snake River Cutthroat are also present. The primary impacts to the fishery are degraded in-stream and riparian habitat resulting from over grazing and poor water management practices. The goal of the project was to demonstrate and monitor restoration techniques that address limiting factors to the trout population and improve riparian function. The restoration design focused on low-flow fish habitat, bioengineered bank stabilization, and riparian vegetation re-establishment. A combination of j-hooks with vegetated benches, rock weirs, excavated pools, willow transplants, logs and point bars were used to promote natural channel functions.

Comprehensive monitoring has been performed since the completion of the construction phase of the project in April 2011. The restoration is showing strong signs of success despite being constructed shortly before an abnormally high and long runoff in 2011. The majority of the components have sustained high flows, remained stable, and are meeting the project objectives. Pool depths are being maintained by the structures and providing valuable low-flow refugia for trout. WGFD performed trout surveys on this reach of the New Fork River before and after project implementation and have found that populations of both brown trout and rainbow trout have experienced increases. The continuing monitoring efforts are helping to assess successful components of the restoration, and are intended to influence future restoration designs within the watershed.

This restoration project was a collaborative effort between private landowners, Intermountain Aquatics Inc., and several government agencies. The river is publicly accessed by drift boat. Funding was provided by the private landowners (46%), WGFD, Wyoming Wildlife Natural Resource Trust Fund, and the Jonah Interagency Mitigation Fund.

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### Kayak-based videomapping river systems for determining habitat distribution and large-scale wild trout population monitoring

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**Abstract:** The need to develop GIS-compatible large-scale maps of aquatic habitat in river systems led to the design of a kayak-mounted GPS-based river videomapping system. The river mapping system is kayak-mounted with georeferenced above and under water cameras, depth sounder, width sensors and underwater lasers. GIS maps of river and streambank characteristics - (pool, riffle, run), substrate (modified Wentworth scale), embeddedness (EPA classification), woody debris, bank cover, depth, width and river characteristic (pool, riffle, run) were developed. River thalweg rugosity and sinuosity were also determined. Every linear foot of river can be mapped at a rate of 10 miles per day. The system provides a GIS-based georeferenced database for river and stream inventory. A technique to define optimum habitat locations and habitat suitability indices for aquatic species was developed and implemented.

Complemented with a GPS-based snorkel videomapping system (GSVMS) and a Sneak Peek under-structure video exploration technique, site-specific fish population monitoring provide video documented georeferenced information regarding population, size, species distribution, location, and habitat. GIS-based video tours of the above and below water river features, providing virtual tours within ArcGIS and Google Earth will be demonstrated.

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### Brook Trout (*Salvelinus fontinalis*) in the Northern Driftless area: are there any natives left?

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**Abstract:** The brook trout (*Salvelinus fontinalis*) inhabits coldwater streams throughout the Driftless Area of western Wisconsin. These fishes are native to the area and reproduce naturally; however, streams throughout the region have also been augmented via stocking of eastern strains since the early 1900s. Presumably, a great deal of hybridization between strains has occurred and it is unknown whether any non-introgressed populations remain. In a collaborative effort with the Wisconsin Department of Natural Resources, nine streams were sampled, including some that have never been stocked but harbor self-sustaining populations. We have genotyped specimens from all these sites plus an outgroup population at 12 hypervariable microsatellite loci. In addition to classical measures of genetic diversity and connectedness (FST), results of Bayesian assays for population structure, including assignment tests and hybridization, will be presented. This information provides the Wisconsin DNR with valuable baseline data to direct management strategies.

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### High hopes: the Shavers Fork story

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**Abstract:** Historical logging, railroad construction, acid precipitation and river warming have degraded a remote and famous brook trout fishery high in the mountains of West Virginia. Those challenges have been and are continuing to be overcome by restoration professionals using state-of-the-art science, modern technology and a century-old steam locomotive. This narrated, multimedia PowerPoint presentation tells that story from a hopeful, yet realistic, perspective.

### Wader Wash Disinfection Project

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**Abstract:** We established 7 disinfection stations throughout the Island Park area for anglers to use to disinfect wading gear so invasive species were not transported to area waters. The goals of these stations were two fold. First to prevent the spread of aquatic invasive species and educate the public about the spread of invasive species. The second goal was to have the community of Island Park take ownership of the stations, and promote them to visitors.

The stations contained 20 gallons of a 1% solution of Virkon aquatic and educational material about aquatic invasive species. Fishermen were encouraged to use the stations by first removing as much debris from their boots, place their boots into the Virkon solution, and get the rest of their gear ready. The recommended amount of time for disinfection was 20 minutes. Fishermen were encouraged to disinfect their gear when they first came to the “caldera” and repeat disinfection only if they fished in another area. The solution was changed weekly and more frequently during peak season by local groups.

The wader wash stations were promoted through newspaper articles, presentations, and local promotion. Additional community groups requested assistance in establishing stations in 2013. Idaho Fish and Game received two grants to fund the project in 2013 (Idaho Fish and Wildlife Foundation and Resource Advisory Committee (RAC)). Western Chemical also donated packets of Virkon aquatic for the stations. The minimal cost of a station for the summer season was \$500 with the bulk of the cost in the Virkon solution. The stations received a lot of positive feedback from many anglers as well as businesses. They have been promoted throughout the season by the community and fishermen. They are a helpful tool to help prevent the spread of invasive species.

### Big Wood River Adopt-a-Trout Project

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**Abstract:** Native and wild salmonids, and the habitat they occupy, face greater threats than ever before. The list includes habitat loss, climate change, and competition from invasive and non-native species. While population and habitat restoration efforts increase, building stewardship for natural resources should be a top priority for conservation agencies and non-government organizations. As the number of anglers and hunters declines, so too does the number of resource proponents. Trout Unlimited’s Adopt-a-Trout program seeks to build long-term resource stewardship through education and on-the-ground field work.

Trout Unlimited’s Adopt-a-Trout (AaT) program is a place-based educational experience catered to elementary school students. AaT programs are focused on engaging students by putting them on the ground; up close and personal with coldwater salmonids and their habitats. The goal of AaT is to ensure that students become active citizens in their community and future stewards of local resources. AaT keeps the focus and attention of students by emphasizing hands-on, real world learning. AaT programs do this by:

- Inspiring students’ curiosity and interest in trout, their habitat, and aquatic ecosystems.
- Partnering students with biologists and resource professionals on research and science projects.
- Exposing students to future aquatic restoration activities and projects.
- Providing students with the knowledge and skills needed to have fun fishing.

### Next generation sequencing analysis searching for molecular markers in the San Pedro Martir Trout.

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**Abstract:** San Pedro Martir Trout, *Oncorhynchus mykiss nelsoni*, is the only native trout species in Baja California peninsula, Mexico, but its genetic condition is not completely understood. In order to increase the number of genetic markers a next generation sequencing analysis has been carried out. Eight wild organisms were collected and DNA was sent for sequencing with Myseq, and Blast2Go in order to find microsatellites and single nucleotide polymorphism in genes of interest. In this paper we will present the results of the analysis obtained for the southernmost coastal rainbow population in North America with this important species for Baja California Peninsula.

