Fisheries

Vol. 40 • No. 7 • July 2015

Silt Happens

Coldwater Fish in a Warming World

Smartphone App Reveals Angler Behavior

AFS


CUSTOM
ELECTROFISHING BOATS
[BUILT YOUR WAY]
PROVIDING PEAK
POWER
ABOVE
AND
BELOW THE WATER
INFINITY BOX
[ELECTROFISHING CONTROL BOX]
INFINITY XSTREAM
[BACKPACK ELECTROFISHER BATTERY OR GENERATOR POWERED]
STEALTH MINI-BOAT
[ELECTROFISHING MINI-BOAT / TOTE BARGE SYSTEM]
You asked. We delivered. MLES offers you innovative electrofishing solutions for the 21st century: top-notch equipment and superior customer service.
EMPOWERING YOU IN THE FIELD.
Midwest
LAKE MANAGEMENT, INC.
MLES
MIDWEST LAKE ELECTROFISHING SYSTEMS
816.804.5604
www.midwestlake.com
7561 SW Prairie Ridge Rd. Polo, MO 64671

Fisheries

Vol. 40 • No. 7 • July 2015

302 West Virginia University undergraduates and DLiWV participants record lengths and weights of captured fish. Photo credit: Daniel Hanks.

304 Culverts in Beaver Creek that prevented fish passage were replaced with a fish-friendly structure in 2005. Photo credit: Elko District BLM.

338 Shayle Matsuda's conference sketches. Image credit: Shayle Matsuda.

Fisheries

American Fisheries Society • www.fisheries.org

EDITORIAL / SUBSCRIPTION / CIRCULATION OFFICES
5410 Grosvenor Lane, Suite 110•Bethesda, MD 20814-2199
(301) 897-8616 • fax (301) 897-8096 • main@fisheries.org

The American Fisheries Society (AFS), founded in 1870, is the oldest and largest professional society representing fisheries scientists. The AFS promotes scientific research and enlightened management of aquatic resources for optimum use and enjoyment by the public. It also encourages comprehensive education of fisheries scientists and continuing on-the-job training.

DUES AND FEES FOR 2015 ARE:

$80 in North America ($95 elsewhere) for regular members, $20 in North America ($30 elsewhere) for student members, and $40 ($50 elsewhere) for retired members.

Fees include $19 for *Fisheries* subscription.

Nonmember and library subscription rates are $191.

FEATURES

AFS ANNUAL MEETING 2015

IN MEMORIAM

UNIT NEWS

JOURNAL HIGHLIGHTS

BACK PAGE

COVER

Rio Grande Cutthroat Trout, one of many western trout whose habitat is increasingly susceptible to drought and higher stream temperature driven by a changing climate. Photo credit: Frank Weissbarth.

Fisheries (ISSN 0363-2415) is published monthly by the American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199

Periodicals postage paid at Bethesda, Maryland, and at an additional mailing office. A copy of *Fisheries* Guide for Authors is available from the editor or the AFS website, www.fisheries.org. If requesting from the managing editor, please enclose a stamped, self-addressed envelope with your request.

Postmaster: Send address changes to Fisheries, American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199.

Fisheries is printed on 10% post-consumer recycled paper with soy-based printing inks.

COLUMN
GUEST COLUMN

Point-Counterpoint: Be Flexible in the Number of Talks per Speaker at Meetings!


Scott A. Bonar

Scott A. Bonar
Unit Leader and Professor, USGS Arizona Cooperative Fish and Wildlife Research Unit, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721.
E-mail: SBonar@ag.arizona.edu

If you read AFS President Donna Parrish's April column, you saw that our meetings are becoming much more crowded. Therefore, as a professional society, we need to decide how we want to manage these larger meetings. Because I am a chair of an international symposium for the 2015 Portland Annual Meeting, Donna and I had a discussion about how the Society should manage its speakers. Should we allow people to present more than one oral presentation, or should our Society follow the lead of other societies who only allow one talk per person? Donna and I disagreed on the issue, and to her credit, she has the wonderful ability to disagree without being disagreeable—a great trait in a leader. She asked me to write an opposing view—sort of a "point-counterpoint" to her argument that it is only fair to allow one talk per speaker. I jumped at the opportunity! I love being argumentative!

I disagree that we should only allow one talk per speaker. At the risk of looking like a curmudgeon, let's face it—some people have more to say than others. I believe AFS is as much about passing on training and information to a new generation of fisheries scientists as it is to give everyone an absolutely fair and equal chance to talk by limiting presentations to only one per person. Many of us desperately want to hear seasoned veterans, or early career scientists with significant breakthroughs, pass on their information to help us advance the science. This is much harder if we use the "one-size-fits-all" approach and limit them to only one 20-minute talk. To take this to its extreme conclusion, what would you think of a conference that would prevent scientists like E.O. Wilson, Paul Ehrlich, or Albert Einstein from speaking more than 20 minutes in an effort to be "fair" to other conference participants? Darn it, it is not fair to those of us who want to hear and learn from these talented scientists!

We ran into this head on when we invited international participants to a standard sampling symposium at AFS Portland. These invited scientists represent some of the best fisheries minds in the world. They have much to say about our future direction, based on their extensive experience. They represent a rare opportunity for AFS to interact with the far-flung reaches of the globe, as a truly international society should do. However, they are limited to one 20-minute talk, hardly worth the effort of paying thousands of dollars for travel arrangements and securing permissions from various governments.

I believe we need some flexibility in the "one-talk-per-speaker" arrangement. Just because some other societies restrict talks to one per person to be "fair" does not justify it in all cases. Do we run the risk of allowing a boring self-absorbed individual to take up too much time at a conference? Certainly. However, I believe the up side to such an arrangement outweighs the downside. One way to minimize this risk might be to allow only one contributed talk per individual. Invited sessions should be given flexibility to invite people to speak again—consider it a reward for hard work in developing expertise so that you are noticed and invited. Not everyone should get a trophy.

In some conferences, more talks or symposia will be submitted than can fit. Conference organizers should have more flexibility to say "no" to some sessions or symposia to allow only the very best ones. This will be somewhat of a judgement call based on the deadline for submitting symposia and the content of the symposia. This will hurt some feelings. However, it is a judgement call similar to the ones many journals make when they limit numbers of articles. This will trim down the number of speakers to a manageable size. Under such an arrangement, I realize I run the risk of getting my suggestions kicked out—but hey—too late for this year! …at least I hope... AFS

Silt Happens...Literally

Thomas E. Bigford, AFS Policy Director

AFS Policy Director
Thomas E. Bigford
tbigford@fisheries.org

"Silt happens!" That simple riff off a common bumper sticker is a quote from Gary Esslinger, manager of the Elephant Butte Irrigation District in southern New Mexico (Weiser 2011). His sentiment arose from desert country but might have been uttered by Exelon Power about its Conowingo hydropower project on the Susquehanna River or the owners of the recently removed Elwha River dams on Washington's Olympic Peninsula. Or perhaps owners of some of the other power, water retention, or flood control structures that dot our landscape. The list of interests expands when those fine-grained sediments carry a heavy burden of contaminants, even mineral-grade levels worthy of a Superfund site. So here's some dirt on the complex issue of accumulating sediments and what they mean to aquatic systems, with implications to science, management, policy, engineering, and every other field.

These issues are ubiquitous because all waterways carry sediments. Where flow is interrupted, sediments drop out of solution and accumulate. If the interruption is a dam, most sediments are trapped immediately upstream of the blockage where they settle to the reservoir bottom. More sediment means less volume remaining for water, which could translate into less electrical power, water storage, aquatic habitat, recreational opportunity, etc. The silver lining is that those very same sediments also sequester significant loads of phosphorus and some nitrogen that otherwise would flush into downstream waters. Those artificial aids to restoration are appreciated until the stilled waters reach a sort of dynamic equilibrium where the reservoir is near capacity, the accumulated sediments must be removed, and potentially nasty mixes of agricultural and industrial chemicals are freed from the watery depths.

This scenario is likely unfolding at some scale in every jurisdiction on every continent. The waterways that deliver sediments and chemicals remain the primary source of most pollutants, but the dams and accumulating sediments are dangerous contributors with costly ramifications. Instead of a natural flow of sediment-laden waters to nourish downstream habitats, a dammed waterway offers pulses of sediments and pollutants. As reservoirs fill, water flow slows and sediments accumulate, so the dams slowly lose their ability to generate power or store water. Those pulses then become a larger concern because they can scour the accumulated sediments and release more material, thereby opening some capacity for the cycle to happen again.

Though those ecological shifts unfold in the main channel, a fine rain of sediments and chemicals falls out of suspension onto the floodplain, often increasing plant and animal production along the fringes of the larger reservoir system. Isn't it often the way—some of what looks good always complicates what we conceive as bad!

Those complex causes, effects, benefits, and costs will eventually lead river managers, dam owners, and society to discuss water and sediment budgets for the entire watershed. Inevitably, sediment removal emerges as a primary issue. If contaminants are involved, the discussion may also involve a responsible party with legal liabilities, and disposal options will narrow. That complex dance has started for the dams on the Susquehanna River and countless other facilities.

The Conowingo Dam and the three other facilities on the lower Susquehanna River (York Haven, Safe Harbor, and Holtwood) offer a current glimpse at these challenges. The Susquehanna River flow and sediment load are major drivers of Chesapeake Bay ecology, including fish and their habitats. The river and the dam/reservoir/sediment are major sources of phosphorus (which tends to bind to sediments) and silt but less significant for nitrogen. A recent report by the U.S. Army Corps of Engineers (2014) concluded that the three dams upstream from Conowingo have essentially reached their limit to trap sediment. Despite that lost capacity and the reality that major weather events dispense phosphorus-laden sediments into the water column, the report concluded that the sediment and pollutant issue relates more to the river than the dam and reservoir. It is essential to discuss these issues at the watershed scale and not with respect to a single dam or reservoir. Those discussions would not be complete without dam removal on the agenda as the shifting national energy business has implications for hydropower facilities. It's complicated.

So how does this affect fish, and what should we do to address sediment and pollutant problems at the watershed level and associated with dams and reservoirs? First, we should encourage engineering solutions evident in dam designs dating back to the 14th century, adopted by the Chinese for their Three Gorges Dam but rarely part of American designs (Weiser 2011), namely, to include a gate at the base of the dam that will enable operators to flush accumulating sediments from the reservoir. Second, we need to improve sediment controls to keep soils on the land, not in waterways. Third, we need to include all parties, including agriculture, mining, transportation, power, fishing, and probably more; they all are involved as sources or part of the solution. The relative importance of these issues wavers depending on the water body, but generally a broader discussion will yield greater prospects for success.

REFERENCES

U.S. Army Corps of Engineers. 2014. Lower Susquehanna River Watershed Assessment, Maryland and Pennsylvania—Phase One. Draft report released October 10, 2014. Available: mddnr.chesapeakebay.net/lsrwa/docs/report/LSRWADraftMain20141010.pdf. (April 2015).

Weiser, M. 2011. Sedimentation is a building problem in the West's reservoirs. High Country News. Available: www.hcn.org/issues/43.6/muddy-waters-silt-and-the-slow-demise-of-glen-canyon-dam/sedimentation-a-building-problem-in-the-wests-reservoirs. (April 2015). AFS

Bluegill Can Be Managed More Effectively with Bag Limits!

Jeff Schaeffer
AFS Co-Chief Science Editor. E-mail: jschaeffer@usgs.gov

Many inland fisheries historically have allowed unlimited harvest of panfish, or have extremely liberal bag limits. The management paradigm is that fishing mortality is usually low and high harvests benefit angling by improving growth and preventing stunting. However, a new study by Andew Rypel of the Wisconsin Department of Natural Resources, Bureau of Science Services, shows that this may not be a universal truth and that bag limits can be used to improve fishing quality.

Rypel evaluated a series of lakes with control (25-fish aggregate bag limit) and experimental treatments that reduced the aggregate bag limit to 10 fish. Mean total length increased by about 20 mm in treatment lakes, although the effect varied with Secchi depth; lower water clarity conferred a greater increase, presumably because lakes with lower water clarity were more productive and Bluegills *Lepomis macrochirus* also grew faster. The effects were also striking in that the experiment ran for three years, and Wisconsin Bluegills routinely achieved age-10. Thus, the regulation covered only 20-30% of the lifespan of individuals in the population. Rypel notes that, although effects were positive, benefits via size structure change might take several years to accrue because of the regulation-lifespan difference. And although few creel data were available to examine angling impacts, experimental lakes developed local reputations for quality Bluegill fishing.

But perhaps the most insightful part of the study was the suggestion that managers need to carefully plan for success in situations where regulation changes may require years to achieve success. Rypel's thoughtful analysis of this problem discusses a broad range of long-term considerations that apply to managers considering any type of long-term management strategy.

REFERENCE

Rypel, A. L. 2015. Effects of a reduced daily bag limit on Bluegill size structure in Wisconsin lakes. North American Journal of Fisheries Management 35:388-397. dx.doi.org/10.1080/02755947.2014.1001929

Solutions to California's Drought Issues: Modeling Suggests Ways to Conserve Chinook Salmon in the Face of Water Diversion

Chinook Salmon *Oncorhynchus tshawytscha* smolts emigrating the Sacramento River in California must navigate through a delta complex with water diversions that confer lower survival for entrained fish that leave the river. Russell Perry of the U.S. Geological Survey, Western Fisheries Research Center, and his colleagues fit an entrainment model to telemetry data and found that probability of water system entrainment depended on tidal flow and river discharge, with more entrainment at flood tides. Increasing river flows to overcome high-tide flow reversals negated entrainment but at a potential cost to human benefits. However, hourly operation to increase hourly flows during night flood tides could reduce entrainment by over 97% while minimizing water loss to the southern delta. The authors stressed that the model applies only to fall run Chinook Salmon of hatchery origin, but their approach seems applicable to other species, not only in the Sacramento Delta, but other areas with migration/diversion conflicts.

REFERENCE

Perry, R. W., P. L. Brandes, J. R. Burau, P. T. Sandstrom, and J. R. Skalski. 2015. Effects of tides, river flow, and gate operations on entrainment of juvenile salmon into the interior Sacramento–San Joaquin River Delta. Transactions of the American Fisheries Society 144:445-455. dx.doi.org/10.1080/00028487.2014.1001038

Probiotics Show Promise for Aquaculture

Television viewers are now being carpet-bombed with advertising for probiotics that are alleged to improve human health via promotion of beneficial gut bacteria. But probiotics may play a real role in aquaculture where ZhiPing Yang (Dalian Huixin Titanium Equipment Development Company) and colleagues fed live yeast to cultured sea cucumbers and later challenged them to bacterial infection. Sea cucumbers fed yeast not only grew better but experienced lower mortality. Yeast persisted in sea cucumber guts for about five weeks when animals were switched back to control diets, so some maintenance supplements are likely required for long-term culture. Sea cucumbers are considered a delicacy in Asia, where they have been harvested for hundreds of years. They take on the flavor of other ingredients, add a crunchy or jelly-like texture, and are prized for their putative ability to maintain human virility and cardiac health. They are traditionally preserved by drying, but frozen ones are now becoming available. Their Chinese name "hoy sum" translates to "ocean heart" or "ocean ginseng" according to several internet Asian cuisine websites. AFS Executive Director Doug Austen has promised to investigate serving them as a complement to barbecue at our 2016 Annual Meeting in Kansas City. Their value is so high that culturing them can be profitable, and probiotic treatment appears to confer multiple benefits.

REFERENCE

Yang, Z., J. Sun, and Z. Xu. 2015. Beneficial effects of *Rhodotorula* sp. C11 on growth and disease resistance of juvenile Japanese spiky sea cucumber *Apostichopus japonicas*. Journal of Aquatic Animal Health 27:71-76. dx.doi.org/10.1080/08997659.2014.993483

More Evidence That Plant-Based Feeds Can Support Sustainable Aquaculture

Many AFS researchers are investigating the utility of plant-based feeds for aquaculture, but Brian Ham of the U.S. Fish and Wildlife Service, Bozeman Fish Technology Center, and other Montana colleagues have added to the body of knowledge via an unusual experiment. They tested the usefulness of soy products as food for Cutthroat Trout *Oncorhynchus clarkii*, a rather undomesticated species compared to many other salmonids. Fish were fed diets of up to 30% soybean meal or soybean protein in replicate treatments. Surprisingly, high soy diets of either source conferred the best growth, with almost no mortality. There was a slight decrease in conversion efficiency, but results were better than expected, especially given mixed results for soy in salmonid diets in other studies. This could have been due to their approach, which substituted soy on an equivalent digestible protein basis rather than a mass balance basis, with additional balance for essential amino acids. This novel approach worked well with one potential drawback: fish fed high soy diets appeared to suffer from some degree of intestinal inflammation. This did not cause mortality during the experiment, but the authors caution that it could be an issue in long-term rearing. Despite that outcome, their study provides additional support for the idea that substitution of plant-based proteins for fish meal is becoming ever more feasible.

REFERENCE

Ham, B. R., F. T. Barrows, A. Huttinger, G. C. Duff, C. J. Yeoman, M. G. Maskill, and W. M. Sealey. 2015. Evaluation of dietary soy sensitivity in Snake River Cutthroat Trout. North American Journal of Aquaculture 77:195-205. dx.doi.org/10.1080/15222055.2014.993489

Using a Video Lander to Assess Difficult Marine Habitats

Deep temperate marine zones are known to support significant biological production, but they are difficult to sample because they are too deep for SCUBA and too complex for traditional nets. Ryan Easton of Oregon State University and his other colleagues found a way to do it that is not only feasible but quantitative. They mounted a drop camera on a video lander designed to support video gear while landing upright on the bottom in a variety of high-relief habitats. A five-minute video proved sufficient to assess fish assemblages quantitatively among a variety of habitats, and they accounted for variation in visual data quality. Grid-based deployments allowed for assessment of assemblage differences among local habitat conditions (e.g., boulders, vertical walls, or fine substrates). The technique was useful in waters too deep and too cold for divers and shows great promise as a method for evaluating long-term changes in newly designated offshore marine reserves. And best of all, its breakaway features allowed gear and data to be retrieved in the event of fouling.

REFERENCE

Easton, R.R., S.S. Heppell, and R.W. Hannah. 2015. Quantification of habitat and community relationships among nearshore temperate fishes through analysis of drop camera video. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7:87-102. dx.doi.org/10.1080/19425120.2015.1007184 AFS

The 2013–2014 Fenske Fellowship: Learning the Ins and Outs of Lake Whitefish Management in the Upper Great Lakes

Marissa L. Hammond
Department of Fisheries and Wildlife, Michigan State University, Manly Miles Building, 1405 South Harrison Rd., East Lansing, MI 48823. E-mail: hammo146@msu.edu

The project that I worked on during my 2013-2014 Janice Lee Fenske fellowship provided me with a unique opportunity to improve our understanding and management of Lake Whitefish *Coregonus clupeaformis* populations in the upper Great Lakes.

Lake Whitefish is the most important commercial species in the upper Great Lakes, with an average annual catch valued at US$16.6 million from 1994 to 2004 (Ebener et al. 2008). Lake Whitefish are cooperatively managed according to the terms of the 2000 Consent Decree, a court-ordered agreement among the Michigan Department of Natural Resources, U.S. Fish and Wildlife Service, and five Native American tribes that is intended to ensure the sustainability of Lake Whitefish populations. The decree dictates that populations will be managed through harvest quotas that are estimated annually based on catch-at-age models and size limits (Modeling Subcommittee, Technical Fisheries Committee 2013). These models forecast recruitment based on a stock-recruitment function without including empirical data on prerecruits or factors such as variation in food abundance or temperature (Brown 1991).

Part of my fellowship was to determine whether prerecruit information could be used to refine the catch-at-age models that estimate harvest quotas. I did this by comparing larval densities of two cohorts to the adult abundances of the same cohorts as they recruited to the commercial fishery. This analysis allowed me to determine whether larval density could be used to forecast future recruitment to the commercial fishery. Having the ability to use larval density as a predictor for recruitment could improve the accuracy of the models used to determine and set harvest quotas and ensure future sustainability of Lake Whitefish populations.

I also designed and analyzed a survey to gather information on sampling protocols used by consent decree agencies to monitor Lake Whitefish populations in the upper Great Lakes. The purpose of this survey was to determine where, when, and how biological data (e.g., length, weight) were being collected from Lake Whitefish harvested by commercial fishers each year. This was important because the biological data collected are used to populate the models that guide management actions. The survey results indicated that sampling strategies for monitoring Lake Whitefish populations were inconsistent across jurisdictions with regard to frequency and seasonality of sampling, number of samples collected, and biological data recorded. These differences could affect management decisions because current catch-at-age models may not provide the most accurate description of the status of Lake Whitefish populations. To help minimize the differences in monitoring protocols, I created a document for the consent decree agencies to support the future development of a standardized sampling protocol for monitoring Lake Whitefish.

LESSONS LEARNED

Being immersed in the management of a commercial fishery broadened my perspective, enhanced my understanding of how management occurs, and taught me many lessons, all of which I will carry forward as I pursue my own career:

Management Is Complex

Stakeholders who have a vested interest in the sustainability of a shared resource frequently come together to provide input and management recommendations that benefit the resource and the people. We hope that this process is efficient and effective, but that is not always the case. Thoughtful decision making occurs, but it often takes days, weeks, months, or even years for stakeholders to come to an agreement on a particular issue, and some people still end up dissatisfied with the outcome, possibly because of their own personal values. This seems to happen because each stakeholder brings a different viewpoint and desire to the table, which adds another layer of complexity to the multifaceted process of obtaining scientific results, making logical management recommendations, and implementing policy changes.

Building Relationships Is a Must

It is important for fisheries professionals to build relationships with stakeholders. Fisheries professionals should get to know the personal and cultural values of stakeholders because these values often determine a stakeholder's way of thinking and whether or not they agree with a management decision. By finding a way to relate to and understand the values of each stakeholder, you cultivate a relationship that is built on trust and understanding, which is important for garnering support from stakeholders when making management decisions. Once this trust is built, it is important to maintain it, which can be done by being transparent so that stakeholders recognize that fisheries professionals are considerate of their concerns and values, along with fisheries resources.

Communication Is Key

Effective communication is imperative for successful fisheries management. Having good communication helps foster better relationships. Listening to stakeholders and making an effort to understand the reasoning behind their position helps to build trust and respect for one another. When managing a commercial fishery, you need to clearly communicate your reasoning for a proposed change and the potential implications. Communicating with stakeholders throughout the entire management process keeps them involved and informed, which increases the likelihood that you will have their support when it is time to implement a change.

ACKNOWLEDGMENTS

A big "thank you!" to the Fenske Fellowship Committee, Jan Fenske, William Taylor (my major advisor), and my agency mentors for providing me with the opportunity to learn these valuable lessons (among many more) and for making this experience an incredibly valuable and influential one on my personal and professional life.

REFERENCES

Brown, R. W. 1991. Factors influencing the larval survival and recruitment of Lake Whitefish in the Upper Great Lakes. Master's thesis. Michigan State University, East Lansing, Michigan.

Ebener, M. P., R. E. Kinnunen, P. J. Schneeberger, L. C. Mohr, J. A. Hoyle, and P. Peeters. 2008. Management of commercial fisheries for Lake Whitefish in the Laurentian Great Lakes of North America. Pages 99–143 *in* M. G. Schechter, N. J. Leonard, and W. W. Taylor, editors. International governance of fisheries ecosystems: learning from the past, finding solutions for the future. American Fisheries Society, Bethesda, Maryland.

Modeling Subcommittee, Technical Fisheries Committee. 2013. Technical Fisheries Committee administrative report 2013: status of Lake Trout and Lake Whitefish populations in the 1836 treaty-ceded waters of Lakes Superior, Huron and Michigan, with recommended yield and effort levels for 2013. AFS

West Virginia University AFS Student Subunit Leads a Citizen Science Program

Daniel Hanks
Division of Forestry and Natural Resources, West Virginia University, 223 Percival Hall, Morgantown, WV 26506.
E-mail: rhanks@mix.wvu.edu

Ross Andrew and Alison Anderson
Division of Wildlife and Fisheries, West Virginia University, Morgantown, WV

Species distribution data are important for monitoring and conservation efforts for managers and citizens alike because they allow for appropriate measures to be taken to ensure the long-term viability of our natural resources through public use, appreciation, and increased understanding of those resources. In order to generate public awareness and participation in the aquatic resources of West Virginia, the West Virginia University (WVU) Student Subunit of the American Fisheries Society (AFS) led a citizen science program entitled, "Discover Life in West Virginia" (DLiWV), at Coopers Rock State Forest in September 2014. The program was organized and led by Ph.D. students in Wildlife and Fisheries Resources with the support of Professor Kyle Hartman and funded through the West Virginia Division of Natural Resources Cooperative Research and Education/Management Grant Program.

Ross Andrew demonstrates the intricacies of collecting aquatic macroinvertebrates via kicknetting to a group of DLiWV participants. Photo credit: Daniel Hanks.

The DLiWV program had the aim of including non-scientists (community members) in a scientific endeavor by engaging them through hands-on activities, within the framework of the scientific process, with the hope that participants would leave with a better understanding of and appreciation for fisheries science. This required scientists to act as liaisons and guides while the public-turned-scientists collected data on fish and aquatic macroinvertebrate communities at two streams within Coopers Rock State Forest. Over the course of the two-day event, 42 individuals participated as citizen scientists. Twelve of those individuals were from the general public, with ages ranging from 3 to 50, and the remaining 30 were WVU students.

West Virginia University undergraduates and DLiWV participants record lengths and weights of captured fish. Photo credit: Daniel Hanks.

The public was encouraged to participate in all collection methods: electrofishing and netting for fish and kicknetting for macroinvertebrates. Fish were identified to species and measured for length and weight along the streamside, and macroinvertebrate samples were preserved for processing and identification back at WVU. Creek Chub *Semotilus atromaculatus* was the only fish species captured. When including the macroinvertebrates, there were a total of 39 families and 50 genera (Chironomidae, Hydrachnidia, and Oligochaetae were identified to family) captured.

By expanding its mission to include the integration of fisheries science and education, the WVU AFS Student Subunit hopes to establish DLiWV as an annual event. Furthermore, the DLiWV staff hopes to increase future participation by including other taxonomic groups, such as birds, amphibians, reptiles, etc. The long-term goal of the DLiWV program is to have a full inventory of all of the "kinds" of organisms within Coopers Rock State Forest while fully engaging the community in the process of collecting important scientific information. AFS

Photo caption: Donna Parrish accepts the Dwight Webster Memorial Award from John Cooper. Photo credit: Chris Millard.

THE 63RD ANNUAL BUSINESS MEETING OF THE NORTHEASTERN DIVISION

The 63rd Annual Business Meeting of the Northeastern Division (NED) of AFS was held in Newport, Rhode Island, and featured a Fisheries Professionals Reception. Peter Aarrestad (director of Inland Fisheries for the Connecticut Department of Energy and Environmental Protection), Chris O'Bara (West Virginia Department of Natural Resources), Doug Austen (AFS executive director), and Donna Parrish (AFS president) addressed the attendees. The NED meeting was held in conjunction with the 71st Northeast Fish and Wildlife Conference in April 2015.

John Cooper, NED president, summarized the discussions between NED, the Northeast Section of The Wildlife Society, and the directors and administrators of fish and wildlife for planning future conferences.

The Dwight Webster Memorial Award, NED's most prestigious award, is given in honor of Dwight Webster, who was twice president of NED. This year's award recipient was Donna Parrish, the unit leader of the Vermont Cooperative Fish and Wildlife Research Unit and research professor in the Rubenstein School of Environment and Natural Resources at the University of Vermont. Parrish teaches a course on the ecology of fishes and graduate seminars on aquatic ecology and watershed science, becoming a successful scientist, and integrating natural science and social science. Parrish became a member of AFS in 1982 and is the current president of the Society. She is also a past-president of the Education Section and NED.

The President's Award was given to Paul Perra, who joined AFS in 1976 and served NED as secretary-treasurer and president, and served on steering committees for several marine fish symposia.

The Meritorious Service Award was given to Greg Kozlowski, a fisheries biologist for the New York State Department of Environmental Conservation in Region 1 and served AFS, NED, and the New York Chapter as an audio-visual technologist at several meetings. Kozlowski also served as NED's website manager for seven years.

Two students were recognized for excellence in presentations: Connor Capizzano, University of New England, was awarded the Best Paper Presentation Award, and Andrew Ransom, University of Connecticut, was given the Best Poster Award. The Moring Student Travel Award was given to Lucas Nathan, University of Connecticut.

The NED ceremonial walking stick, carved by Robert Carline, was presented to Richard Hames, who joined AFS in 1956 and has the longest AFS membership within NED.

—John Cooper, NED President

FEATURE

Climate Change Adaptation and Restoration of Western Trout Streams: Opportunities and Strategies

Climate change is contributing to the severity and rate of stream degradation by changing the timing of peak flows, altering flow regimes, creating more frequent and intense disturbances, and increasing stream temperatures. Herein we describe three case studies of trout stream adaptation that address existing and climate-driven causes of degradation through habitat restoration. The case studies vary in geography and complexity, but all include restoration efforts intended to address multiple causes of stream degradation and improve the resilience of these streams to floods, droughts, and wildfires. Four elements of successful climate adaptation projects emerge: (1) habitat assessments that help drive project location and design, (2) projects that directly address climate change impacts and increase habitat resilience, (3) projects that combine to achieve watershed-scale impacts, and (4) projects that include sufficient monitoring to determine their effectiveness. We describe solutions to common challenges in conducting climate change adaptation, including how to balance scientific assessments with opportunities when choosing projects, how smaller projects can be aggregated to achieve watershed-scale benefits, and how citizen science efforts can augment monitoring programs.

Adaptación al cambio climático y restauración de los ríos occidentales para la trucha: oportunidades y estrategias

El cambio climático está contribuyendo a incrementar la severidad y la tasa de degradación de los ríos a través de la alteración en la estacionalidad del flujo máximo, modificación del régimen de flujos, generación de perturbaciones más frecuentes e intensas e incremento de la temperatura de los ríos. Aquí se describen tres casos de estudio de la adaptación de ríos en donde habita la trucha, en los que se abordan las causas de la degradación que son provocadas por el cambio climático, mediante la restauración del hábitat. Los casos de estudio varían en cuanto a ubicación geográfica y complejidad, pero en todos se contemplan esfuerzos de restauración enfocados a abordar múltiples causas de degradación de ríos y mejoramiento de la resiliencia de éstos ante inundaciones, sequías e incendios naturales. Se consideraron cuatro elementos para lograr una adaptación exitosa al cambio climático: 1) evaluaciones del hábitat que ayuden a diseñar y establecer dónde llevar a cabo los proyectos; 2) proyectos que aborden directamente los impactos del cambio climático y el incremento en la resiliencia del hábitat; 3) proyectos que, al combinarse, logren resultados a nivel de cuenca hidrológica; y 4) proyectos que incluyan un monitoreo suficiente como para que se pueda determinar su efectividad. También se describen soluciones a los clásicos retos que implica la adaptación al cambio climático, incluyendo cómo encontrar un balance entre evaluaciones científicas y elección de proyectos, cómo se pueden integrar varios proyectos pequeños para conseguir beneficios a escala de cuenca y cómo se puede incrementar el monitoreo mediante esfuerzos ciudadanos.

Jack E. Williams
Trout Unlimited, 4393 Pioneer Road, Medford, OR 97501. E-mail: jwilliams@tu.org

Helen M. Neville and Amy L. Haak
Trout Unlimited, Boise, ID

Warren T. Colyer
Trout Unlimited, Missoula, MT

Seth J. Wenger
University of Georgia, Athens

Stan Bradshaw
Trout Unlimited, Helena, MT

INTRODUCTION

Climate change is rapidly becoming one of the most challenging issues for management of trout, salmon, and other coldwater fisheries. Climate-induced changes in flows and disturbance regimes (Stewart et al. 2005; Haak et al. 2010) will confound stream restoration efforts as rising temperatures and other stressors reduce suitable coldwater fish habitat (Kaushal et al. 2010). Despite the added complexity and uncertainty, stream managers have begun to integrate climate change adaptation into restoration and monitoring efforts.

Over the past decade, researchers have recommended adaptation strategies that promote resistance and resilience to reduce the impacts of climate change (Lawler 2009). "Resistance" is the ability of a system to remain unchanged in the face of external forces. "Resilience" is the ability of a system to recover from disturbance. The most common types of adaptation strategies suggested for dealing with climate change include the expansion of reserve systems (Halpin 1997), increasing landscape connectivity and corridors among occupied habitat patches (Hulme 2005; Beechie et al. 2012), restoring degraded habitats (Harris et al. 2006), and removing other threats and stressors such as invasive species (Noss 2001), yet there are few specific examples of how these strategies can be applied in the context of climate adaptation in stream systems.

The effects of climate change are likely to increase the cumulative impacts of a variety of stressors on stream systems.

In this article, we briefly review likely impacts of climate change on trout and their habitats and describe how these impacts were addressed in three stream restoration case studies. One common theme is that the long legacy of human-induced habitat degradation and fragmentation that has led to current levels of decline for native trout species now provides many opportunities for restoration that could help address threats of climate change. These studies demonstrate different approaches to stream restoration in terms of assessment, spatial and temporal scales, and tactics and strategies to increase the persistence of trout populations in a warming but uncertain future.