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### Movement patterns and habitat use of Westslope Cutthroat Trout in the South Fork Clearwater River basin

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**Abstract:** Despite the wide distribution of Westslope Cutthroat Trout (WCT) *Oncorhynchus clarki lewisi* across Idaho, populations in some systems remain depressed. Snorkel surveys conducted on the South Fork Clearwater River (SFCR) basin suggest that densities of WCT are low and length structure is small. Over-harvest and limiting environmental factors (e.g., habitat, temperature) during the summer are hypothesized to have influenced populations of WCT in the SFCR system. Radio telemetry was used to describe seasonal movement patterns and habitat use of WCT during the summer of 2013. Thirty five tags were surgically implanted into fish (170-365 mm) from 30 May through 25 June, 2013. Analyses were conducted on movement and environmental characteristics measured during each tracking event for the 20 fish that survived the summer of 2013. Results described the sample of fish exhibiting two distinct movement patterns in the SFCR system. Nine of the tagged fish moved up into tributaries as stream temperatures increased exhibiting large home range. Eleven fish exhibited smaller home range and persisted in the mainstem river despite warm summer stream temperatures. No significant difference of temperature use between fish that remained in the mainstem and fish that moved into tributaries were found.

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### Engaging anglers in native trout recovery in southern Alberta: the stewardship Licence Pilot Project

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**Abstract:** Brook Trout *Salvelinus fontinalis*, although not native to Alberta, are present in many montane and foothills waters as a result of extensive stocking. In southern Alberta, Brook Trout populations have generally increased while native Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* and Bull Trout *Salvelinus confluentus* populations have declined. Attempts to conserve and restore native salmonids often require removing or reducing non-native species. The Stewardship Licence Pilot Project, initiated by Fish and Wildlife in 2009, is a collaborative project with Trout Unlimited Canada. The objectives of the project are to: 1) remove, by angling, as many Brook Trout as possible from specified streams so as to facilitate a recovery of the native trout populations,

2) increase public awareness about the importance of fish identification and the threat that invasive, non-native salmonids pose to native salmonids and 3) encourage stakeholder participation in recovery of native trout populations. In order to participate in the project, anglers must annually pass a four-species fish identification test and have completed one supervised outing. In 2012, outings were conducted on seven streams in three drainages in the Bow and Oldman River watersheds. Angler hours increased from 53 in the first year to 1,100 in 2012. The number of Brook Trout harvested increased from 104 in 2009 to 2,064 in 2012. A summary of the first several years of the project, including findings of interest, will be presented. The value and future of this project and other stewardship initiatives aimed at native fish will be discussed.

### Assessing the impact of illegal fishing on endangered Mongolian salmonid species using household interviews and surveys for derelict fishing gear

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**Abstract:** Although fishing and fish consumption are historically uncommon in Mongolian culture, they may be gaining prevalence, potentially as new sources of income or protein, as climate change makes herding more difficult. However, knowledge of fishing is largely anecdotal; little is known about the motivations for fishing, the frequency and methods of fishing, and the potential impact of fishing on Mongolian fish species, especially globally unique salmonids like the endangered endemic Hovsgol grayling (*Thymallus nigrescens*) and endangered taimen (*Hucho taimen*), the largest trout species in the world. The purpose of this study is to: (1) gain a better understanding of the motivations for fishing and the frequency and methods of fishing through interviews with herding families and (2) validate responses from these interviews using surveys for derelict fishing gear as an indirect indicator of illegal fishing activity. Preliminary interview responses suggest that gillnet fishing for grayling is widespread in Lake Hovsgol National Park and occurs primarily in river mouths during the spring spawn. Interviewees report decreases in the size and abundance of Hovsgol grayling as a result of fishing. Surveys for derelict fishing gear partially validate interview responses: fishing gear, predominantly gillnet material, was the second most abundant type of anthropogenic debris observed in shoreline surveys and was concentrated on accessible shorelines near river mouths. Furthermore, the most frequently observed gillnet mesh size in surveys for derelict fishing gear is also the most efficient mesh size at capturing Hovsgol grayling in our long-term monitoring study. These preliminary results suggest that illegal gillnet fishing could have an impact on the endemic grayling population. Additional data collection this summer will provide further insight into the prevalence of fishing in Mongolia's lakes and rivers and its potential impact on endangered salmonids.

### The movement and habitat use of Brown Trout (*Salmo trutta*) in the Au Sable River, MI: a radio telemetry study

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**Abstract:** Understanding habitat choice and movement patterns of trout may be a key element for maintaining viable populations. Using radio telemetry, we tracked the movements of 35 brown trout (*Salmo trutta*) in the Mainstream, South Branch, and North Branch of the Au Sable River, MI from July 1, 2012 through December 1, 2012 to determine summer daily movements, seasonal movements to spawning locations, and post-spawning movement. Fish ranging in size from 25-61 cm were located every three days in the summer, once a week in the fall, and bi-weekly in the winter. Sites occupied by fish >5 times were designated home sites (daytime) or feeding sites (nighttime), 1-5 times were designated secondary sites, and transitional sites were occupied once. Fish

averaged one home site, one feeding site, 2.3 secondary sites, and 2.6 transitional sites. Summer daily movement averaged 50 m (day to night locations) and home ranges averaged 170 m<sup>2</sup>. Individuals tended to move to nighttime sites on overcast days, and moved into small cold seeps or shallow water adjacent to coldwater discharge zones during hot weather. Spawning movement averaged 680 meters but ranged from 2 m to 10 km. All individuals returned to their respective home sites after spawning. No fish migrated between branches during the study. Our data indicate that brown trout have high home site fidelity throughout the year and move relatively little to feed and spawn. Thus, habitat improvement efforts should consider the distances from structures to potential feeding and spawning sites and temperature refugia when planning habitat improvement projects.

### Scale resorption in migrating and spawning steelhead trout of the Snake River basin

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**Abstract:** Scales have been used as a tool to interpret life histories in salmon populations for at least a century. Resorption can affect the accuracy of life history interpretations based on scale patterns, depending on severity, e.g., the strength and characteristics of spawn checks. Spawn checks have been reported in many species but no published studies have established the relationship between reproduction and scale features. Our objectives were to quantify scale resorption and identify contributing factors in migrating and spawning Snake River steelhead trout. Pre- and post-spawn scale samples from 72 free-ranging fish were paired for analysis. We found much individual variability in the amount of material resorbed between pre- and post-spawn samples. Most resorption occurred during the winter as the gonads were matured and secondary sex characteristics formed. In many cases, resorption was sufficient to obscure or eliminate an annulus. In a few cases, resorption was minor enough that the eventual spawn check may be hard to identify. We recommend that ancillary marks be investigated as a means to help identify weak spawn checks and to determine if resorption was sufficient to cause loss of an annulus. To our knowledge, this is the first quantification of scale resorption in free-ranging anadromous salmonids.