How Climate Change Affects Trout

Trout are likely to be particularly susceptible to the effects of climate change. Though there is considerable uncertainty as to the rate of change and variability of these impacts over space and time (Wenger et al. 2013), there is general agreement on the types of impacts that are expected. There also is growing evidence that these impacts are already manifesting themselves on the landscape as described below.

Warmer Summer Temperatures

Trout are coldwater fish and generally cannot tolerate temperatures above 22–28°C, depending on the species (Selong et al. 2001; Dunham et al. 2002). When temperatures are too high, many trout species experience reduced growth, survival and reproductive capacity, and heightened stress that can leave them more vulnerable to disease and displacement by competitor species. As temperatures warm beyond the preferred range for a trout species, suitable habitat shrinks and becomes increasingly fragmented, reducing population sizes and connectivity (Rieman et al. 2007; Wenger et al. 2011b).

Earlier Peak Flows, Lower Summer Flows, and More Droughts

In recent decades, stream flow in the western United States has been characterized by earlier timing of spring runoff (Stewart et al. 2005) and declining summer flows (Luce and Holden 2009; Cayan et al. 2010; Fu et al. 2010). Earlier spring runoff and earlier peak flows serve as important behavioral cues for many aquatic species and thus change the phenology of aquatic insect emergence and fish migrations (Harper and Peckarsky 2006; Kovach et al. 2013). Declining flows typically lead to higher water temperatures and overall degradation of habitat condition, size, and connectivity.

More Intense Wildfires and Other Disturbances

The warming trend in the United States has been accompanied by more frequent and larger wildfires in the West (Westerling et al. 2006) and increasing storm events in the East (Spierre and Wake 2010). These events can kill fish directly, but they also make hillsides more susceptible to landslides and debris flows that can block channels, fill in spawning areas, and impede fish movement (Brown et al. 2001). The combination of increasing disturbance intensity and fragmentation of stream habitats results in more severe degradation of fish populations than would occur under more natural conditions (Rieman and Clayton 1997).

More High Flows in Winter (for Snow-Dominated Areas)

In mountainous regions in the West, precipitation occurs mainly in the form of winter snow. Stream flows in these locations tend to be steady and moderate over winter, which provide safe conditions for the incubation of the eggs of fall-spawning trout species such as Bull Trout *Salvelinus confluentus*. However, as climate warms, rainstorms in a snowy landscape can melt snow and lead to increasing winter floods (Graybeal and Leathers 2006; Haak et al. 2010), which may be particularly detrimental to fall-spawning of Bull Trout and Brook Trout *S. fontinalis*. Winter floods can scour stream beds and drastically increase erosion.

Increased Cumulative Stressors, Nonnatives, and Disease

The effects of climate change are likely to increase the cumulative impacts of a variety of stressors on stream systems. High water temperatures also may render trout more susceptible to invasive species and diseases, including whirling disease (Rahel and Olden 2008). Recent studies examined the combined effects of increasing temperatures, declining summer flows, increasing winter high flows, and invasion by competing trout species in the Interior West. The authors found that warming temperatures negatively affect both native and nonnative species, but increasing winter high flows primarily harmed fall-spawning trout species (Wenger et al. 2011a, 2011b). Cutthroat Trout *Oncorhynchus clarkii* were negatively affected by competition with introduced trout species, but Bull Trout were not. However, the combined effects of temperature and flow changes were predicted to lead to large declines of Bull Trout (Wenger et al. 2011a), which is among the most threatened trout species in the lower 48 states. Lawrence et al. (2014) showed

Figure 1. Graphic depicts watershed-scale adaptation strategy consisting of protecting headwater sources of cold water, reconnecting the fragmented stream network, and restoring the mainstem and valley bottom habitats. Illustration courtesy of Bryan Christie Design and Trout Unlimited.

how degraded riparian habitat combines with climate change to facilitate an upstream invasion of salmonid habitat by Smallmouth Bass *Micropterus dolomieu*.

METHODS

The general approach advocated by Trout Unlimited (TU) to trout conservation consists of watershed-scale efforts to protect remaining high-quality habitats, reconnect mainstem habitats to tributaries through removal of passage barriers and improvements to instream flows, and restoration of degraded riparian, wet meadow, and mainstem channels (Figure 1). Here we describe three restoration case studies from the western United States that incorporate a wide range of likely climate change effects and a mix of the above corresponding adaptation strategies (Table 1). By describing actual case studies, we can compare on-the-ground realities among existing projects and better understand questions of spatial scale. All of the case studies are multiyear projects involving first- to third-order stream systems. The projects were initiated and carried out by a variety of agencies, nongovernmental organizations, and private landowners and corporations. Goals of the individual projects vary, but all focus primarily on the restoration of degraded native trout populations and their habitats.

Results of each case study are presented below. Each case study includes background information that provides context to the restoration effort, a description of habitat assessment data (if any) that supported the project, a description of the adaptation work, and a description of effectiveness as determined by moni-

Table 1. Comparisons of climate effects, corresponding adaptation strategies and restoration actions, and case studies where these strategies and actions have been implemented.

Climate effects	Adaptation strategies	Restoration actions	Case studies
Warmer summer temperatures	Increase stream shading and increase cool water habitat	Restore riparian areas; increase meanders, deep pool, and undercut bank habitats	Maggie Creek, NV; Crow Creek, ID; Wasson Creek, MT
Earlier peak flows, decreasing summer flows, and more drought	Keep flows in headwaters longer; recharge aquifers; increase refuge habitats	Restore headwater meadows and wetlands; increase channel meanders; restore instream flows; increase number and size of deep pools	Maggie Creek, NV; Wasson Creek, MT
More wildfires	Create large wet zones along stream that are resistant to burning	Increase width and lushness of riparian areas; slow flows and remeander to increase shallow groundwater in meadows; introduce beavers	Maggie Creek, NV
More floods and higher flows in winter	Increase natural capacity of streamside habitats to absorb and dissipate flow energy	Reconnect and restore floodplains; expand and revegetate riparian areas; improve culvert designs and capacity	Maggie Creek, NV; Wasson Creek, MT; Crow Creek, ID
Increased cumulative stress to stream systems	Reduce other sources of stress to minimize cumulative impact of increased climate stressors	Reduce or otherwise improve livestock use; reduce roads and/or improve their maintenance; reduce pollution sources	Maggie Creek, NV; Crow Creek, ID; Wasson Creek, MT

toring. The assessment data allowed us to examine the relative importance of strategy versus opportunity in project development. The adaptation work facilitated an understanding of spatial scales in project development and how reach-scale projects compare to those at watershed-scale. Monitoring data provided clues as to the success of projects relative to addressing resistance and resiliency to climate change as well as other stressors and provided insights into temporal scales and understanding long-term project success.

Like many degraded streams across the country, the streams described herein have been altered through a long history of intense and long-term livestock use, land use change, off-road vehicles, diversion of flows, and/or stream channelization. Restoration actions focus on the removal of existing stressors through restoring streams to their historical channels, fencing and revegetation of riparian areas, introducing beavers, reconnecting stream fragments, and restoring instream flows. Restoration actions are designed to reduce the cumulative stress on stream systems, increase habitat complexity, increase the number and size of deep pools, reduce channel width–to-depth ratio, and increase shading, all of which generally increase resistance and resiliency to impacts of climate change (Williams et al. 2007; Rieman and Isaak 2010).

CASE STUDIES

Maggie Creek, Nevada

Project Context

Maggie Creek in northeastern Nevada was assumed historically to support an interconnected "metapopulation" of Lahontan Cutthroat Trout (LCT) *O. c. henshawi,* where fish accessed tributary and mainstem habitats needed for growth, gene exchange, spawning migrations, and refuge from stressful conditions (Neville et al. 2006). But decades of intensive livestock grazing, water diversions, and road construction degraded streams and fragmented populations into a few small remnants, making remaining fish particularly vulnerable to increasing stream temperature, drought, and wildfires.

Habitat Assessment

Previous work demonstrated that LCT in isolated habitats were less likely to persist (Dunham et al. 1997) and that larger habitat patches had a greater probability of occupancy than smaller patches (Dunham et al. 2002). Furthermore, research in a neighboring large, interconnected system (Neville et al. 2006) demonstrated the importance of a migratory life history and metapopulation dynamics in interconnected habitats and the contrasting negative effects of isolation in fragmented streams. Restoring larger interconnected habitats was therefore a high priority for LCT recovery, and reconnecting the three Maggie tributaries would restore one of the largest habitat patches—and assumedly functional metapopulations—in the entire range. A small number of land managers in the watershed (a few large ranches and the Elko District of the Bureau of Land Management [BLM]) helped to facilitate this large-scale work.

Climate Adaptation

Restoration actions included the removal of existing stressors, in this case, livestock overgrazing; degradation of stream, riparian, and wet meadow habitats; and isolation of tributaries from the mainstem Maggie Creek. In 1993, as mitigation for Newmont Mining Corporation's expanding operations in the basin, Newmont, the BLM, and local landowners and partners initiated the Maggie Creek Watershed Restoration Project to enhance 132 km of stream, 800 ha of riparian habitat, and 16,200 ha of upland watershed in the basin. Although the project included a number of components, including riparian plantings and fencing, a conservation easement, and water developments, the most important change was application of prescriptive livestock grazing practices to limit hot season grazing. Prior to 1993, cattle were present on most riparian areas throughout the growing season. Revised grazing prescriptions ranged from total exclusion to rotational grazing patterns incorporating changes in season and duration of use. Further upstream, along Beaver Creek, the BLM, Nevada Mining Association, and Twenty-Five Ranch constructed a riparian pasture encompassing almost 5,300 ha of public and private lands on more than 48 km of stream habitat. Grazing was changed from season-long use throughout the growing season every year to hot season (July and August) grazing occurring no more than once in four years, and the pasture was either rested or grazed during the spring in other years. Though not official partners, the native beavers that moved back into Maggie Creek following habitat improvements have provided further restoration services.

Finally, three tributaries contained road culverts at their confluence with Maggie Creek. The culverts at two of the primary tributaries, Little Jack and Coyote creeks, were thought to be partial barriers, whereas the structure at the largest tributary, Beaver Creek, was assumed to prevent all LCT movement. In 2005, the culverts were replaced and an irrigation diversion in the mainstem creek was modified with fish-friendly structures designed to allow fish passage (Figure 2), effectively reconnecting the three tributaries to the mainstem river corridor. To safeguard the entire system from nonnative fish invasion, a large instream barrier was installed in 2012 below the reconnected part of the watershed near the Humboldt River.

Monitoring and Effectiveness

The BLM—in cooperation with Newmont Mining Corporation and other partners —has employed a variety of monitoring protocols, including stream surveys, proper functioning condition assessments, remote sensing, and photography to track changes in stream and riparian habitat conditions throughout the basin over time. Parts of the system were so severely trampled by cattle that they lacked clear stream channels and were completely bare, but now stream channels are narrower and deeper and show improvements in meandering, pool development, and riparian vegetation (Figure 3).

Additional analysis of aerial photography over time has allowed a birds-eye view of habitat improvements, showing the replacement of upland vegetation with riparian vegetation at broad landscape scales (Figure 4). As habitat improved, the number of beaver increased dramatically, and their success as ecosystem engineers is evident: wetlands created by beavers recolonizing Maggie Creek now provide high-quality habitat for fish and many species of wildlife, including waterfowl and other birds, muskrats, mule deer, mink, and raccoons. Water storage and sediment capture also have improved. Groundwater has increased in elevation by 0.6 m below the restoration area, and the input of suspended sediments during floods has decreased, demonstrating the filtering effect of the restored vegetation.

Trout Unlimited initiated monitoring in 2001 to determine fish responses to the newly established connectivity provided by culvert replacements. Knowing that the culverts were to be removed in 2005, we established 44 monitoring sites in 2001 across the streams and began counting the numbers and sizes of fish at each site. As expected, after the partial barriers in Little

Figure 2. Culverts in Beaver Creek that prevented fish passage (top) were replaced with a fish-friendly structure in 2005 (bottom). Photos courtesy of Elko District BLM.

Jack and Coyote creeks were replaced, the numbers of fish continue to fluctuate almost as before, with possibly a slight bump in numbers. The newly connected Beaver Creek, however, has shown a marked response: not only are there more fish collected in surveys (with fairly stable averages of 25 fish captured at our sites before remediation and 215 after), but there is increasing evidence of successful spawning as indicated by the numbers of young-of-year fish. Larger, migratory-sized fish are also more common. Prior to culvert replacement, nearly all fish collected were less than 100 mm total length, but after fish passage was restored, LCT in the 200–300 mm total length class were collected. These improvements held true even in 2012, one of the worst drought years recorded. All of this suggests both that populations within each stream are benefiting from the restoration work and the system as a whole is now functioning more like it did historically: it now supports large migratory individuals with

Figure 3. BLM monitoring photos of the mainstem Maggie Creek in 1980 (top) and 2011 show obvious improvements in stream ponding, bank stability, and vegetation—in part thanks to an influx of beavers. Photos courtesy of Elko District BLM.

the ability to move among different habitat types in tributaries and the mainstem river to escape areas of habitat disturbance or degradation to find suitable conditions.

Crow Creek, Idaho

Project Context

The Salt River drainage in Wyoming and Idaho is a major tributary to the iconic South Fork of the Snake River and supports populations of native Yellowstone Cutthroat Trout (YCT) *O. c. bouvieri* as well as nonnative Brown Trout *Salmo trutta*, Brook Trout, and Rainbow Trout *O. mykiss*. Crow Creek is a tributary to the Salt River that provides important spawning habitat for migratory YCT from the mainstem as well as being home to resident populations. Like many western streams, Crow Creek has a legacy of habitat and water quality degradation stemming from human activities that include agriculture, mining, and roads—all of which have increased sediment loads that bury spawning gravels and smother trout eggs. As a result, Crow Creek currently has been identified by the state as being impaired in water quality pursuant to Section 303(d) of the Clean Water Act.

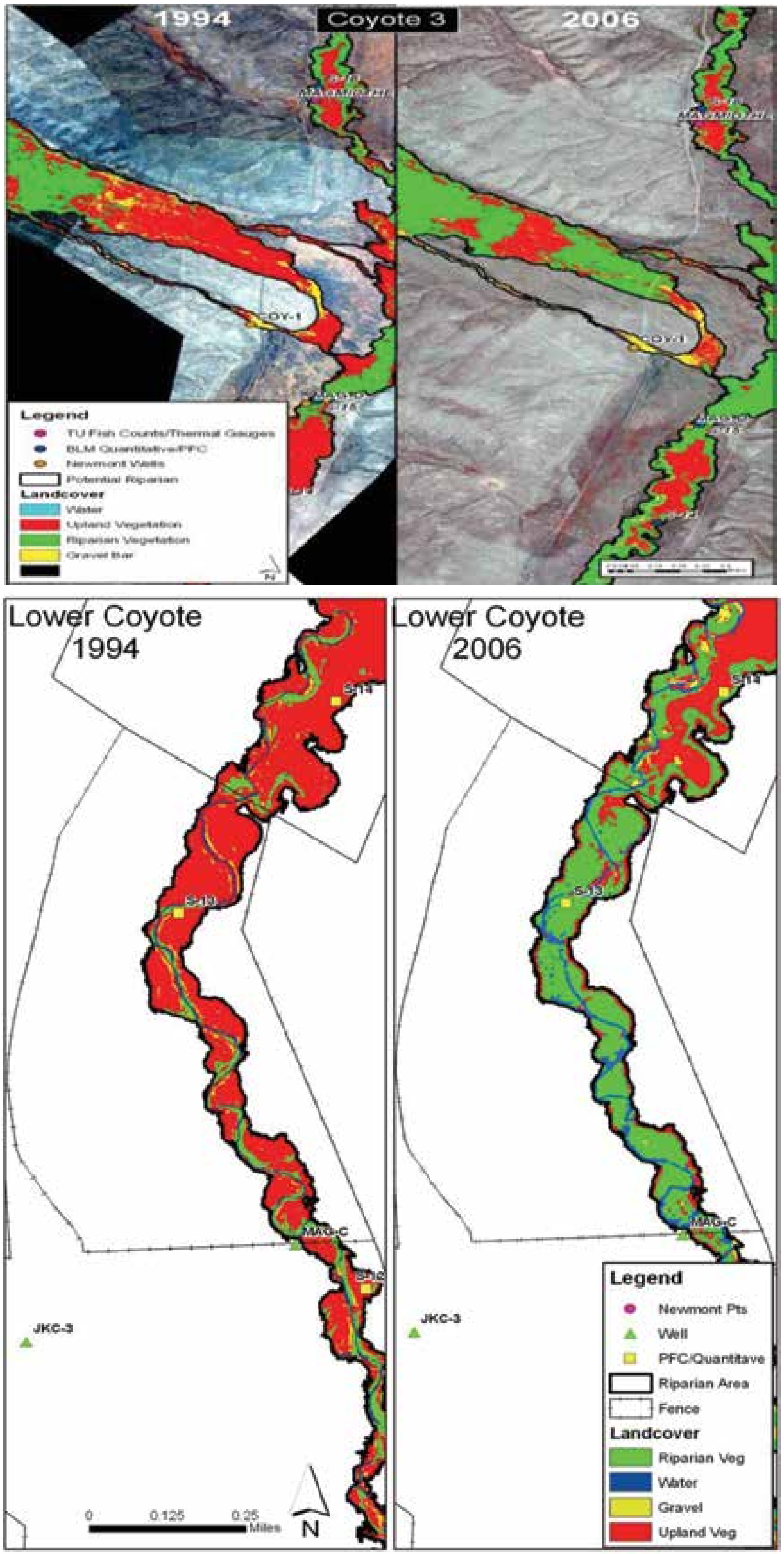


Figure 4. Remote sensing analyses completed by Open Range Consulting show increases in the amount of riparian vegetation (green) and reductions in upland vegetation (red) along Coyote Creek, a tributary of Maggie Creek. Figure from Simonds et al. (2009).