### A large-scale field assessment of underwater epoxy use to install annual temperature monitoring sites in rivers and streams

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**Abstract:** Stream temperature regimes are fundamentally important to understanding pattern and process in aquatic communities. Modern digital sensors can provide accurate and repeated temperature measurements that span multiple years, but are rarely deployed for more than a few summer months due to logistical constraints with seasonal stream access and concerns that large annual floods will destroy sensors. We developed an inexpensive, rapid protocol (sensor installation takes ~20 minutes) that uses underwater epoxy to attach sensors to large rocks and cement bridge structures so that annual temperature monitoring is feasible. Initial field trials suggested sensors were not biased by heat conduction through the attachment structure as long as solar shields were used. Subsequently, a large field assessment was initiated during the summers 2010 - 2012 wherein more than 500 temperature monitoring sites were established with epoxy in streams ranging in channel slope from 0.1% - 16% across the northwest U.S. Revisits to 179 sites indicate good sensor retention rates, with 88% - 100 % of sensors retained after one year in low-gradient streams (< 3%) and 70% - 78% retained in high-gradient streams (> 3%). The underwater epoxy technique is viable for installing temperature sensors in a wide range of streams and rivers and can be used anytime during low flows over a wide range of stream temperatures (2°C - 20°C). The technique

increases the efficiency of temperature monitoring by reducing the number of site visits to < 1/year rather than the current norm of 2/year for summer data and facilitates the collection of continuous data over multi-year periods for ~\$120 in initial equipment costs (primarily sensor costs). To access a copy of the protocol, visit the TreeSearch website at this weblink ([www.treesearch.fs.fed.us/pubs/44251](http://www.treesearch.fs.fed.us/pubs/44251)).

### **Saving wild trout In Banff National Park, Canada.**

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**Abstract:** Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) are in trouble in Canada. In 2006, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recommended the Alberta designatable unit be listed as threatened and in March 2013 the Federal Government of Canada accepted this recommendation, adding this fish to the federal list of species at risk. The Bow River and associated tributaries represent the northern most distribution of Westslope Cutthroat Trout in Alberta, Canada. The headwaters of this river system lie in the heart of Banff National Park.

Parks Canada undertook extensive DNA level sampling for Westslope Cutthroat Trout between 2005 and 2010. Only twelve populations (a combination of upper headwater river and stream segments, and isolated lakes) with pure genetics (i.e. 99% pure) and within the historic range remain within the park. Similar to other locations across North America, Banff National Park has issues with genetic introgression, competition and predation with non-native fish, all as a result of historic stocking practices.

In response to the 90-95% decline in distribution of this trout, Parks Canada has begun two subalpine lake restorations. Here I report of the work undertaken at Hidden Lake. In 2011, Parks Canada began a multi year project to remove non-native Brook Trout (*Salvelinus fontinalis*) from Hidden Lake. Once the Brook Trout are removed we plan reintroduce native Westslope Cutthroat Trout to the lake. For social reasons manual methods, primarily gill netting in the lake, and electrofishing in the associated outlet tributaries are being used. By October 2012, 3127 Brook Trout were removed from the lake and 930 Brook Trout were removed from approximately 4km of associated tributaries to a known barrier waterfall. The project has received considerable and positive media coverage as well as volunteer and stakeholder support.

### **Using carbon stable isotope analysis to assess autochthonous and allochthonous influences on an endangered Mongolian salmonid, the Taimen (*Hucho taimen*)**

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**Abstract:** The taimen (*Hucho taimen*), an endangered species native to the Eg-Uur Rivers of northern Mongolia, is the world's largest salmonid. Reaching a record length of 210 cm and weight of 105 kg, the taimen is the apex predator within this ecosystem, and has become the focus of a world-renowned catch-and-release fly fishery. Taimen are restricted to fluvial environments, achieving their large size based on production within these rivers and their riparian zones. Taimen are known to consume a wide variety of aquatic and terrestrial prey, including fish, amphibians, birds, and small mammals. Some degree of terrestrial subsidy is evident; however, the relative importance of different food sources is not well understood. Our research investigated the relative use of terrestrial versus aquatic carbon sources by taimen using  $^{13}\text{C}$  stable isotope analysis. We examined the carbon isotopic composition of key organisms in the Eg-Uur food web, including taimen, benthic invertebrates, aquatic plants, and terrestrial plants. Smaller taimen (360-525 mm) from the larger Uur River displayed  $\delta^{13}\text{C}$  values similar to benthic invertebrates, whereas the  $\delta^{13}\text{C}$  of larger taimen (700-766 mm) from the smaller Eg River was

most similar to terrestrial plants, with some influence from aquatic plants. While our current results are not statistically significant, these trends may be clarified through further study. This work suggests that terrestrial and aquatic contributions are both critical for this large endangered species, and conservation goals must take both of these components into account.

### Climate velocity in streams: what does it mean for trout?

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**Abstract:** Climate velocity is the rate at which a temperature isotherm shifts within a stream or river. To ensure persistence this century, species distributions must track the locations of isotherms that delimit thermally suitable habitat as they move upstream with climate warming. Here, we develop the equations for calculating isotherm shift rates in streams that can be used to represent historic or future warming scenarios and be calibrated to individual streams using local measurements of stream temperature and slope. A set of reference equations and formulas are provided for application to most streams. Example calculations for streams with lapse rates of 0.8 °C/100 m and long-term warming rates of 0.1-0.2 °C decade indicate that isotherms shift upstream at 0.13-1.3 km decade in steep streams (2-10% slope) and 1.3-25 km decade in flat streams (0.1-1% slope). Used more generally with global scenarios, the equations predict isotherms shifted 1.5-43 km in many streams during the 20th Century as air temperatures increased by 0.6 °C and would shift another 5-143 km in the first half of the 21st Century if midrange projections of a 2 °C air temperature increase occur. Variability analysis suggests that short-term variation associated with inter-annual stream temperature changes will mask long-term isotherm shifts for several decades in most locations, so extended biological monitoring efforts are required to document anticipated distribution shifts. Resampling of historical sites could yield estimates of biological responses in the short term and should be prioritized to validate bioclimatic models and develop a better understanding about the effects of temperature increases on stream biotas. To access a copy of this research paper, visit the TreeSearch website at this link ([www.treesearch.fs.fed.us/pubs/42640](http://www.treesearch.fs.fed.us/pubs/42640)).

### The NorWeST Regional Stream Temperature Database, Model, and Climate Scenarios

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**Abstract:** Stream temperatures strongly regulate the distribution and abundance of coldwater fishes like trout, salmon, and charr. Concerns about climate change and warming stream temperatures have prompted efforts to learn more about spatial patterns and temporal trends in streams and rivers across the northwest U.S. Here, we describe the NorWeST (i.e., NorthWest Stream Temperature) project to develop a comprehensive interagency stream temperature database and high-resolution climate scenarios across Washington, Oregon, Idaho, Montana, and Wyoming (~600,000 stream kilometers). The NorWeST database consists of stream temperature data contributed by >60 state, federal, tribal, and private resource agencies and may be the largest of its kind in the world (>45,000,000 hourly temperature recordings at >15,000 unique monitoring sites). These data are being used with spatial statistical network models to accurately translate ( $R^2 = 90\%$ ;  $RMSE < 1$  °C) global climate patterns to all perennially flowing reaches within river networks at 1-kilometer resolution. At present, stream temperature maps showing historic and future scenarios have been developed for 400,000 stream kilometers across all of Idaho, Oregon, and western Montana using data from more than 10,000 monitoring sites. The raw temperature data and stream climate scenarios are made available as ArcGIS geospatial products for download through the NorWeST website when individual river basins are completed ([www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml](http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml)). By providing open access to temperature data and scenarios, the project is fostering new research on stream temperatures and better collaborative management of aquatic resources through improved: 1) prioritization of habitat restoration projects, 2) climate vulnerability assessments for sensitive species, 3) decision support tools based on regionally consistent scenarios, and 4)

temperature and biological monitoring programs. Additional project details are contained in this Great Northern Landscape Conservation Cooperative newsletter ([www.greatnorthernlcc.org/features/streamtemp-database](http://www.greatnorthernlcc.org/features/streamtemp-database)).

### A thermal map for all Idaho streams

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**Abstract:** The diverse topography of Idaho, where elevations range from 600 - 13,600 feet, creates an equally diverse stream thermal landscape for trout. It is now possible to accurately describe that thermal landscape for all of Idaho's streams using the significant amounts of stream temperature data the aquatics community within the state has amassed in past decades. As part of a larger regional effort, the NorWeST project funded by the Northern Pacific and Great Northern LCCs has developed a comprehensive, interagency stream temperature database for Idaho that consists of data from >4,888 unique sites and >12,500 summers of monitoring effort. Those data were used with spatial statistical network models to develop an accurate ( $R^2 \sim 90\%$ ;  $RMSE < 1^\circ C$ ), high-resolution (1 kilometer) stream temperature model, which was then used to predict consistent sets of historical and future climate scenarios for all 100,000 kilometers of Idaho's streams. This poster depicts a historical composite scenario that represents average August temperatures from 1993-2011. The data for stream climate scenarios are available as ArcGIS shapefiles for download from the NorWeST website ([www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html](http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html)). Daily summaries (min/max/mean) of the temperature data used to develop the temperature model for Idaho are also available through the website if permission was given for their distribution. All data distributed through the website are attributed to the original source agency and contributing biologists/hydrologists in metadata files. Similar stream temperature maps and databases are being developed for Oregon, Washington, Montana, and Wyoming as the project progresses. More details regarding the NorWeST project are described here [www.greatnorthernlcc.org/features/streamtemp-database](http://www.greatnorthernlcc.org/features/streamtemp-database).

### Using microsatellite DNA analysis for monitoring Arctic Grayling populations

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**Abstract:** Arctic grayling (*Thymallus arcticus*) are highly adaptable to extreme conditions, utilizing variable spawning habitat, are able to tolerate low dissolved oxygen and harsh winter conditions. These fish migrate long distances but also shows high site fidelity.

There are four known life history strategies in northern Alberta with varying migration and holding patterns which may lead to behavioral changes and sorting that can be measured in population genetics.

Arctic grayling were collected from two locations in north-east Alberta: the Christina River mainstem and an unnamed upper tributary to the Christina River. Using microsatellite DNA analysis, we can describe: gene diversity; the level of population subdivision; heterozygosity/homozygosity (inbreeding coefficients); relatedness between populations (fixation index); and effective population number.

Results of analysis showed: there was no differentiation between upper tributary and lower main-stem river group (one population); genetically diverse (comparable to other populations in the Peace River basin); the population does not appear vulnerable to population substructure (appears genetically robust); there was a large effective population size; and good baseline as a reference population and for future monitoring.

### The world of trout: The First International Congress

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**Abstract:** Trout are present on every continent in the world except Antarctica. Probably no other fish, with the exception of salmon has inspired such a passionate following of artists, writers, anglers, scientists, and the public. For those of us who have spent our lives associated with trout in some way, they've managed to capture our imagination and have become part of who we are. Whether they are native or introduced they play an important role in ecosystems worldwide and are an integral part of the socioeconomic fabric of many local communities across the globe. These iconic species draw a passionate following from native peoples, commercial fisheries, anglers, and communities whose livelihoods depend on trout and their healthy populations. The economic return from these species contributes billions of dollars to people and communities around the globe. Unprecedented human population growth, rapidly changing climate, and resource exploitation have already contributed to dramatic declines in trout populations worldwide and will undoubtedly influence their future survival. In the First International Congress, we'll look at trout from a variety of aspects; trout in the literature, the art related to trout in media from video to painted canvas, the socioeconomic contributions of trout world wide and the unique role that trout play in many communities, the science and management of trout - what have we learned about their life histories and their habitat, and trout in the classroom and how they've been used to educate students and the public on the value of clean water and high quality habitat. We'll examine how, in spite of an increasingly warm and uncertain future, we can all ensure this remarkable group of fishes continues to provide the values and benefits that have inspired such a passionate following. Join us July 26-31, 2015 in Bozeman, Montana to be part of the conversation!

### The effect of environmental factors on the movement of Rainbow Trout in the Deerfield Reservoir system

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**Abstract:** Spawning movements of adfluvial salmonids can be influenced by a variety of environmental factors that have important implications for fisheries managers. In this study, we examine the influence of environmental factors on movement patterns of an adfluvial Rainbow Trout *Oncorhynchus mykiss* population in the Black Hills, South Dakota. We implanted passive integrated transponder (PIT) tags into three unique strains of hatchery-reared Rainbow Trout and resident Rainbow Trout and monitored their movements between Deerfield Reservoir and the Castle Creek tributary system from August, 2010-July, 2011. Movements of Rainbow Trout were detected using a stationary PIT tag reader deployed near the mouth of Castle Creek. We used multiple linear regression to model the relationship between Rainbow Trout movement and water temperature, photoperiod, and discharge. Using Akaike's information criterion (AIC), stream discharge was the top supported model explaining variation in Rainbow Trout movement. Models containing water temperature and photoperiod were also supported. Overall, however, models explained only moderate amounts of variation (<23%) in Rainbow Trout movement, implying that one or more important variables was missing from the analysis. Understanding how environmental variables affect the movement patterns of this unique population is essential in determining the proper management strategy for the Deerfield Reservoir system.

### A demographic description and economic analysis of trout fishing

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**Abstract:** The U.S. Fish and Wildlife Service, in conjunction with the U.S. Census Bureau, recently released the results of the National Survey of Fishing, Hunting, and Wildlife Associated Recreation that was administered in 2011. This report will dig deeper into the data to specifically look at various socio-demographic characteristics of

trout anglers and compare the findings to previous surveys to identify the extent of change over time. Among other things, this analysis will look at participation rates over time, demographic characteristics of participants over time, and expenditures. The analysis will also look at how trout fishing participation has compared to fishing for other species over time both in the number of participants and total effort (e.g. days of fishing). Other interesting demographic characteristics that will be evaluated include looking at the number of anglers and days of participation for both urban and rural anglers and by ethnicity and race. Age, household incomes, and education are other demographic characteristics that will be considered. Trends in how trout anglers compare in these categories to other anglers may also be of interest to better understand the changing nature of participants. Finally, the analysis will discuss how these findings may be used to improve support for trout fisheries.