Figure 5. Photo of Crow Creek, Idaho, project immediately after we began to divert streamflow from the straightened channel (adjacent to road) into the reconstructed channel (top).

One especially significant source of sediment on Crow Creek was a channelized section of stream located in the Caribou-Targhee National Forest. Sometime around the mid-1900s, a local rancher used a bulldozer to straighten the channel and move it to one side of the valley in order to increase the land available for hay cultivation. The resulting lack of meanders and pools not only reduced cover and habitat for fish but also significantly increased erosion.

Habitat Assessment

Crow Creek and the Salt River support resident and migratory life histories of genetically pure YCT, which makes their protection and restoration a high priority within TU's climate adaptation strategies (Haak and Williams 2012). The Salt River drainage supports genetically unaltered metapopulations of both the large- and fine-spotted forms of YCT. From the Forest Service's perspective, Crow Creek was a high priority in their five-year watershed action plan because of its importance for water quality, fisheries, and aquatic stream stability as well as the presence of willing partners and available funding (Louis Wasniewski, Caribou-Targhee NF, personal communication).

Climate Adaptation

In 2009, TU and the U.S. Forest Service initiated a project to reconstruct the historic Crow Creek channel and restore the natural hydrologic processes that had been interrupted when the channel was straightened. The goal of the project was to restore channel function, increase available instream habitat, and improve water quality to buffer Salt River YCT populations from catastrophic environmental events like floods, fires, and droughts that are predicted to increase in the region (Haak et al. 2010). Intact stream channels and vegetated floodplains mitigate the effects of those events by attenuating flood flows, storing and slowly releasing ground water back to streams during low flows, and providing lush riparian vegetation that resists fire and filters sediment and ash during run-off events.

The Crow Creek restoration project was implemented in three phases. First, a combination of aerial imagery and topographic survey data from the project reach and an upstream reference reach (e.g., stream reach that had not been modified and represented a "natural" condition) was used to design a new channel with a meander pattern representative of historical conditions (Figure 5). Where the original channel was still evident, it was used; where it was not, a new channel was designed consistent with historical meander patterns. During the second phase of the project, a new channel was excavated and the resulting fill stockpiled at regular intervals along the old, straightened channel. At this point, a new channel was connected to the existing channel at the upstream and downstream ends, and a water control device was installed at the upstream end of the straightened channel. In phase three, flow was gradually diverted into the new channel over the course of a few months in 2011–2012, rather than flooding it immediately, thereby allowing vegetation to become established and begin to stabilize the new channel (Figure 6). To that end, sod mats were installed on raw, excavated stream banks, and willow clumps were transplanted from adjacent reaches. Stockpiles of excavated fill material were then used to fill in the old channel.

Monitoring and Effectiveness

Trout Unlimited and project partners continue to monitor the YCT population responses to the newly restored channel and expect that fish numbers will increase in the project reach within a few years. The physical habitat benefits, in contrast, have been immediate (Table 2). The project reduced the stream gradient by nearly 50% and more than doubled the sinuosity to match reference conditions. The result is slower stream velocities and less streambank erosion, as well as a gradual elevation of the groundwater table, which will promote wetland and riparian vegetation and augment late season stream flows with cool water. Remeandering stream channels can decrease stream temperatures by increasing pool development and increasing the length of hyporheic flows, which cools water during the summer (Arrigoni et al. 2008). Available stream habitat was significantly increased by nearly doubling the length of stream through the project reach—from 1,007 to 1,973 m—and increasing pools and associated tail outs (preferred spawning habitat for YCT) by nearly a factor of 10. The resulting combination of increased and improved habitat, restored stream and riparian function, and improved water quality will increase resiliency to environmental disturbances in both Crow Creek hydrologic systems and the native YCT populations that depend on them.

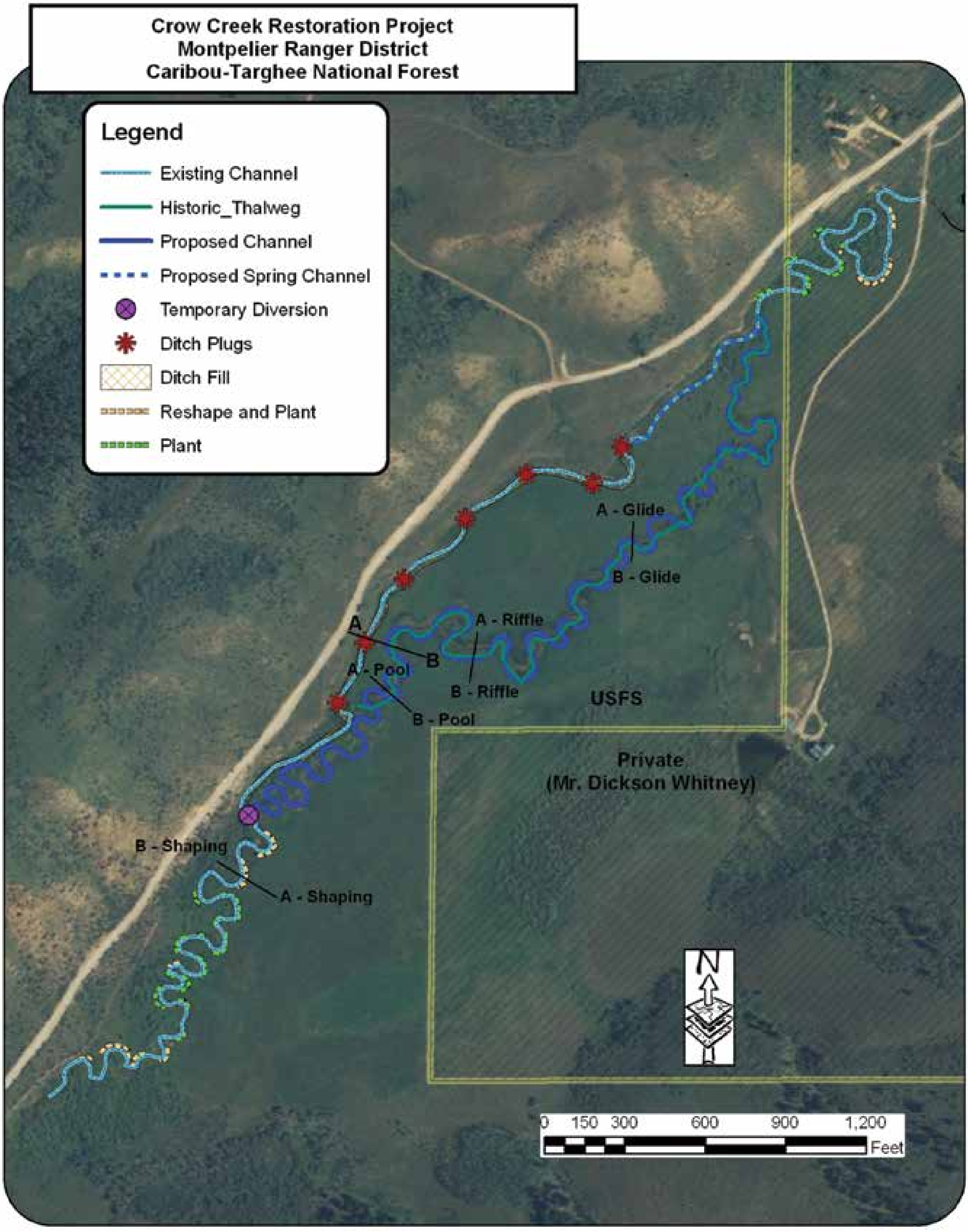


Figure 6. Diagram of Crow Creek, Idaho, showing project design. Graphic courtesy of Louis Wasniewski and U.S. Forest Service.

Table 2. Comparison of Crow Creek, Idaho: project reach characteristics before and after restoration.

	Stream gradient (%)	Sinuosity	Stream length (m)	# Pools
Before	0.7	1.1	1,007	9
After	0.4	2.4	1,973	86

Wasson Creek, Montana

Project Context

Wasson Creek is a small second-order tributary of the Nevada Creek drainage of the Blackfoot River in Montana. Nevada Creek has been identified as a major source of nutrient, sediment, and increases in temperature to the middle reach of the Blackfoot River as a result of past ranching and other human uses. In 2003, the Montana Department of Fish, Wildlife & Parks (MDFWP) documented a genetically pure population of Westslope Cutthroat Trout (WCT) *O. c. lewisi* in the upper reaches of Wasson Creek, which provided further stimulus to undertake restoration actions.

Wasson Creek suffered from a litany of impairments, including fish barriers, diversion of water for irrigation, entrainment of fish into ditches, channel straightening, livestock damage to banks, and water quality impairments from agricultural runoff. As a result, lower reaches of the creek heated to near-lethal temperatures for trout in the summer (Figure 7), and low flows often precluded any fish migration. The genetically pure WCT population was effectively isolated from the watershed below the irrigation diversions.

Habitat Assessment

Staff from MDFWP have been conducting fisheries inventories and establishing stream restoration priorities in the Blackfoot River Basin since 1989. Their most recent stream and native fish assessment for the Blackfoot ranked Wasson Creek as a "high priority" for restoration based on the potential for improvements to flows and water quality (Pierce et al. 2005). The small but persisting genetically pure population of WCT also indicated good potential for restoration. These factors, plus the presence of interested landowners, made the project a high priority for TU and other partners.

Climate Adaptation

In 2004, TU, the MDFWP, local ranchers, and a host of other partners embarked on a restoration project with the goal to restore hydrologic connectivity and resilience to Wasson Creek. A variety of restoration actions were undertaken, including livestock exclusions with other long-term improvements to grazing management, channel reconstruction and reconnection of the creek to its floodplain, screening of two critical ditches, and restoration of minimum flows in the lower creek in late summer.

In 2005, TU and the ranchers entered into a series of one-year agreements to keep a minimum of 0.5 cfs in the stream while the parties worked for state approval of a long-term instream flow lease. At the same time, the ranch fenced off the creek from livestock, and TU initiated channel restoration efforts. Even before all parts of the restoration were complete, small numbers of trout started to appear below the diversions just through the maintenance of 0.5 cfs. Completion of a 10-year lease for 0.75 cfs was reached in 2007 along with the installation of fish screens on the two ditches.

Monitoring and Effectiveness

The summer of 2007 was one of the hottest on record in the Blackfoot, and the temperature response to increased flows was immediate. Temperatures at the mouth of Wasson Creek, which rose as high as 27°C in 2003, peaked at just over 18°C in 2007 (Figure 7). Cutthroat Trout populations below the diversions went from zero in 2003 to an average of 30.4 fish/100 m in 2007–2012. Downstream areas that were inhabited by small numbers of Brown Trout but no Cutthroat Trout prior to the project in 2000 showed upwards of 81 Cutthroat Trout/100 m by 2010. In 2012, the MDFWP radio-tagged 14 mature migratory Cutthroat Trout in Nevada Creek and tracked their movements over the course of the spring and summer. Of the 14, 10 migrated up Wasson Creek past the irrigation diversions and spawned.

DISCUSSION

As the impacts of climate change on stream flows, stream temperatures, and disturbance regimes become more pronounced, it becomes important to examine the efficacy of stream and riparian restoration within the context of a rapidly changing environment. Herein we report on three case studies of trout stream restoration for insights into the following elements of climate change adaptation: (1) how projects are chosen and specifically what role habitat assessments are likely to play in these decisions, (2) how restoration efforts address climate change impacts, (3) how local projects can achieve results at watershed scales, and (4) how projects are monitored and evaluated.

Restoration projects that ultimately improve climate resistance and resiliency for trout may be initiated for a variety of reasons, and thus initial habitat assessments may vary in both focus and scale. In the above examples, assessments and project selection were carried out with a variety of goals, ranging from a local opportunity that fit an ecologically-based, range-wide need for species recovery (Maggie Creek: the need to restore and reconnect a large metapopulation of LCT) to a desire to maximize multiple resource benefits (Crow Creek: the U.S. Forest Service's desire to improve water quality, bolster the status of multiple fishes, and increase habitat stability) to a focus on a specific habitat attribute such as water quality (Wasson Creek).

Recognizing that species declines result not just in fewer populations but potential losses in important characteristics of a species' evolutionary and ecological history, TU has recently developed a broad-scale conservation assessment approach to help maximize restoration and retention of these diverse attributes. Our portfolio approach helps compare existing levels of genetic, life history, and geographic diversity to historical levels range-wide in order to determine gaps in each species or subspecies' portfolio that may leave them at particular risk, with climate change as an explicit risk factor to consider (Haak and Williams 2012, 2013). Where desirable, this type of broad spatial analysis can be used as a range-wide prioritization tool by highlighting projects that would improve specific components of the portfolio—while evaluating areas of the range least at risk of climate change or where the best improvements in habitat or population status could be made.

Ideally, this type of large-scale assessment would be a first step in prioritization, following which factors such as landowners, partners, and available funding can then be overlain to determine final project location. Typically, the process of project selection combines part scientific strategy and part opportunity; it is important that habitat assessments and a strong fundamental knowledge of the species' ecology drive project selection, but

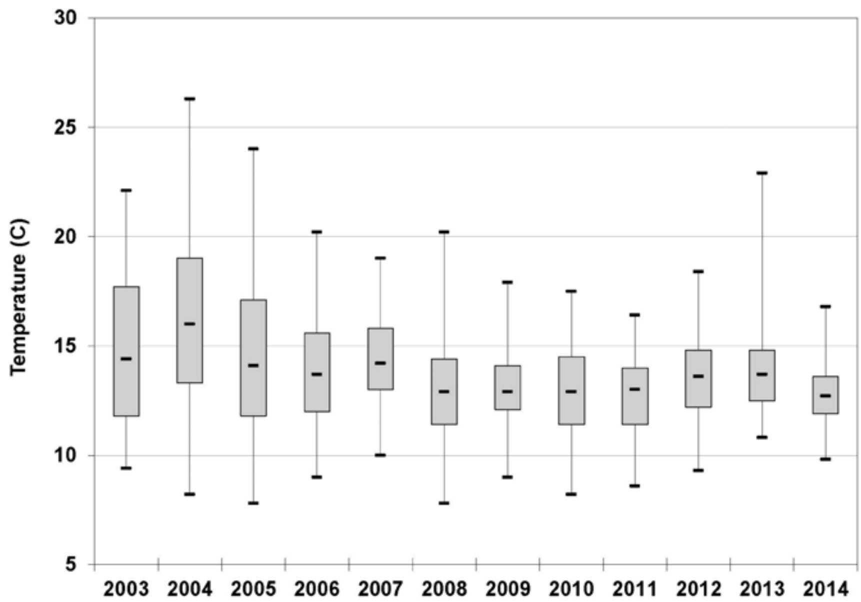


Figure 7. July water temperatures for Wasson Creek, Montana, just upstream of Nevada Spring Creek, 2003–2014.

the presence of willing landowners, partners, and funding is an integral part of project reality. The three case studies described herein all have elements of science-driven assessments but also landowner, partner, and funding opportunities. For some species and geographies, there are many projects that will rank as high priority, but in other regions, choices are more limited. Wasson Creek, for example, was one of 34 streams designated as high restoration priority in the Blackfoot River drainage (Pierce et al. 2005). But in more arid regions, such as northern Nevada's Great Basin, there are few places where a metapopulation of LCT could be restored. It was fortunate in the case of Maggie Creek that there were opportunities for collaboration among BLM, landowners, and partners in this particular basin and that the drainage contained just a few ranches in addition to BLM lands, which facilitated work across the entire watershed.