### Fish community changes in Schoharie Creek tributaries (Mohawk Valley, NY) following hurricane Irene and Tropical Storm Lee

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**Abstract:** Hurricane Irene and Tropical Storm Lee delivered a flood-of-record event to the Schoharie Creek watershed on 26 August and 6 September 2011. Eight streams historically supporting wild brook trout were surveyed, once before and twice after flooding to analyze fish community changes. Post-flood mitigation (reduced sinuosity, berms, channelization and riparian damage) dominated 75% of survey sites (12/16). Average turbidity increased from pre-flood to 2013 post-flood, most notably in downstream reaches (8.23 NTU to 24.3 NTU, 196%). Average conductivity increased 45% at upstream sites (37.83  $\mu\text{S}/\text{cm}$  pre-flood to 55.13  $\mu\text{S}/\text{cm}$  post-flood) and by 17% downstream (54.50  $\mu\text{S}/\text{cm}$  pre-flood to 63.57  $\mu\text{S}/\text{cm}$  post-flood). Erosion, due to lack of riparian buffers may explain increases. Average brook trout catch per unit effort (CPUE) increased 122% in upstream reaches (pre-flood=36.0, post-flood 2012=68.0, 2013=79.8). Downstream brook trout CPUE initially decreased 31% six months post-flood (2012=18.6), but returned to pre-flood (pre-flood=26.7) levels 18 months post-flood (2013=27.9). CPUE increase may be explained by reduced habitat complexity, increasing capture efficiency. Brown trout (*Salmo trutta*) CPUE upstream (pre-flood=8.1) initially spiked 6 months post-flood (2012=37.5) but returned to pre-flood levels (2013=10.2). Downstream brown trout pre-flood CPUE (15.8) was comparable to 6 month post-flood levels (2012=16.6), but reduced 70% 18 months post-flood (2013=4.8). Blacknose dace (*Rhinichthys atratulus*) average CPUE increased across all years in upstream (pre-flood= 46.3 and post-flood; 2012=98.5 and 2013=78.0) and downstream (pre-flood=38.7 and post-flood; 2012=47.3 and 2013=156.9) study sites. Increased riffles from channelization may explain blacknose dace CPUE increase. Sensitive slimy sculpin (*Cottus cognatus*) did not follow this trend. Despite increased riffles, sculpin CPUE decreased 24% upstream (pre-flood=45.6 to post-flood 2012=45.0 and 2013=34.6) and had minimal population fluctuations downstream (pre-flood=51.9 to post-flood 2012=42.0 and 2013=48.9). Post-flood downstream sites had altered, unsuitable trout habitat (excessive, unnaturally shallow riffles) with poor water quality (increased turbidity and conductivity).

### Wild trout and native freshwater mussels: their relationship, focusing on *Margaritifera falcata* (Western Pearlshell).

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**Abstract:** Trout and native freshwater mussels have co-evolved, even crossing the continental divide together, literally. Native mussels have a unique life history. Native mussel reproduction includes a parasitic larval state, in which larval mussels, glochidia, attach themselves to a host fish's gills and fins. These mussel-bearing fish can travel extensively within rivers and among watersheds. This almost guarantees that larval mussels will be deposited in new locations. In the case of the western pearlshell (*Margaritifera falcata*, WPM), it can use a

multitude of hosts, almost all of which are salmonids: cutthroat trout, rainbow trout, brown trout, brook trout, sockeye salmon, Coho salmon, Chinook salmon, speckled dace, Tahoe sucker, and Lahontan redband. WPM can live upwards of 80-100 years, but without trout present, a key step in its life history is missing, securing its peril. North America hosts the world's highest diversity of freshwater mussels (over 300 species) and more than 70% have an imperiled conservation status. Native mussels continue to decline, including the WPM in the western U.S., which is found in Alaska, California, Idaho, Montana, Nevada, Oregon, Washington, Wyoming, British Columbia, and is presumed extirpated in Utah. The headwater nature of Wyoming drainages increases the risk of native mussel extirpation due to limited habitat for them in the state. Recent efforts have focused surveying on the western drainages in Wyoming: Bear and Snake Rivers, home to the WPM. In 2011 and 2012, the Wyoming Game and Fish Department performed systematic surveys for WPM at 23 sites. Their range in Wyoming extends from Grand Teton National Park to the southern Wyoming-Utah border. At sites with WPM, they were found in large numbers ranging from 500~1,200 individuals. Using the presence absence data obtained coupled with habitat and water quality data, a conservation status will be determined.

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### Monitoring and modeling to understand climate change impacts on Wisconsin trout streams

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**Abstract:** Initial modeling efforts to quantify the impact of climate change on Wisconsin trout streams suggested significant losses of native brook trout and introduced brown trout based on changes in water temperature. Here we present updates to our stream temperature and trout distribution models, and we present stream monitoring data to show how potential climate impacts may be realized in Wisconsin streams. We developed a soil-water-balance model, as an addition to our original artificial neural network stream temperature model, to generate daily time series estimates of potential groundwater recharge from precipitation, thereby linking precipitation to groundwater and stream temperature. The updated models highlight the relative resilience to climate impacts of Driftless Area streams, which are heavily influenced by inputs of cold groundwater, compared to streams in other areas of Wisconsin. We estimated changes in coldwater thermal habitat suitable for trout under the A1B emissions scenario using 10 global circulation models. Current climate conditions support 57% of stream kilometers across the state as thermally suitable for trout. By mid-century our models project a decrease to 47% (best-case) or 26% (worst-case). Trout distribution models project significantly greater losses for brook trout than brown trout, with many brook trout streams turning to brown trout streams. Following monitoring efforts that began in 2007 we have experienced significant flooding caused by multiple heavy precipitation events, drought, and wide ranges of air temperatures at various times of the year. We present empirical data on stream temperature, water levels, and trout distribution to show how thermal refugia and trout populations may persist, albeit at reduced levels, under projected changes in Wisconsin's climate. Finally, we discuss how monitoring data and model projections can inform adaptation strategies for building resiliency in trout streams threatened by changes in climate.

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### Improved grazing practices and stream reconnection restore riparian habitat and build trout resiliency in a Nevada watershed

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**Abstract:** With so much private land encompassing trout habitats in the West (e.g., 50% of the historic distribution of Lahontan cutthroat trout is on private lands), promoting positive change with private landowners and the ranching community is essential if we are to improve the conservation status of western native trout and increase resiliency to climate change at landscape scales. We detail progress on a long-term collaborative grazing restoration and reconnection effort in Maggie Creek, NV benefiting the federally-listed Lahontan cutthroat trout (LCT). Restoration in this watershed was initiated in 1993 by a suite of partners, including BLM, Newmont Mines, Inc., and several mine-owned and private ranches. Habitat restoration has focused primarily on implementing a combination of seeding, grazing rest and strategic rotational grazing schemes. Additionally, in 2005 the three primary tributaries housing LCT were physically reconnected via culvert remediation and an irrigation diversion structure on the mainstem creek was reconstructed to enable LCT dispersal throughout the watershed. Riparian habitat has improved dramatically both in extent and quality based on remote sensing and BLM measurements of metrics such as pool quality, amount of woody riparian vegetation and width to depth ratios. An influx of beavers has had substantial effects on the system; for instance, the number of beaver dams more than doubled in a recent assessment from 2006-2010, adding nine miles of additional ponding. One of Newmont Mine's shallow monitoring wells in lower Maggie Creek has shown a two foot rise in groundwater over the course of the partnership. Since 2001 Trout Unlimited has monitored LCT at 44 sites in the three tributaries; data suggest populations are responding positively to the habitat improvements and restored connectivity, with a steady increase since 2005 in the number of age 1+ fish along with an improved age distribution, even in drought years. This project demonstrates the value of collaborative monitoring to document habitat improvements and trout responses to restoration efforts, and suggests that encouraging 'conservation ranching' and ameliorating fragmentation at larger scales could dramatically improve the resiliency of LCT to climate change.

### Great Basin National Park - 15 years of successful Bonneville Cutthroat Trout reintroductions.

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Tod Williams, National Park Service

**Abstract:** In 1999 the park published its first fisheries management plan to reintroduce Bonneville cutthroat trout (BCT), unaware that a remnant population of pure BCT was harbored in a remote park stream. In 1999 and 2000 fin clips were and sent to the genetics lab at BYU and to Wild Trout and Salmon Genetics Lab University of Montana for genetic analysis and the results sparked a wave of successful native trout reintroductions.

Since discovering the pure remnant BCT, the park has successfully removed nonnative fish with rotenone, antimycin, and targeted electrofishing. The park has successfully reintroduced BCT to 4 watersheds totaling over 9.5 miles of streams or 39% of their historic stream habitat within the Park. In 2016, the park plans on constructing a fish barrier and expanding the BCT yet another 2.2 miles bringing the historic range within Great Basin National Park to almost 50%.

### Arctic Grayling population structure and diversity in Alberta

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**Abstract:** Arctic grayling (*Thymallus arcticus*) are cold-water, salt-water intolerant salmonids with a holarctic distribution including most of northern Canada. In Alberta, the abundance of Arctic grayling has been steadily declining since the 1950s and the species is now provincially classified as a Species of Special Concern. Although the suspected factors behind the Arctic grayling decline have been documented, no genetic studies of Alberta

Arctic grayling have been completed. We investigated population structure by examining genetic variation at nine microsatellite markers within 1100 individuals collected from 40 sites in the Hay River, Peace River and Athabasca River watersheds. We found that Arctic grayling were genetically distinct between major watersheds. Within the Athabasca River watershed, a significant and positive isolation-by-distance relationship was found indicating spatially limited gene flow. Fine-scale population structure in the Athabasca River watershed consisted of sub-populations linked by frequent gene flow. In the future, we plan to investigate correlations between contemporary landscape features and genetic diversity of Arctic grayling sub-populations.

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### Following Fishes: an anadromous lesson for secondary science students

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**Abstract:** The Following Fishes lesson plan is a joint project between the Idaho Chapter of the American Fisheries Society and the Idaho Department of Fish and Game. There is a need to educate the populace about anadromous fisheries issues and recruit able young scientists to the fisheries management field. There are 330 public secondary schools in Idaho, all of which must teach biology as per the Idaho State Content Standards, and about 116,000 high school aged students in Idaho, all of whom must pass through those biology classes. This allows us a unique opportunity to make an impact on those who will guide policy and join the work force in the future. I created a complete lesson about anadromous salmonid biology, lifecycle, and management. This was sent to 53 high school science teachers in Idaho as a pilot project. Participating teachers agreed to teach the lesson during the spring of 2014, and provide feedback. They were sent packets including electronic and hard copies of a formal lesson plan and supporting materials. In addition to biology teachers, environmental science teachers, oceanography teachers, and college professors have also shown an interest in using the lesson plan. Feedback thus far has been both constructive and positive, with some teachers choosing to use the lesson as-is and others extending the lesson using the list of accessory resources provided. The long term goal is to get this lesson into the hands of every biology teacher in the state of Idaho. In the poster I show an overview of the lesson plan and an example of how a student can track a Chinook or steelhead trout through its life cycle using PTAGIS and DART databases.

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### Restoration of coldwater ecosystems previously impaired by abandoned mine drainage

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**Abstract:** The objective of this project was to develop one of the first long-term, comprehensive chemical and biological monitoring plans to document the restoration of coldwater ecosystems from abandoned mine drainage (AMD) pollution. Water chemistry and biological monitoring, which included; benthic macroinvertebrate community metrics, fish species diversity, salmonid population dynamics, and genetic and morphological data for native brook trout were completed pre- and post-treatment in several watersheds located in the West Branch Susquehanna River basin in Pennsylvania. Following treatment of AMD, significant water quality improvements were documented and were accompanied by a shift from pollution tolerant benthic macroinvertebrate taxa to pollution sensitive taxa, and eventual increases in brook trout biomass and density. Differences in the morphometrics of brook trout inhabiting areas previously impaired by AMD compared to unimpaired reaches were also documented. These results indicate investments to abate AMD lead to incremental restoration and increased connectivity in coldwater ecosystems. In addition, this study highlights the importance of prioritizing native trout restoration projects in order to maximize the potential of natural recolonization without the need of stocking or reintroduction.

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### High mountain stream restoration - West Virginia style

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**Abstract:** Imagine a stream flowing northward at an elevation of 3,500 feet above MSL, whose riverbanks were lined with spruce and hemlock; whose depths were filled with scores of large brook trout, and was visited 100 years ago by individuals, who helped shape America during the industrial revolution, to enjoy incredible trout fishing. Now, fast forward 100 years and see the same stream that, because of past timbering that removed much of the riparian habitat and changed the character of the river, is incapable of sustaining but a handful of trout in many of those same reaches – this is Upper Shavers Fork. The West Virginia Division of Natural Resources' Stream Restoration Program began over 50 years ago to reverse the damage to streams caused by acid precipitation. Limestone drums and the addition of limestone sand directly to streams have been very successful in raising stream pH. However, some stream systems require more than just chemical treatment to restore viable trout populations. So a few years ago the WV DNR added a physical habitat improvement component to its Stream Restoration Program. Over the past several years, working with many partners, a number of habitat projects have been initiated and completed, with additional projects planned. However, habitat work in Upper Shavers Fork presents many challenges, of which access has been one of the biggest - because the only access is by railroad. Science and technology were used, and continue to be utilized, to design, implement and monitor habitat improvement projects in the Upper Shavers Fork watershed. The goal of these projects is to improve, enhance, and reconnect trout populations through habitat improvements and barrier removal so they can productively utilize the main channel of Shavers Fork, as well as move back and forth into the tributaries.