Along these lines, our work in Maggie Creek has emphasized the importance of increasing efforts to work with private landowners. Partly because the private landowner realm can be contentious and partly because of the difficult logistics in coordinating many different landowners, much of the restoration work for LCT to date has been on public lands—management teams have effectively tackled the "low-hanging fruit" first. But for LCT and many other native trout, much of the historical range falls on private lands, including the habitat along larger streams that is critical for restoring migratory life histories. So our greatest gains in the future are likely to come from working effectively with the private sector. Accordingly, we have initiated a suite of strategies, including funding a biologist with the state fish and wildlife agency to implement safe harbor agreements with landowners. These agreements protect landowners from legal aspects of having a listed species, such as LCT, on their properties and are thus an essential step in being able to carry out restoration activities on private properties. We are also working with our partner ranches to outreach to their peers, rancher-to-rancher, about the benefits of "conservation ranching" to improve habitat and species status.

For restoration work to have long-term benefits to native coldwater fishes, projects must directly address climate change impacts. Often, the most obvious need is to mitigate warming stream temperatures through riparian restoration and creation of coldwater refuge habitats within stream channels (Seavy et al. 2009). However, riparian restoration work can vary in effectiveness according to channel width (Cristea and Burges 2009) and riparian area species composition (Price 2013). Riparian restoration in multiple headwater streams may be necessary to realize benefits in downstream reaches. For salmon restoration in the western United States, Beechie et al. (2012) argued the importance of large-scale projects that jointly restore floodplain connectivity, instream flows, and re-aggrade incised channels (rather than more localized instream work in isolation) in order to ameliorate climate change effects.

In Maggie Creek, the beavers that recolonized helped re-aggrade channels and restore floodplain connectivity. Beaver dams slow stream flows, help offset drought conditions (Hood and Bayley 2008), and aid in restoration of incised channels (Pollock et al. 2014). Based on our experience in the Great Basin, the increased extent of wet meadow and riparian habitats created by beaver provide a wet refuge area resistant to wildfires. Beavers were an important component to the Maggie Creek project, and their positive impacts resulted in changed attitudes among local ranchers, who might have readily shot any beavers seen 15 or more years ago.

Climate change is having a dynamic influence on stream systems, but our understanding of how environmental change will play out on the landscape is imprecise. Given this uncertainty, projects that restore proper function and diversity across larger scales are more likely to be successful than projects that are driven solely by local site conditions. Based on case studies of climate change impacts on Rocky Mountain trout populations, Isaak et al. (2012) described the value of large, interconnected populations as a hedge against climate change uncertainty and how these populations are less likely to be eliminated by large-scale disturbances that are becoming increasingly common in western landscapes. It is relatively easy for stream restoration efforts to address problems at the stream reach scale but much more difficult to remediate them at the scale of larger rivers or watersheds, yet these larger basins are precisely the scale where we need to see improvements if trout and salmon are to persist.

One way for the restoration practitioner to address this issue of scale is to integrate reach-scale flow restoration and hydrologic reconnection efforts across multiple headwater streams to result in watershed-scale improvements in climate change impacts. Another approach is to implement reach-scale restoration projects that result in larger-scale benefits. Projects such as Wasson Creek are a good model and can have watershed-scale benefits for native trout if such projects can be replicated across multiple headwater streams or if restored reaches create refugia and limiting habitat types (e.g., spawning areas) that can be accessed by individuals from throughout the watershed. Efforts that treat isolated stream reaches that do not address watershed-scale limiting factors are more likely to fail in the long term (Williams et al. 1997; Bernhardt and Palmer 2011).

Restoration projects need clear and quantified goals and monitoring programs designed to detect changes in desired conditions to determine their success. Monitoring for effectiveness of projects designed to reduce climate change effects is sorely needed as managers struggle to fully understand climate change impacts over longer time scales. Unfortunately, funding for monitoring programs often is a lower priority especially long after project completion. Practitioners should ensure that funding for monitoring is an integral component of overall project funding. For example, the monitoring conducted at Maggie Creek since 2001 has provided essential confirmation to agency, funding, and landowner partners of restoration benefits, thus garnering support for continued work and monitoring. Given the complex and synergistic relationships among livestock grazing, drought, LCT movement, cheatgrass *Bromus tectorum* invasion, and wildfire in the watershed, continuing such monitoring in the long term will be particularly valuable for evaluating future benefits in light of climate change.

Whereas in Maggie Creek nonnative species were not an issue (but were a threat that was address by the permanent barrier), determining long-term project effectiveness for both Wasson and Crow creeks is complicated by the presence of native and nonnative trout in the drainages. Habitat restoration projects that improve channel conditions and stream temperature but do not convey a distinct advantage for the native over nonnative trout may be problematic. To date, the Wasson Creek project appears to provide a distinct advantage to native Cutthroat Trout because access to historical spawning areas of the Cutthroat Trout is now available. Projects such as Crow Creek that restore instream channels clearly improve local conditions and remove cumulative stress to the stream, but the relative benefits to native versus nonnative trout are less certain. For this reason, it is especially important to monitor the effectiveness of these projects to determine whether supplemental work or some form of nonnative control efforts is warranted.

Angler-based citizen science efforts can help augment monitoring capabilities. Many local TU chapters are already engaged in stream monitoring programs, and others are being encouraged to participate through development of stream monitoring manuals designed for anglers. The U.S. Environmental Protection Agency's (2014) best practices manual for monitoring stream temperatures and flows is an excellent reference for citizen science monitoring programs. Recent technological innovations that provide new tools (such as smartphone applications for naturalists, websites such as the U.S. Environmental Protection Agency's How's My Waterway) or reduce the costs of monitoring equipment (such as temperature data loggers) also facilitate an expansion of angler-based and other citizen science stream monitoring efforts.

The case studies examined herein demonstrate some of the complexities of restoration actions that are intended to restore degraded habitats and address impacts of a changing climate. We recommend restoration projects that incorporate science-driven habitats and species-level assessments, address local climate drivers but work at larger scales and across varying land ownerships, and have long-term monitoring components. The ability to work across entire watersheds, including streams, riparian areas, floodplains, and uplands, may be necessary to result in desired changes, especially in larger drainages and mainstem rivers. Similarly, the ability to implement and monitor projects over multiple years or even decades may be required to determine success in landscapes characterized by increasingly rapid change and future uncertainty.

ACKNOWLEDGMENTS

Early restoration work on Maggie Creek was conducted by the Elko District of the BLM, Newmont Mining Corporation, and Elko Land and Livestock. The Wasson Creek project could not have been completed without the assistance of Montana Department of Fish, Wildlife & Parks and local ranchers. This article benefited greatly by reviews from Jeff Kershner, Dan Dauwalter, Kurt Fesenmyer, Dan Isaak, and one anonymous reviewer.

FUNDING

Funding was provided by the National Fish and Wildlife Foundation, BLM, Trout Unlimited (TU), the Western Native Trout Initiative, the Ruby Pipeline Endangered Species Conservation Fund, Barrick Goldstrike Mines Inc., and Nevada Mining Association, with support from the Maggie Creek and Twenty-Five Ranches. Funding for Crow Creek restoration was provided by the U.S. Forest Service, National Forest Foundation, Idaho Department of Environmental Quality, TU, and the Simplot Corporation. Funding for our analyses was provided by TU's Coldwater Conservation Fund.

REFERENCES

Arrigoni, A. S., G. C. Poole, L. A. K. Mertes, S. J. O'Daniel, W. W. Woessner, and S. A. Thomas. 2008. Buffered, lagged or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. Water Resources Research 44:WO9418.

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2012. Restoring salmon habitat for a changing climate. River Research and Applications. 29:939–960.

Bernhardt, E. S., and M. A. Palmer. 2011. River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. Ecological Applications 21:1926–1931.

Brown, D. K., A. A. Echelle, D. L. Propst, J. E. Brooks, and W. L. Fisher. 2001. Catastrophic wildfire and the number of populations as factors influencing risk of extinction for Gila Trout (*Oncorhynchus gilae*). Western North American Naturalist 61:139–148.

Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov. 2010. Future dryness in the Southwest U.S. and the hydrology of the early 21st century drought. Proceedings of the National Academy of Sciences 107:21271–21276.

Cristea, N. C., and S. J. Burges. 2009. An assessment of the current and future thermal regimes of three streams located in the Wenatchee River basin, Washington state: some implications for regional river basin systems. Climatic Change. 102(3-4):493-520.

Dunham, J. B., B. E. Rieman, and J. T. Peterson. 2002. Patch-based models to predict species occurrence: lessons from salmonid fishes in streams. Pages 327–334 *in* J. M. Scott, P. Heglund, F. Samson, J. Haufler, M. Morrison, M. Raphael, and B. Wall, editors. Predicting species occurrences: issues of accuracy and scale. Island Press, Covelo, California.

Dunham, J. B., G. L. Vinyard, and B. E. Rieman. 1997. Habitat fragmentation and extinction risk of Lahontan Cutthroat Trout. North American Journal of Fisheries Management 17:1126–1133.

Fu, G., M. E. Barber, and S. Chen. 2010. Hydro-climatic variability and trends in Washington state for the last 50 years. Hydrological Processes 24:866–878.

Graybeal, D. Y., and D. J. Leathers. 2006. Snowmelt-related flood risk in Appalachia: first estimates from a historical snow climatology. Journal of Applied Meteorology and Climatology 45:178–193.

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.

———. 2013. Using native trout restoration to jumpstart freshwater conservation planning in the Interior West. Journal of Conservation Planning 9:38–52.

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 climate change on the persistence of salmonids in the Inland West. U.S. Geological Survey, Open-File Report 2010-1236.

Halpin, P. N. 1997. Global climate change and natural area protection: management responses and research directions. Ecological Applications 7:828–843.

Harper, M. P., and B. L. Peckarsky. 2006. Emergence cues of a mayfly in a high-altitude stream ecosystem: potential response to climate change. Ecological Applications 16:612–621.

Harris, J. A., R. J. Hobbs, E. Higgs, and J. Aronson. 2006. Ecological restoration and global climate change. Restoration Ecology 14:170–176.

Hood, G. A., and S. E. Bayley. 2008. Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. Biological Conservation 2008:556–567.

Hulme, P. E. 2005. Adapting to climate change: is there scope for ecological management in the face of a global threat? Journal of Applied Ecology 42:784–794.

Isaak, D. J., C. C. Muhlfeld, A. S. Todd, R. Al-Chokhachy, J. Roberts, J. L. Kershner, K. D. Fausch, and S. W. Hostetler. 2012. The past as prelude to the future for understanding 21st-century climate effects on Rocky Mountain trout. Fisheries 37:542–556.

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 United States. Frontiers in Ecology and the Environment 8:461–466.

Kovach, R. P., J. E. Joyce, J. D. Echave, M. S. Lindberg, and D. A. Tallman. 2013. Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. Plos One 8:1–10.

Lawler, J. J. 2009. Climate change adaptation strategies for resource management and conservation planning. Annals New York Academy of Science 1162:79–98.

Lawrence, D. J., B. Stewart-Koster, J. D. Olden, A. S. Reusch, C. E. Torgersen, J. J. Lawler, D. P. Butcher, and J. K. Crown. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24:895–912.

Luce, C. H., and Z. A. Holden. 2009. Declining annual streamflow distributions in the Pacific Northwest United States. Geophysical Research Letters 36:L16401.

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.

Noss, R. F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. Conservation Biology 15:578–590.

Pierce, R., R. Aasheim, and C. Podner. 2005. An integrated stream restoration and native fish conservation strategy for the Blackfoot River Basin. Montana Fish, Wildlife and Parks, Missoula.

Pollock, M. M., T. J. Beechie, J. M. Wheaton, C. E. Jordan, N. Bouwes, N. Weber, and C. Volk. 2014. Using beaver dams to restore incised stream ecosystems. BioScience 6:279–290.

Price, J. E. 2013. Potential methods to cool streams containing Apache Trout in the White Mountains of Arizona and implications for climate change. Master's thesis, University of Arizona, Tucson.

Rahel, F. J., and J. D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521–533.

Rieman, B. E., and J. Clayton. 1997. Wildfire and native fish: issues of forest health and conservation of native species. Fisheries 22:6–15.

Rieman, B. E., and D. J. Isaak. 2010. Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management. USDA Forest Service, Rocky Mountain Research Station, RMRS-GTR-250.

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.

Seavy, N. E., T. Gardali, G. H. Golet, E. T. Griggs, C. A. Howell, R. Kelsey, S. L. Small, J. H. Viers, and J. F. Weigand. 2009. Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Restoration Ecology 27:330–338.

Selong, J. H., T. E. McMahon, Z. V. Zale, and F. T. Barrows. 2001. Effects 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.

Simonds, G., M. Ritchie, and E. Sant. 2009. Evaluation of factors affecting Lahontan Cutthroat Trout recovery in three large watersheds. Open Range Consulting, Park City, Utah.

Spierre, S. G., and C. Wake. 2010. Trends in extreme precipitation events for the northeastern United States 1948–2007. Carbon Solutions New England, University of New Hampshire, Durham.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes towards earlier streamflow timing across Western North America. Journal of Climate 18:1136–1155.

U.S. Environmental Protection Agency. 2014. Best practices for continuous monitoring of temperature and flow in wadable streams. USEPA, National Center for Environmental Assessment, EPA/600/R-13/170F.

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 River Basin, USA. 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., N. A. Son, D. C. Dauwalter, D. J. Isaak, H. M. Neville, C. H. Luce, J. B. Dunham, M. K. Young, K. D. Fausch, and B. E. Rieman. 2013. Probabilistic accounting of uncertainty in forecasts of species distributions under climate change. Global Change Biology 19:3343–3354.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Sweetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science 313:940–943.

Williams, J. E., A. L. Haak, N. G. Gillespie, H. M. Neville, and W. T. Colyer. 2007. Healing troubled waters: preparing trout and salmon habitat for a changing climate. Trout Unlimited, Arlington, Virginia.

Williams, J. E., C. A. Wood, and M. P. Dombeck. 1997. Understanding watershed-scale restoration. Pages 1–13 *in* J. E. Williams, C.A. Wood, and M.P. Dombeck, editors. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland. AFS

FEATURE

Smartphones Reveal Angler Behavior:

A Case Study of a Popular Mobile Fishing Application in Alberta, Canada

Successfully managing fisheries and controlling the spread of invasive species depends on the ability to describe and predict angler behavior. However, finite resources restrict conventional survey approaches and tend to produce retrospective data that are limited in time or space and rely on intentions or attitudes rather than actual behavior. In this study, we used three years of angler data from a popular mobile fishing application in Alberta, Canada, to determine province-wide, seasonal patterns of (1) lake popularity that were consistent with conventional data and (2) anthropogenic lake connectivity that has not been widely described in North America. Our proof-of-concept analyses showed that mobile apps can be an inexpensive source of high-resolution, real-time data for managing fisheries and invasive species. We also identified key challenges that underscore the need for further research and development in this new frontier that combines big data with increased stakeholder interaction and cooperation.

Teléfonos inteligentes revelan comportamiento de pescadores: el caso de estudio en Alberta, Canadá, de una aplicación para teléfono móvil

El manejo exitoso de las pesquerías y el control de la dispersión de especies invasivas depende de la habilidad para describir y predecir el comportamiento de los pescadores. Sin embargo, la limitación de recursos restringe el uso de muestreos convencionales y tiende a producir datos históricos incompletos en tiempo y espacio, y se fundamenta en intenciones o actitudes más que en el comportamiento real de los pescadores. En este trabajo se utilizan tres años de datos sobre pescadores obtenidos mediante una aplicación para teléfonos móviles en Alberta, Canadá, para determinar, a nivel provincie, los patrones estacionales de: 1) popularidad del lago de acuerdo a los datos convencionales, y 2) conectividad antropogénica del lago que no ha sido ampliamente descrita en Norteamérica. El análisis para poner a prueba el concepto mostró que las aplicaciones para teléfono celular pueden representar una fuente de datos barata, de alta resolución y que opera en tiempo real para manejo de pesquerías y de especies invasivas. También se identificaron retos clave que resaltan la necesidad de realizar investigación en el futuro y desarrollar información acerca de esta nueva frontera tecnológica que combina grandes cantidades de datos y mayor interés y cooperación por parte de los inversionistas.