### Status of a freshwater ecosystem after a hurricane event

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**Abstract:** Brook trout (*Salvelinus fontinalis*) are classic indicators of ecosystem health. They are very particular when it comes to where they can live. Brook trout were studied to determine how they and in turn, the stream system had recovered after Hurricane Irene in 2011. From July to early November, water temperature and ambient light were recorded using data loggers in six different locations in Styles Brook of the eastern Adirondacks in New York State. Two sets of dissolved oxygen readings were monitored at three sites. Brook trout were visually surveyed and underwater video was taken throughout the stream to document presence and behavior. Scales were safely taken from nine fish for aging. Stream bottom sediment was obtained in one heavily damaged area of Styles Brook to be analyzed. Temperature and dissolved oxygen levels were excellent for brook trout survival. Underwater video documented feeding and territorial behaviors by brook trout due to unique dynamic of surrounding stream features brought on by Hurricane Irene. Sediment revealed to be thousands of years old, evidence of the damage caused by Hurricane Irene. Fish aging indicated trout being born in this stream after Irene. It was concluded that certain areas of Styles Brook can still support and propagate brook trout despite the devastation caused by Irene.

### **Bull Trout age structure estimation based on mark-recapture history in the East Fork Salmon River, Idaho**

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**Abstract:** The East Fork Salmon River (EFSR) trapping facility is operated annually to capture wild adult Chinook salmon. However, Bull trout (*Salvelinus confluentus*) are also incidentally captured at the trap. Since 2007, all Bull trout captured have been tagged with Passive Integrated Transponder (PIT) tags. From these fish, 455 recaptures occurred at least 1 year after the previous capture. Thus, with minimal additional resources, a powerful mark-recapture data set was acquired. Fabens' and Wang's modifications to the Von Bertalanffy model were applied to this data to construct growth models for males, females, and all combined. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and R<sup>2</sup> values were used to determine which model was the best representation of the data. It was found that the Fabens' model with combined sexes was the best fit. This model was then used to estimate the age, based on length at the time of capture, for all individuals (n=1,358). The age at time of capture varied from 3-13 years old with most individuals being 5 years old (n=417, 30.7%). Bull trout 4 to 8 years in age comprised 90% of all fish. When compared with previous studies that aged similar populations of Bull trout using fin rays, the Fabens mark-recapture age structure appears similar. However, validation is needed to determine the accuracy of this estimation. This method may provide a simple and non-invasive means to estimate age structure and subsequent population metrics in robust sampling scenarios.

### **Coeur d'Alene Basin restoration: planning restoration of natural resources injured by mine waste contamination**

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**Abstract:** Large-scale restoration of natural resources and associated services is being planned in the Coeur d'Alene Basin through a partnership of state and federal agencies and the Coeur d'Alene Tribe. Restoration will address injuries to natural resources caused by historic releases of mine waste contamination from the Coeur d'Alene Mining District including lead, cadmium, and zinc. Injured natural resources include fish, wildlife, plants, wetlands, surface waters in lakes and streams, and associated services include hunting and fishing, wildlife watching, recreation, and other benefits.

A comprehensive Restoration Plan/Environmental Impact Statement is being developed to describe the philosophies, priorities, and strategies for restoration. It will also describe existing conditions and evaluate possible effects of restoration actions. Concurrent with comprehensive planning, several restoration projects are ongoing under a 2007 interim plan. Additionally, restoration will be coordinated with ongoing remediation (clean-up actions) of the Coeur d'Alene Basin Superfund site led by the Environmental Protection Agency.

This initiative is being led by natural resource trustees represented by the U.S. Fish and Wildlife Service, Bureau of Land Management, USDA Forest Service, Coeur d'Alene Tribe, Idaho Department of Environmental Quality, and the Idaho Department of Fish and Game. Funds from a series of legal settlements for natural resource damage awards made approximately \$140 million available to restore, rehabilitate, replace, or acquire the equivalent of the injured natural resources. Community outreach and involvement are vital components of the work and public scoping is scheduled for early summer 2013.

Aquatic resources of interest include westslope cutthroat trout, bull trout, and surface water quality. Assessments will describe the current status of these resources as well as the desired future condition post-restoration. The

effects of mine waste contamination on the resources will be identified and other limiting factors will be addressed.

### Is different fishery management in boreal large lakes reflected in salmonid stocks?

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**Abstract:** Fishery management differs between Swedish, Finnish and Russia Karelian inland waters by fishing regulations and conservation status of endangered salmonid species. In large lakes in Sweden, gillnet fishing is strongly regulated. In Lake Vänern, wild individuals of landlocked Atlantic salmon and brown trout are protected, that is, they must be released in fishing. In Lake Vättern, three large areas, historically desirable for fishermen, but considered as important rearing areas for juvenile salmonids, are closed for fishing. In addition, seasonal closures of areas are also used to protect migrating salmonids, both in lakes and rivers. In Finnish lakes, gillnet fishing is only slightly regulated, and wild salmonids are only recommended to be released, and just in a few lakes. Gillnet is the main method in salmonid catch in Finnish lakes, but trolling in Swedish lakes. In this study, gillnet fishing effort, state of spawning stocks, estimated number of wild smolts, and catch of stocked smolts were compared in most important salmonid lakes in Sweden and Finland and in Lake Pääjärvi in Karelia. In four lakes, CPUE of large salmonids in trolling could be compared, too. Gillnet fishing effort per lake hectare was much higher in Finland, and the state of wild and stocked spawning stocks was better in Sweden and in Lake Pääjärvi. Number of wild smolts and mass catch of stocked smolts were also higher in Sweden. Northern Lake Inari was an exception among the Finnish lakes by salmonid stocks. Differences in the salmonid stocks between the Finnish lakes and the other lakes are most likely because of high fishing mortality of wild and stocked fish due to widely used gillnet fishing in Finnish lakes.

### Migration patterns of wild adult Brook Trout in northern New Hampshire

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**Abstract:** Self-sustaining wild brook trout populations may be found in many brooks throughout New Hampshire and Maine but few exceed a lifespan of 4 years, or attain lengths over 152-178mm. The Dead Diamond River and the Magalloway River are rare in that they produce wild brook trout in excess of 381mm. Annual electrofishing assessments confirmed a high level of brook trout under 225mm. This raised many questions. Where are the larger fish that so many anglers speak of? Do they exist? Do they leave the Dead Diamond system and live in the Magalloway? Do they come back to spawn? What does this mean for fisheries managers? We utilized radio-telemetry to gather information to determine the migration patterns of wild adult (greater than 9") brook trout (*Salvelinus fontinalis*) both in the Dead Diamond and the Magalloway River systems.

Migration patterns varied for individual fish, with the greatest movement occurring in autumn. Movements were also affected by weather patterns. Thermal stress was a major cause of early migration but when water levels were consistent throughout the year, fish stayed in the Dead Diamond system and spawned. Fish then migrated to deeper portions of the Magalloway River and Umbagog Lake for the winter and returned in the spring. These fish migrated great distances throughout the year, some fish traveled greater than 119 kilometers. This research has been utilized by many state agencies and NGO's to argue the need for passage in both small and large river systems.

### The population and status of Bonneville Cisco in Bear Lake 1990-2012

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**Abstract:** Hydroacoustic monitoring of the Bonneville cisco (*Prosopium gemmifer*), a main prey item of Bonneville cutthroat trout, population in Bear Lake was developed by Utah State University (USU) in 1990. USU continued to monitor the population annually through 1996. In 1996, the Utah Division of Wildlife Resources (UDWR) acquired their own hydroacoustic system. Comparisons of the cisco population estimates made by the USU dual beam system were compared to estimates made by the UDWR split beam system. Only small, insignificant differences in the population estimates were observed. From 1996-2013, the UDWR has assumed sole responsibility of annual hydroacoustic sampling in order to monitor the population of cisco in Bear Lake. The annual data that have been collected on a long-term basis shows some promise in being able to track stronger year classes of cisco throughout their lifetime as well as recognizing differences in length/frequencies of cisco in some of the years. Population fluctuations are discussed and we have also attempted to show correlations of cisco population as a function of water level and the predator population in the system.

### Jumping the falls? Interactions between resident and anadromous *O. mykiss* populations at a putative natural barrier, Big Bear Falls, Potlatch River, Idaho

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**Abstract:** Big Bear Creek in Potlatch River, ID contains a strong wild *O. mykiss* population despite significant habitat degradation within the drainage. The population is comprised of both anadromous and resident *O. mykiss* groups. Anadromous populations spawn and rear in lower Big Bear Creek, whereas resident populations occur approximately 20 kilometers upstream in the headwaters. Located between the populations is Big Bear Falls; a putative upstream migration barrier. This experiment was conducted to determine the effect of the falls on steelhead upstream migration to guide potential habitat restoration approaches in Big Bear Creek. We collected tissue samples from 424 anadromous and resident *O. mykiss* throughout Big Bear Creek; all individuals were genotyped at 191 SNPs. Using multi-locus SNP data we evaluated directional gene flow in the creek, specifically at the waterfall. Our objectives were two-fold: 1) identify whether Big Bear Falls is a complete barrier to upstream migration for adult steelhead, and 2) gauge evidence for downstream migration from resident fish into the anadromous population. SNP allele frequency data shows that anadromous and resident populations are highly differentiated and that exchange of genetic material between populations is limited. However, we determined that juvenile *O. mykiss* captured directly above the waterfall were offspring of anadromous steelhead that successfully migrated and reproduced above the waterfall. Further, we identified evidence of downstream gene flow, suggesting that resident fish may contribute genetic material to anadromous populations. The Big Bear Creek drainage is a candidate for habitat restoration efforts that would likely benefit both native resident and anadromous *O. mykiss* life history forms in the drainage.

### Wyoming Trout Unlimited's Adopt-a-Trout Program

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**Abstract:** Wyoming Trout Unlimited's (WYTU) Adopt a Trout (AAT) program is an educational real-world science program pairing fisheries movement studies with a classroom. Participating students, typically between 4th and 8th grade, adopt their fish for the year and follow along with a movement study taking place in local

waters. WYTU and the Wyoming Game and Fish Department (WGFD) work together to come up with relevant fisheries studies. These studies have led to on-the-ground habitat, fish passage, and entrainment projects.

### **Morphological comparison of Southern Appalachian Brook Trout (*Salvelinus fontinalis*) relegated to allopatric headwater systems in Great Smoky Mountains National Park**

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**Abstract:** Environmental principle components influencing variations in salmonid population traits are well documented among geographical isolated populations. Brook Trout (*Salvelinus fontinalis*) from geographically isolated headwater streams in Great Smoky Mountains National Park present an idealistic phylogenetic modeling opportunity to differentiate phenotypic relatedness. Through the configuration of a landmark truss network, shape analysis comprised of individual static landmarks allowed me to examine phenotypic variance of individual isolated Brook Trout populations.

Here we analyzed the affects sex, elevation, and flow aspects have upon phenotype to Brook Trout populations from Great Smoky Mountains National Park headwater streams (n=38). We examined twenty-three morphometric and ten meristic characters, constructed a landmark truss network for multiple statistical examinations. Minimal Polygon Clusters were generated by plotting the retained largest contributing principle components of variance from to illustrate phenotypic variance amongst populations. Analysis of variance (ANOVA) was utilized to compare co-variate means of retained principle components. Populations that did not exceed critical alpha values under ANOVA testing conditions of  $P < 0.05$ , for morphometric and meristic characters, were considered unique phenotypic polymorphisms.

To further examine affects sex, elevation, aspect and locality had upon Brook Trout morphometrics and meristics; Nonmetric Multidimensional Scaling (NMDS) ordination plots were generated using PC-ORD with greatest vectors of similarity influence.

Our findings indicate high variation in Brook Trout shape analysis as represented by low p-values ( $<0.0001$  to  $0.1267$ ) from all ANOVA results. Meristic counts displayed greater continuity of outward expression similarities as represented by p-values ranging from ( $<0.0001$  to  $0.669$ ) across all ANOVA results. Here we provide significant evidence that the observed shape variation of unblocked Brook Trout analyzed is an artifact of sexual dimorphism coupled with phenotypic plasticity.

### **Identification of Native Fish Conservation Areas in the Upper Snake River basin**

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**Abstract:** Native Fish Conservation Areas (NFCAs) are watersheds where management emphasizes proactive conservation and restoration for long-term persistence of native fish assemblages while allowing for compatible uses. NFCAs are intended to complement traditional fisheries management that can be reactive to existing stressors and focused on single fish species rather than entire communities. We identified potential NFCAs in the Upper Snake River basin above Hells Canyon Dam using a process that ranked all subwatersheds (Hydrologic Unit Code 12) using data on native trout distributions, abundance, and genetics (bull trout *Salvelinus confluentus*;

redband trout *Oncorhynchus mykiss*; and Yellowstone cutthroat trout *O. clarkii*, including fine-spotted form); known occurrences and modeled potential distributions of native non-game fishes; differential species weights; drainage network connectivity; and land protection status. Clusters of high-ranking subwatersheds were identified as potential NFCAs that were then classified according to the presence of non-game fishes listed as Species of Greatest Conservation Need in state wildlife action plans. Last, we compare and contrast some of the potential NFCAs identified, and discuss the practical implementation of an NFCA in the Upper Snake River basin and how the concept relates to existing conservation partnerships.



Photo courtesy of Eric Stark.

# List of Participants



This list is generated from the participants registered prior to the start of the symposium. It does not include participants who joined the symposium as a walk-in registration.



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**Beartooth Pass – high lakes. Photo by Eric Stark**

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