Jason T. Papenfuss
University of Minnesota, Department of Fisheries, Wildlife, and Conservation Biology, Saint Paul, MN

Nicholas Phelps
University of Minnesota, Department of Veterinary Population Medicine, University of Minnesota, Saint Paul, MN

David Fulton
U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit, University of Minnesota, Saint Paul, MN

Paul A. Venturelli
University of Minnesota, Department of Fisheries, Wildlife, and Conservation Biology, 135 Skok Hall, 2003 Upper Buford Circle, Saint Paul, MN 55108. E-mail: pventure@umn.edu

INTRODUCTION

Anglers and angler regulations determine the magnitude, distribution, and timing of fishing within a region. Therefore, the ability to predict angler behavior can provide insight into multiple stressors such as exploitation, the potential spread of aquatic invasive species, and fish diseases (Drake and Mandrak 2010). Accordingly, both successful fisheries management and invasive species control depend on the ability to quantify and forecast angler behavior (Buchan and Padilla 1999; Muirhead and MacIsaac 2005; Hunt et al. 2011).

Typically, angler behavior is quantified through a variety of empirical approaches (e.g., creels, diaries, interviews, mail surveys) that vary widely in effort, cost, and efficacy (Fenichel et al. 2013; Griffiths et al. 2013). However, these approaches tend to produce retrospective data that are limited in time or space and often reveal intensions or attitudes rather than actual behaviors (Adamowicz et al. 1994). The amount of data generated using these approaches is also limited by decreasing budgets (Riecke et al. 2013).

Mobile smartphone applications (apps) are a novel approach to collecting scientific data. As of January 2014, the percentage of American adults who owned a smartphone was 85% for ages 18–29, 79% for ages 30–49, 54% for ages 50–64, and 27% for ages 65+ (Pew Research Center 2015). Similarly, app use has increased dramatically in the last decade, and global app downloads are predicted to surpass 100 billion by 2015 (Dufau et al. 2011; Edvinsson 2013). Cellular and wireless coverage are

Where other tools require a project to be launched, along with the need to train and motivate volunteers, apps can collect data passively.

also broad, and smartphones come standard with GPS, accelerometers, gyroscopes, and high-resolution digital cameras. This combination of mobility and measurement capability makes apps ideal for citizen science (Newman et al. 2012). Relevant examples include botany (BudBurst[M]), entomology (Journey North), ornithology (BirdLog), and wildlife (Moose Hunter Survey). (Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.)

Although smartphone usage and the number of science-based apps have grown significantly, the use of apps for fisheries science remains limited, especially in recreational fisheries (Gutowsky et al. 2013). Notable exceptions include iAngler, which is generating data in support of Common Snook *Centropomus undecimalis* stock assessments in Florida (Muller and Taylor 2013); International Game Fish Association Catchlog, which is currently in beta testing in Everglades National Park, Florida (IGFA 2014); iFishWatcher, which is generating fisheries data in Europe (Abou-Tair et al. 2013); and iSnapper, which for-hire vessel captains in Texas are using to generate real-time harvest data for Red Snapper *Lutjanus campechanus* (Stunz et al. 2014). Researchers in North Carolina are also experimenting with a text-based data collection system for coastal recreational anglers (Baker and Oeschger 2009).

The limited use of fishing app data by management agencies and the fisheries community in general is surprising given that these data essentially represent volunteer angler diaries in digital format. Diaries can be biased, but they are also a low-cost, high-resolution form of data collection that can inform multiple fisheries management topics (reviewed by Cooke et al. 2000). Fishing apps have the added benefit of providing fine-scale movement data, platforms for on-demand angler surveys, opportunities for real-time communication and interaction, and ease of distribution and collection. In addition, where other tools require a project to be launched, along with the need to train and motivate volunteers, apps can collect data passively. For example, a recent study found that passive data from a similar medium (an online angler forum) predicted spatial and temporal patterns of fishing effort in Nebraska reservoirs (Martin et al. 2014). Therefore, fishing apps represent an underutilized tool for efficiently collecting information on angler behavior and other data relevant to fisheries management and invasive species control.

Fishing apps are particularly suited to generating data pertaining to the spread of aquatic invasive species and fish diseases. These phenomena are increasing in both scale and frequency (MacIsaac et al. 2004; Bain et al. 2010) and can be important to sustainable fisheries management (Dextrase and Mandrak 2006; Faisal et al. 2012). Apps allow for rapid reporting and detection (e.g., MISIN 2014) and have the added benefit of generating movement data that reveal transmission pathways and trends, and ultimately inform prevention and response efforts.

This study describes a proof-of-concept analysis involving three years of existing app data that were generated by anglers in Alberta, Canada. We are particularly interested in province-wide, seasonal patterns of lake popularity and angler movement in the context of aquatic invasive species and fish diseases. More generally, this case study serves to (1) illustrate the available potential of fishing app data, (2) highlight key issues and challenges, and (3) identify future applications and research directions.

METHODS

App Data and Filtering

We obtained user-generated data from the iFish Alberta smartphone app for the period December 2010 to January 2014. This app is developed and distributed by The App Door of Edmonton, Alberta, Canada. The app provides anglers with fishing-related information for more than 700 lakes in Alberta, which represent over 90% of all managed lakes (Environment and Sustainable Resource Development [ESRD] 2014). The app also collects user-generated data (henceforth "records") in the form of hotspot logs, catch logs, ice reports, and lake reports. A hotspot record is created when a user enters the date, time, and geographic location of a catch. Similarly, a catch log record is created when a user enters information pertaining to a fish caught (e.g., species, length, location). An ice report record is created during the ice-fishing season when a user shares information about ice conditions, and a lake report record is created when a user shares lake-specific information related to fishing (e.g., types, sizes, and quantities of fish caught). Associated with each record are a unique and anonymous user identification number, a lake identification number, a date/time stamp, and text that the user has entered.

To first determine the relative popularity of lakes in Alberta, we filtered for those records that appeared to indicate that a user visited a specific lake on a specific date (henceforth "visits"). Because a visit is implied when a user records a hotspot, logs a catch, or reports on ice conditions, we assumed that most of these record types were authentic. Exceptions were redundant records and records unrelated to fishing (as identified by user text). Due to the conversational nature of lake reports, however, we did not assume that all lake report records indicated actual lake visits. Many lake report records within the data set were discursive, consisting of chatter about technique, regulations, lake access, or text not related to fishing. Therefore, we individually assessed the text associated with each lake report record and filtered out those that did not indicate an actual visit to a specific lake. Because users often recorded their lake reports subsequent to their visit, we also filtered out all records that indicated a visit more than a week prior to the recorded entry. Thus, any lake report time stamp in our filtered data was likely to be accurate to within seven days.

Analysis of App Data

We used the frequency of both visits and records summed over lakes to determine popularity among Alberta lakes and the extent to which unfiltered records gave a reliable signal for visits (Pearson correlation). We then interpolated filtered frequency data by season to generalize seasonal patterns of angler distribution in relation to population centers and principle highways. For seasons, we coded each visit as either open water fishing (May to November) or ice fishing (November to April) according to approximate ice-on and ice-off dates that we estimated from ice report records. Spatial interpolation was via inverse distance weighting (cell size = 1.6 decimal degrees, power = 1, fixed radius, points = 0, distance = 2.2 decimal degrees).

To assess the anthropogenic connectivity of lakes in Alberta in the context of the spread of aquatic invasive species, we identified all instances of the same user visiting two lakes within seven days and then summed across users. The result was a

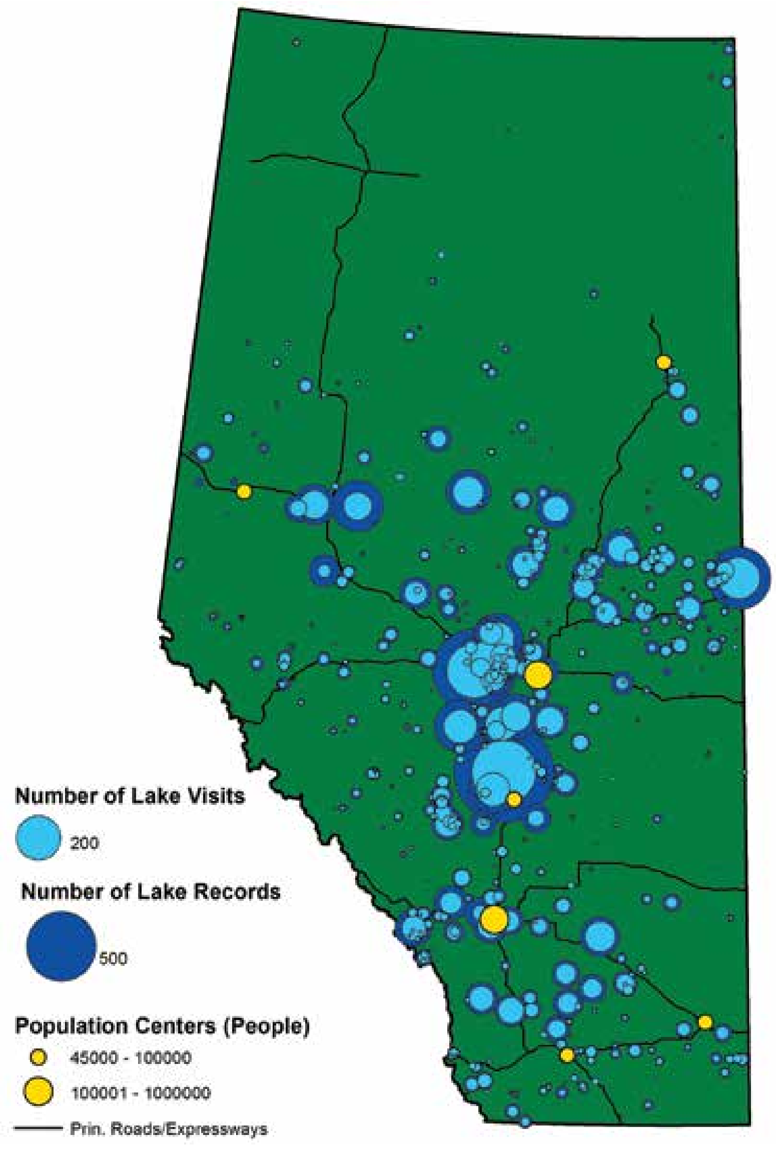


Figure 1. Popularity of lakes in Alberta and their proximity to population centers and principle transportation infrastructure according to 12,268 lake records generated by 2,827 users (unfiltered data) and 6,004 lake visits by 2,358 users (filtered data).

number of spatial connections of varying degree (i.e., cumulative visit frequency) between pairs of lakes. The seven-day window has been shown to be a critical period for the spread of aquatic invasive species and fish diseases relevant to Alberta (Ricciardi et al. 1995; Havel and Stelzleni-Schwent 2001; Hawley and Garver 2008). Therefore, anthropogenic connectivity in this study is a proxy for likely pathways of species invasion among Alberta lakes.

Comparison to Conventional Data

We used simple linear regression to compare the frequency with which app users visited Alberta lakes (seasons combined) to the popularity of Alberta lakes as revealed by two Alberta ESRD data sets. We first compared app-based visits in summer to the number of angler visits as estimated by the most recent ESRD summer creel survey data that were available. Survey details are given in M. G. Sullivan (2003). This analysis was restricted to those lakes for which we had both creel and app data. The second analysis compared the annual percentage of total app-based visits within each of Alberta's 10 fish management watershed units to the annual percentage of total angling effort within these units as determined by a voluntary mail-in survey that was conducted in 2010 (Zwickel 2012). We forced each regression through the origin because it was reasonable to assume that the absence of anglers visiting a lake or watershed unit precludes a subset of these anglers (i.e., app users) from visiting that lake or watershed unit. No angler movement data were available to validate our estimates of anthropogenic connectivity. All statistical analyses were performed in R version 2.15.1 (R Core Team 2012), and all spatial analyses were performed in ESRI ArcMap version 10.0. (Redlands, CA).

RESULTS

Lake Popularity

Between December 2010 and January 2014, 2,827 app users (~1.3% of active resident anglers in Alberta; DFO 2012) generated over 12,000 records by logging hotspots and catches and submitting ice reports and lake reports. Nearly half of all records (6,004 records from 2,358 users) appeared to indicate that a user visited a specific lake on a specific date. Across all 497 Alberta lakes that were visited by app users, records and visits were highly correlated (Pearson correlation, $r = 0.99$, $P < 2.2e\text{-}16$). Both showed that the most popular lakes among app users were concentrated around the Edmonton census metropolitan area (CMA), the Calgary CMA, and the Calgary–Edmonton corridor (Figure 1). Other areas of modest lake popularity included several of the provincial parks and recreation areas within recreational driving distance of Edmonton (e.g., Cold Lake and Lesser Slave Lake provincial parks). Despite the Calgary CMA having a slightly higher population and approximately the same number of nearby (albeit smaller) lakes, both records and visits were much lower than in the Edmonton CMA.

Seasonally interpolated visit data also showed that app users preferred lakes near the Calgary–Edmonton corridor and the

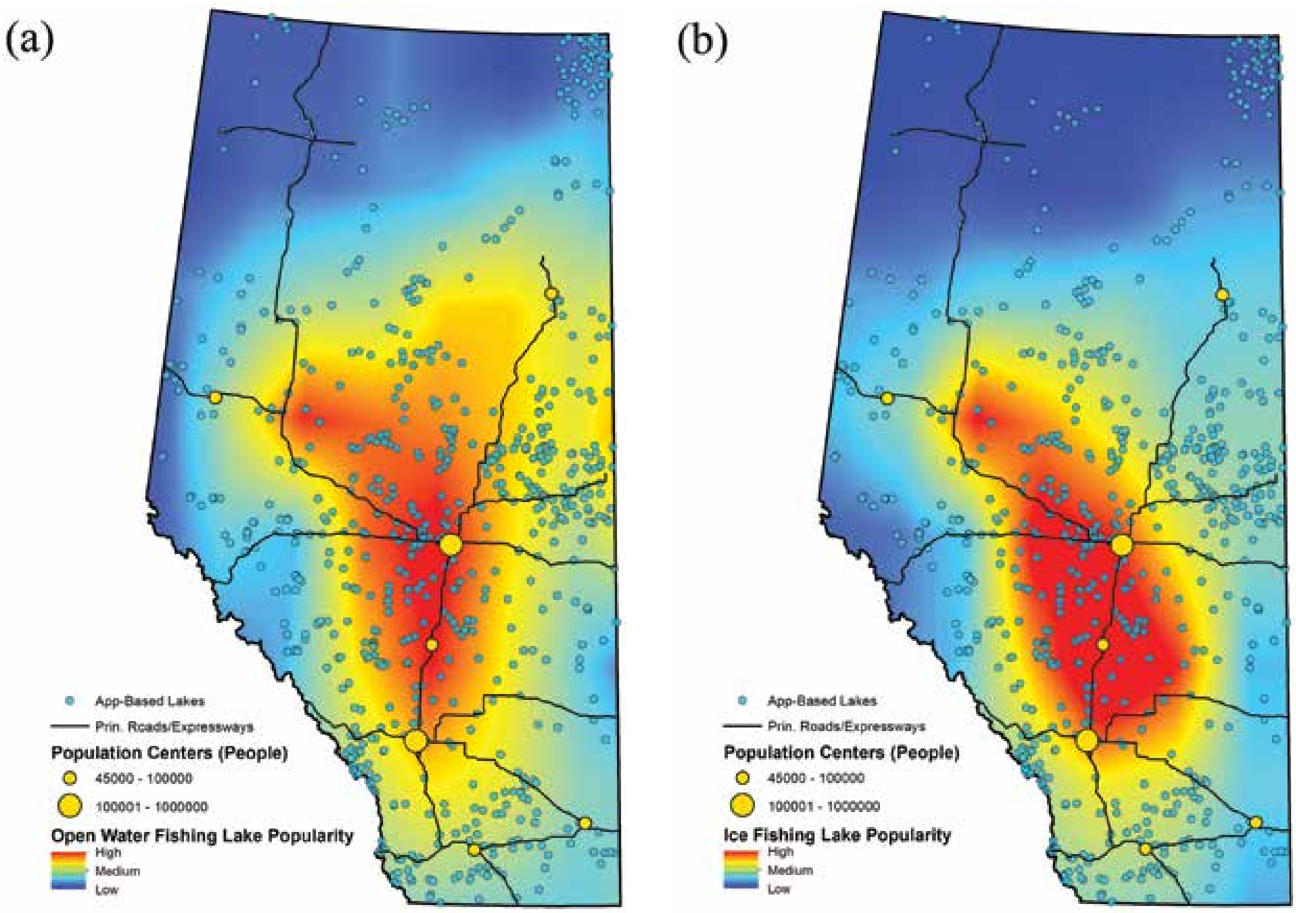


Figure 2. Seasonal popularity of lakes in Alberta for open water fishing: (a) 2,986 visits to 362 lakes by 1,431 users and ice fishing (b) 3,013 visits to 289 lakes by 1,222 users.

regions northwest and northeast of Edmonton and that this pattern was highly influenced by population centers and infrastructure (Figures 2a, 2b). This pattern also varied seasonally in that app users preferred lakes closer to population centers in winter, whereas app users were more likely to visit lakes in the east-central region of the province during the open-water season.

Anthropogenic Connectivity

We identified 1,246 instances where an angler visited two Alberta lakes within a seven-day window. A majority (57%, although not significant) of these trips occurred during the ice fishing season. In both seasons, approximately 80% of trips were less than 150 km in Euclidean distance (centroid to centroid). The frequency of trips greater than 300 km (4.3%), though uncommon, was still significant. Combined, these anthropogenic connections formed a network that was similar in pattern to the distribution of lake popularity (Figures 1, 2), with most connections located around or near population centers and transportation infrastructure (Figures 3a, 3b). The influence of population centers and transportation infrastructure was particularly evident in winter. However, in both seasons we observed several connections that were isolated from the larger network. For example, app users who fished Laurier Lake in Whitney Lakes Provincial Park in winter also tended to fish nearby Stoney Lake (linear distance of 38.2 km) in the same week.

Comparison to Conventional Data

We found a linear relationship between the frequency of app-based visits in summer and the number of angler visits as estimated by summer creel surveys on 36 Alberta lakes (Figure 4). The linear relationship was significant ($r^2 = 0.74$, $F_{1,35} = 99.7$, $P = 8.81e\text{-}12$) and implied that, on average, app visits underestimated total angler visits by a factor of approximately 254. We also found a linear relationship between the percentage of app visits by watershed unit and the popularity of these watershed units, according to the 2010 survey (Figure 5). This relationship was also significant ($r^2 = 0.82$, $F_{1,8} = 40.8$, $P = 2.12e\text{-}4$) but not significantly different from the 1:1 line. However, app data tended to overestimate the relative popularity of the Parkland Prairie 2 watershed unit (i.e., Edmonton CMA) and underestimate the popularity of the Eastern Slopes 1 watershed unit (i.e., Calgary CMA).

DISCUSSION

Our analysis of data from a popular fishing app revealed both annual and seasonal patterns of lake popularity and anthropogenic lake connectivity. The former were consistent with conventional data, and both analyses revealed patterns at spatial and temporal scales that are impractical with conventional survey methods. In this section, we discuss our results in the context of

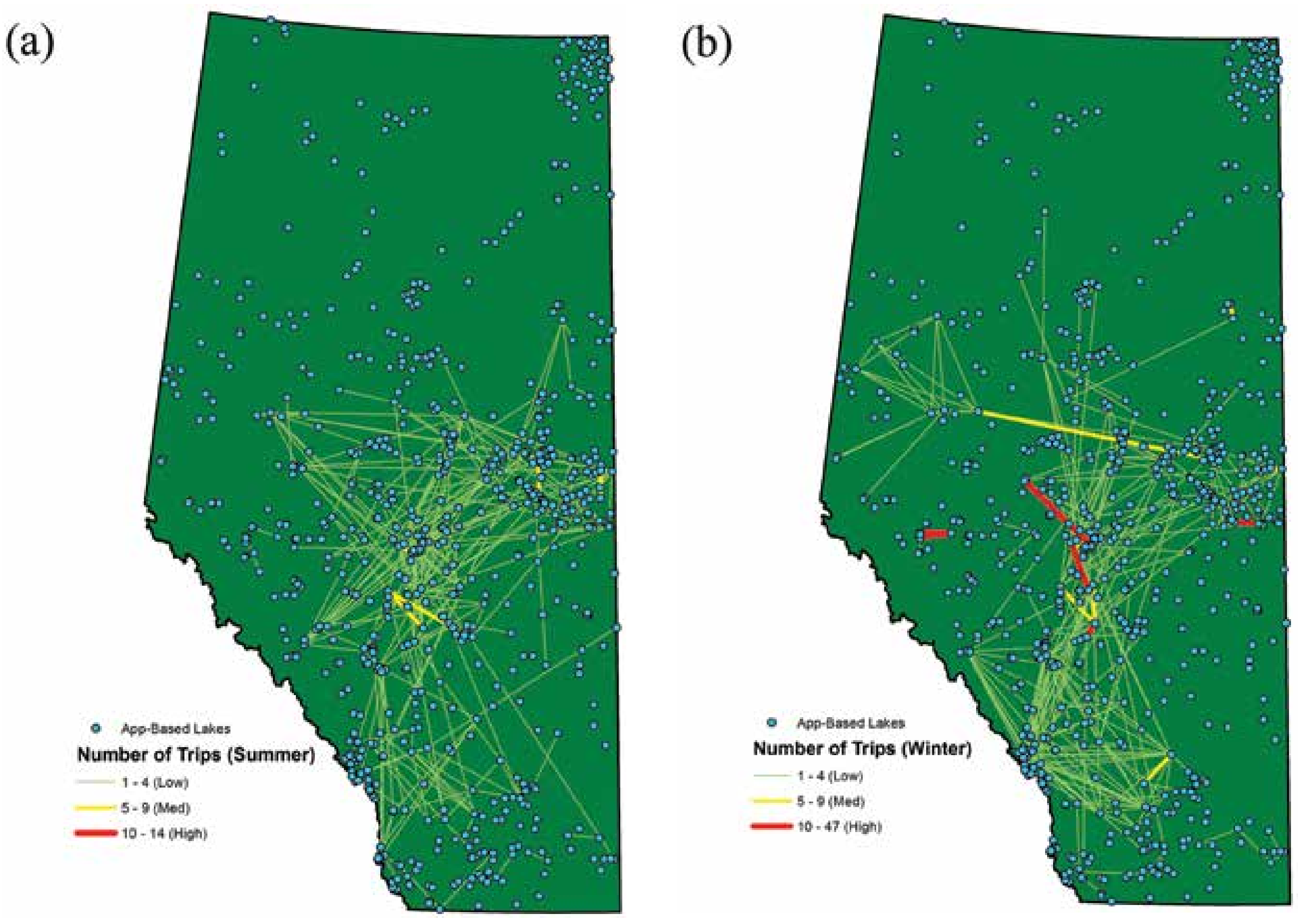


Figure 3. Seasonal anthropogenic connectivity of lakes in Alberta for open water fishing: (a) 304 low-, 7 medium-, and 1 high-strength connections and ice fishing: (b) 293 low-, 10 medium-, and 8 high-strength connections.

the spread of invasive species, expand this discussion to include broader applications of app data to fisheries, and identify some of the challenges and next steps for working with app data.

App Data and the Spread of Invasive Species

Our results demonstrate that app data can address the need for timely, inexpensive, and high-resolution information regarding the vectors and dispersal pathways of aquatic invasive species and fish diseases. Anglers and their equipment are significant vectors for the dispersal of many aquatic species (Johnson et al. 2001; Cameron et al. 2007; Drake and Mandrak 2014), and understanding how (and why) anglers move about the landscape is crucial to understanding and controlling the spread of invasive species and identifying critical control points, such as high-frequency linkages of lake connectivity. Consequently, several approaches to understanding angler movement patterns have emerged in recent decades. Mathematical approaches have included such methods as gravity and transportation network modeling (Leung et al. 2006; Drake and Mandrak 2010), and empirical approaches have focused mainly on survey methods (Buchan and Padilla 1999; Muirhead and MacIsaac 2005).

Although it is possible to derive networks from surveys and interviews, networks derived from app data would be easier to obtain, include more lakes, and show how invasive species transmission risk varies seasonally and changes over time.

App data can contribute to our understanding of angler movement in a number of ways. First, app data are observational and therefore likely to expose the revealed preferences of anglers. This is in contrast to conventional survey data (which reveal stated preference and are usually retroactive) and simulation models (which predict preference but can be data-hungry, assumption-rich, and difficult to validate; Nicholls 1989; Johnston et al. 2010). When combined with information on the location of infected waterways, these revealed preferences might better inform invasive species risk assessments. Second, app data reveal anthropogenic connectivity. Information about which lakes anglers travel between, in addition to which lakes they travel to, is a significant step forward in elucidating potential pathways of transmission of aquatic invasive species and fish diseases. For example, the hypothetical introduction of dreissenid mussels into popular and well-connected areas such as the Calgary–Edmonton corridor might pose a much greater risk to Alberta's aquatic resources than an introduction into less popular and poorly connected areas such as the southeast corner of the province. Although it is possible to derive networks from surveys and interviews, networks derived from app data would be easier to obtain, include more lakes, and show how invasive species transmission risk varies seasonally and changes over time. For example, formal analyses of the seasonal networks in Alberta (e.g., Junker and Schreiber 2008) are likely to reveal the distribution and direction of lake connections and show how connections vary seasonally and are influenced by lake characteristics such as area, species composition, watershed development, and proximity to population centers and other lakes. Third, app data are unique in that they are available at fine spatial and temporal resolutions over broad spatial and temporal scales. Data collection by apps is largely limited, not by fiscal resources but by the number, frequency, and distribution of app users. Finally, whereas conventional surveys reveal angler behavior at discrete points in space and time, app data are continuous and can therefore reveal patterns over seasons, years, months, or even days. This flow of real-time data will help managers to quickly and effectively plan for and respond to the detection and spread of aquatic invasive species and fish diseases.

Benefits and Broad Applications

In general, high-resolution, real-time app data offer exciting opportunities to explore long-term and spatially broad trends in angler demographics, behavior (e.g., individual/group home ranges), and harvest as well as responses to regulation changes, disease outbreaks, fish kills, and stocking events. Information can also feed back onto agencies (i.e., adaptive management) and anglers instantly, providing lake-specific estimates of fishing pressure or harvest relative to a fisheries reference point. App data are also likely to complement, and in some cases provide a viable alternative to, conventional lake and angler surveys. For example, our analyses show that app data predict survey-based estimates of angler effort in most regions of Alberta as well as creel-based estimates of angler visits to specific Alberta lakes (see also Martin et al. 2014). The latter relationship was less strong, perhaps because creel data preceded app data by up to 19 years. Because surveys, creels, and other conventional methods are relatively expensive, time consuming, and limited in space and time, substituting or supplementing with app data might allow agencies to allocate their resources more efficiently. In order to realize these efficiencies and avoid redundant efforts and issues with data compatibility, we recommend that agencies collaborate to develop apps or app standards.

Social network analysis could also be applied to app data to reveal patterns of social engagement and connectivity. Recent studies have demonstrated the importance of social networks in both the exploitation and conservation of fisheries resources (e.g., Mueller et al. 2008). Anglers comprise coupled socioecological systems in that they relate to and interact with each other, lake ecosystems, and management. Socioecological systems in general have been the focus of much study in the past decade (Liu et al. 2007; Hunt et al. 2011; Schlueter et al. 2012), and apps could provide another tool for furthering this research and transforming it into effective policy. For example, a social network analysis of app data could help to identify which angler groups are most likely to bring together diverse segments of a network to facilitate collective action around a problem such as invasive species (Prell et al. 2009 and references therein).

Finally, mobile apps represent a significant opportunity for the development of citizen science approaches within fisheries. Citizen science approaches provide a cost-effective means of collecting continuous data over large spatial scales (Cohn 2008). To date, we are aware of only two published examples of apps that were designed specifically for citizen science: one for watershed monitoring (Kim et al. 2011) and the other for ornithology (Sullivan et al. 2014). The number of recreational anglers in

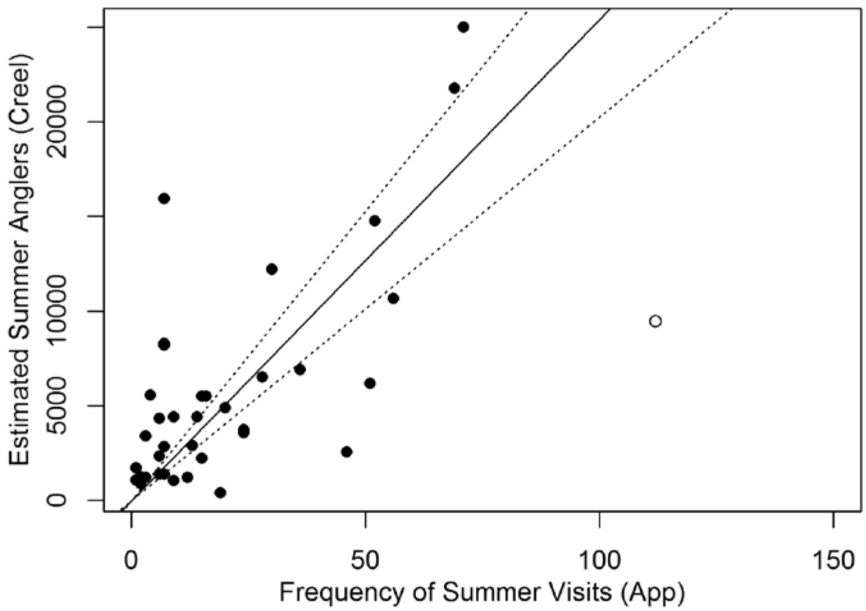


Figure 4. Scatterplot of ESRD summer creel survey data for 36 popular Alberta lakes (1995–2012) versus the frequency of app-based summer visits to these lakes. The solid line is the linear regression line forced through the origin (slope = 254.0 estimated angler visits per app user visit). Dotted lines are 95% confidence intervals for the regression line, and the open circle is an influential outlier (Lake Wabamun) that we excluded from the analysis.

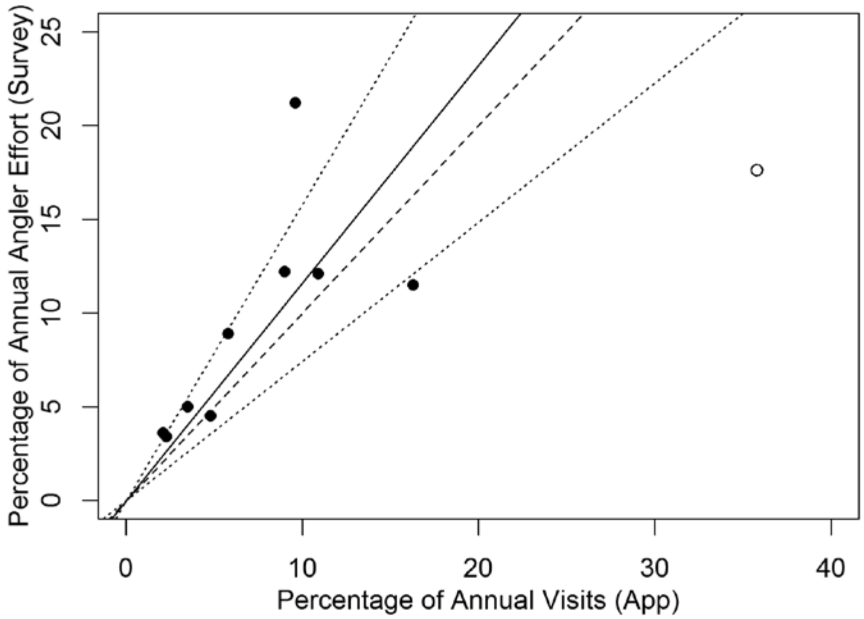


Figure 5. Scatterplot of the percentage of total angling effort in Alberta by fish management watershed unit versus the percentage of total app-based visits by fish management watershed unit. The dashed line is the 1:1 relationship, the solid line is the linear regression line forced through the origin (slope = 1.16), and dotted lines are 95% confidence intervals for the regression line. The open circle is an outlier (Parkland Prairie Zone 2) that we excluded from the analysis.

many regions of the world (e.g., >36 million in Canada and the United States; DFO 2012; USDOI et al. 2011) represents a large and mostly untapped resource for fisheries science and management. Specially designed apps (or features within existing apps) could be developed and deployed in citizen science contexts to provide fisheries researchers with information on a diversity of topics including the distribution and occurrence of species of interest, the occurrence of outbreaks of fish diseases, and the timing and duration of fish migrations and spawning.

Challenges and Next Steps

Properly designed apps are a source of high-resolution, real-time, and cost-effective data that can be utilized in fisheries management and science; however, there are challenges to collecting app data of sufficient quality. One challenge is that app data are subject to unique forms of bias. For example, our analysis of relative popularity within Alberta's fisheries management watershed units showed decreased lake popularity near Calgary and increased lake popularity near Edmonton, relative to a conventional survey. These discrepancies are likely due to our app data not including riverine locations, which are abundant along the Eastern Slopes region of Alberta but were not included in the app until after our analysis. Sampling bias may also help to explain why app data underestimated angler effort in some Alberta lakes (e.g., Pigeon Lake, Lesser Slave Lake) and overestimated in others (e.g., Gull Lake, Wabamun Lake) (S. Spencer, Alberta Environment and Sustainable Resource Development, personal communication). Thus, an understanding of any inherent biases that result from app design and user demographics is essential prior to making inferences about an angler population.

Other sources of bias in app data include transiency (the short-term use of an app) and avidity (a small number of users creating a disproportionate amount of data). In our study, for example, ~ 7% of the users that downloaded the app generated location data. Of these users, 37% generated 75% of that data. These challenges underscore the importance of design requirements that facilitate the ease and enjoyment of app use. Biases associated with reporting (e.g., anglers exaggerating catches) and avoidance (due to lack of agency trust or a reluctance to share) are also likely to cause inaccuracy in the context of app-based data collection. Therefore, fisheries scientists might initially focus on validating app-based data collection methods by comparing apps with creel and mail-based methods (the current standards) as well as comparing app user demographics against angler demographics. If demographic bias is unavoidable, then fisheries scientists can, as a minimum, determine what segment(s) of the angler population app data represent.

Where specific forms of bias can complicate the collection of app data, noise filtering can also complicate its analysis. Noise filtering of user-generated text is a common challenge, particularly in social media contexts (Aggarwal and Zhai 2012). Variance is typically larger with user-generated text data; consequently, preprocessing techniques have been developed to improve data quality. These techniques span a wide spectrum of complexity and efficacy, and obtaining high-quality data can be challenging (Agichtein et al. 2008). Filtering approaches are context dependent in that they depend on the question or pattern of interest. Therefore, each new question requires a different set of assumptions, which complicates the task of defining and identifying noise. For example, analyzing our data set for the relative popularity of freshwater game fishes would have required a completely different filtering approach than the one used. Haphazardly applying filters can result in the inclusion of low-quality data, reducing the power of the analysis. Conversely, overfiltering the data can result in the exclusion of high-quality data and lead to collective patterns of behavior that are not consistent with individual preferences (Zafarani et al. 2014). In our study, filtering of the text-based data resulted in the reduction of over 50% of the total records. Therefore, in the interest of reducing noise and improving efficiency, apps could be designed with specific data needs and analyses in mind.

CONCLUSIONS

Fishing apps are broadly applicable to research, facilitate regular monitoring, and improve the efficiency, spatial and temporal extents, and resolution of conventional survey methods. But with only a few notable exceptions (e.g., Sweeney 2011; Presley 2012), fisheries science lags behind other fields and disciplines in the development and use of app technology (Gutowsky et al. 2013). Our finding that anglers visited lakes that were within a reasonable driving distance of large population centers is nothing new; it is consistent with conventional data from Alberta and well established in the literature (e.g., Post et al. 2008; Ward et al. 2013). However, the fact that we observed angler preferences (and movement networks) by applying fairly basic analyses to data from the uncoordinated use of an app that was not developed for research demonstrates the enormous potential of this technology. Fully realizing this potential could be achieved by (1) developing and/or modifying apps for research; (2) being aware of the biases inherent in and limitations to analyzing app data; (3) conducting more formal ecological, social, and coupled system analyses; and (4) exploring novel applications. To this end, we encourage coordinated research and agency collaboration to improve the application and use of these technologies alongside and even in place of existing data collection methods, particularly when trying to understand complex angler behaviors that determine harvest, distribute revenue, and control the spread of invasive species and diseases.

ACKNOWLEDGMENTS

We thank Ben Chen for conversations that inspired this project, Quick-Draw, Inc. for sharing iFish Alberta data, and Stephen Spencer and Michael Sullivan (both of ESRD) for sharing creel data and insight. Previous versions of this manuscript benefited from comments by Andrew Drake, Olaf Jensen, Tom Lang, Stephen Spencer, Kristin Vickstrom, and two anonymous reviewers.

FUNDING

Funding was through the University of Minnesota.

REFERENCES

Abou-Tair, D., M. Bourimi, R. Tesoriero, M. Heupel, D. Kesdogan, and B. Ueberschär. 2013. An end-user tailorable generic framework for privacy-preserving location-based mobile applications. Applied Mathematics & Information Sciences 7:2137–2148.

Adamowicz, W., J. Louviere, and M. Williams. 1994. Combining revealed and stated preference methods for valuing environmental amenities. Journal of Environmental Economics and Management 26:271–292.

Aggarwal, C. C., and C. Zhai. 2012. Mining text data. Springer, New York.

Agichtein, E., C. Castillo, D. Donato, A. Gionis, and G. Mishne. 2008. Finding high-quality content in social media. Pages 183–194 *in* Proceedings of the 2008 International Conference on Web Search and Data Mining, Palo Alto, California.

Bain, M. B., E. R. Cornwell, K. M. Hope, G. E. Eckerlin, R. N. Casey, G. H. Groocock, R. G. Getchell, P. R. Bowser, J. R. Winton, and W. N. Batts. 2010. Distribution of an invasive aquatic pathogen (viral hemorrhagic septicemia virus) in the great lakes and its relationship to shipping. PloS One 5:e10156.

Baker, M. S., Jr., and I. Oeschger. 2009. Description and initial evaluation of a text message based reporting method for marine recreational anglers. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:143–154.

Buchan, L. A., and D. K. Padilla. 1999. Estimating the probability of long-distance overland dispersal of invading aquatic species. Ecological Applications 9:254–265.

Cameron, E. K., E. M. Bayne, and M. J. Clapperton. 2007. Human-facilitated invasion of exotic earthworms into northern boreal forests. Ecoscience 14:482–490.

Cohn, J. P. 2008. Citizen science: can volunteers do real research? Bioscience 58:192–197.

Cooke, S., W. Dunlop, D. Macclennan, and G. Power. 2000. Applications and characteristics of angler diary programmes in Ontario, Canada. Fisheries Management and Ecology 7:473–487.

Dextrase, A. J., and N. E. Mandrak. 2006. Impacts of alien invasive species on freshwater fauna at risk in Canada. Biological Invasions 8:13–24.
DFO (Department of Fisheries and Oceans Canada). 2012. Survey of recreational fishing in Canada 2010. Available: dfo-mpo.gc.ca/stats/rec/can/2010/RECFISH2010_ENG.pdf. (June 2014).
Drake, D. A. R., and N. E. Mandrak. 2010. Least-cost transportation networks predict spatial interaction of invasion vectors. Ecological Applications 20:2286–2299.
———. 2014. Ecological risk of live bait fisheries: a new angle on selective fishing. Fisheries 39:201–211.
Dufau, S., J. A. Duñabeitia, C. Moret-Tatay, A. McGonigal, D. Peeters, F. Alario, D. A. Balota, M. Brysbaert, M. Carreiras, and L. Ferrand. 2011. Smart phone, smart science: how the use of smartphones can revolutionize research in cognitive science. PloS One 6:e24974.
ESRD (Environment and Sustainable Resource Development). 2014. Alberta fish and wildlife management information system. Available: esrd.alberta.ca/fish-wildlife/fwmis. (September 2014).
Edvinsson, L. 2013. IC 21: Reflections from 21 years of IC practice and theory. Journal of Intellectual Capital 14:163–172.
Faisal, M., M. Shavalier, R. K. Kim, E. V. Millard, M. R. Gunn, A. D. Winters, C. A. Schulz, A. Eissa, M. V. Thomas, and M. Wolgamood. 2012. Spread of the emerging viral hemorrhagic septicemia virus strain, genotype IVb, in Michigan, USA. Viruses 4:734–760.
Fenichel, E. P., J. K. Abbott, and B. Huang. 2013. Modelling angler behaviour as a part of the management system: synthesizing a multi-disciplinary literature. Fish and Fisheries 14:137–157.
Griffiths, S. P., M. T. Zischke, M. L. Tonks, J. G. Pepperell, and S. Tickell. 2013. Efficacy of novel sampling approaches for surveying specialised recreational fisheries. Reviews in Fish Biology and Fisheries 23:395–413.
Gutowsky, L. F., J. Gobin, N. J. Burnett, J. M. Chapman, L. J. Stoot, and S. Bliss. 2013. Smartphones and digital tablets: emerging tools for fisheries professionals. Fisheries 38:455–461.
Havel, J. E., and J. Stelzleni-Schwent. 2001. Zooplankton community structure: the role of dispersal. Internationale Vereinigung Fur Theoretische Und Angewandte Limnologie Verhandlungen 27:3264–3268.
Hawley, L. M., and K. A. Garver. 2008. Stability of viral hemorrhagic septicemia virus (VHSV) in freshwater and seawater at various temperatures. Diseases of Aquatic Organisms 82:171–178.
Hunt, L. M., R. Arlinghaus, N. Lester, and R. Kushneriuk. 2011. The effects of regional angling effort, angler behavior, and harvesting efficiency on landscape patterns of overfishing. Ecological Applications 21:2555–2575.
IGFA (International Game Fish Association). 2014. What is IGFA Catchlog? Available: igfacatchlog.com. (October 2014).
Johnson, L. E., A. Ricciardi, and J. T. Carlton. 2001. Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. Ecological Applications 11:1789–1799.
Johnston, F. D., R. Arlinghaus, and U. Dieckmann. 2010. Diversity and complexity of angler behaviour drive socially optimal input and output regulations in a bioeconomic recreational-fisheries model. Canadian Journal of Fisheries and Aquatic Sciences 67:1507–1531.
Junker, B. H., and F. Schreiber. 2008. Analysis of biological networks. John Wiley & Sons, Hoboken, New Jersey.
Kim, S., C. Robson, T. Zimmerman, J. Pierce, and E. M. Haber. 2011. Creek watch: pairing usefulness and usability for successful citizen science. Pages 2125–2134 *in* Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, British Columbia, Canada.
Leung, B., J. M. Bossenbroek, and D. M. Lodge. 2006. Boats, pathways, and aquatic biological invasions: estimating dispersal potential with gravity models. Biological Invasions 8:241–254.
Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of coupled human and natural systems. Science 317:1513–1516.
MacIsaac, H. J., J. V. Borbely, J. R. Muirhead, and P. A. Graniero. 2004. Backcasting and forecasting biological invasions of inland lakes. Ecological Applications 14:773–783.
Martin, D. R., C. J. Chizinski, K. M. Eskridge, and K. L. Pope. 2014. Using posts to an online social network to assess fishing effort. Fisheries Research 157:24–27.
MISIN (Midwest Invasive Species Information Network). 2014. The MISIN Smartphone App. Available: misin.msu.edu/tools/apps/#. (October 2014).
Mueller, K. B., W. W. Taylor, K. A. Frank, J. M. Robertson, and D. L. Grinold. 2008. Social networks and fisheries: the relationship between a charter fishing network, social capital, and catch dynamics. North American Journal of Fisheries Management 28:447–462.
Muirhead, J. R., and H. J. MacIsaac. 2005. Development of inland lakes as hubs in an invasion network. Journal of Applied Ecology 42:80–90.
Muller, R. G., and R. G. Taylor. 2013. The 2013 stock assessment update of Common Snook, *Centropomus undecimalis*. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg, Florida. In House Report: 2013-004.
Newman, G., A. Wiggins, A. Crall, E. Graham, S. Newman, and K. Crowston. 2012. The future of citizen science: emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment 10:298–304.
Nicholls, A. 1989. How to make biological surveys go further with generalized linear models. Biological Conservation 50:51–75.
Pew Research Center. 2015. The smartphone difference. Pew Research Center, Washington, D.C. Available: pewinternet.org/2015/04/01/us-smartphone-use-in-2015. (April 2015).
Post, J., L. Persson, E. A. Parkinson, and T. van Kooten. 2008. Angler numerical response across landscapes and the collapse of freshwater fisheries. Ecological Applications 18:1038–1049.
Prell, C., K. Hubacek, and M. Reed. 2009. Stakeholder analysis and social network analysis in natural resource management. Society and Natural Resources 22:501–518.
Presley, R. 2012. Fishery data collection now accomplished by smartphone. Available: snookfoundation.org/news/research/561-iangler.html. (May 2014).
R (R Core Team). 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available: R-project.org. (December 2012).
Ricciardi, A., R. Serrouya, and F. G. Whoriskey. 1995. Aerial exposure tolerance off zebra and quagga mussels (bivalvia: Dreissenidae): implications for overland dispersal. Canadian Journal of Fisheries and Aquatic Sciences 52:470–477.
Riecke, D. K., K. H. Ferry, J. M. Hardiman, R. M. Hughes, C. S. Kolar, P. Moy, D. L. Parrish, G. D. Pitchford, and K. Schroeder. 2013. Federal funding for programs to prevent, control, and manage aquatic invasive species. Fisheries 38:480–480.
Schlueter, M., R. McAllister, R. Arlinghaus, N. Bunnefeld, K. Eisenack, F. Hoelker, E. Milner-Gulland, B. Müller, E. Nicholson, and M. Quaas. 2012. New horizons for managing the environment: a review of coupled social–ecological systems modeling. Natural Resource Modeling 25:219–272.
Stunz, G. W., M. J. Johnson, D. Yoskowitz, M. Robillard, and J. Wetz. 2014. iSnapper: design, testing, and analysis of an iPhone-based application as an electronic logbook in the for-hire Gulf of Mexico red snapper fishery. Grant NA10NMF4540111 Final Report. National Marine Fisheries Service, St. Petersburg, Florida.
Sullivan, B. L., J. L. Aycrigg, J. H. Barry, R. E. Bonney, N. Bruns, C. B. Cooper, T. Damoulas, A. A. Dhondt, T. Dietterich, and A. Farnsworth. 2014. The eBird enterprise: an integrated approach to development and application of citizen science. Biological Conservation 169:31–40.
Sullivan, M. G. 2003. Exaggeration of walleye catches by Alberta anglers. North American Journal of Fisheries Management 23:573–580.
Sweeney, M. 2011. Rebuilding fisheries: there's an app for that. Available: blog.nature.org/conservancy/2011/11/15/rebuilding-fisheries-theres-an-app-for-that. (May 2014).
USDOI (U.S. Department of the Interior), U.S. Fish and Wildlife Service, U.S. Department of Commerce, and U.S. Census Bureau. 2011. National survey of fishing, hunting, and wildlife-associated recreation. Available: census.gov/prod/2012pubs/fhw11-nat.pdf. (June 2014).
Ward, H. G., M. S. Quinn, and J. R. Post. 2013. Angler characteristics and management implications in a large, multistock, spatially structured recreational fishery. North American Journal of Fisheries Management 33:576–584.
Zafarani, R., M. A. Abbasi, and H. Liu. 2014. Social media mining: an introduction. Cambridge University Press, Cambridge, UK.
Zwickel, H. 2012. Sport fishing in Alberta 2010; summary report from the Eighth Survey of Recreational Fishing in Canada. Available: mywildalberta.com/fishing/documents/SportFishingInAlberta-2010Survey-Mar2012.pdf. (May 2014). AFS

AFS ANNUAL MEETING 2015

Portland 2015 Schedule at a Glance

HHD = Hilton Hotel Downtown   OCC = Oregon Convention Center   DTH = DoubleTree Hotel   PSU = Portland State University

For the most up-to-date Annual Meeting information, please visit 2015.fisheries.org

Friday August 14

Time		Event	Location	Room
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
8:00 AM	12:00 PM	AFS Officers' Meeting (Invitation Only)	HHD	Presidential Suite
1:00 PM	5:00 PM	Management Committee-Budget Review Meeting	HHD	Forum Suite

Saturday August 15

Time		Event	Location	Room
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
6:00 AM	11:55 PM	AFS Internet Cafe	HHD	Plaza Foyer
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
7:00 AM	6:00 PM	Large Wood, Partnerships, and Lessons Learned	Field Sites	Salmon River & Still Creek
8:00 AM	4:00 PM	Introduction to Hard-Part Microchemistry of Fishes	HHD	Broadway IV
8:00 AM	4:30 PM	A Brief and Gentle Introduction to Program MARK for Fisheries Biologists	HHD	Broadway II
8:00 AM	5:00 PM	Bayesian I: Introduction to BUGS for Fish Biologists	HHD	Studio Suite
8:00 AM	5:00 PM	Beginning/Intermediate GIS for Fisheries Scientists	Off-site PSU	GIS Lab
8:00 AM	5:00 PM	Governing Board Meeting	HHD	Pavilion East
8:00 AM	5:00 PM	Decision Support Tools for Adaptive Management	HHD	Broadway III
8:30 AM	5:00 PM	Analyzing Fish Diets to Assess Trophic Status	HHD	Directors Suite
10:00 AM	5:00 PM	American Institute of Fisheries Research Biologists (AIFRB), Board of Control Meeting	HHD	Skyline III
12:00 PM	5:00 PM	Registration	HHD	Plaza Foyer
5:00 PM	7:00 PM	Governing Board Reception (Governing Board Members Only)	HHD	Skyline II

Sunday August 16

Time		Event	Location	Room
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
6:00 AM	11:55 PM	AFS Internet Cafe	HHD	Plaza Foyer
7:00 AM	5:00 PM	US Forest Service National Fish Meeting	DTH	TBD
8:00 AM	12:00 PM	Leading at All Levels in AFS	HHD	Grand Ballroom - Parlor C
8:00 AM	5:00 PM	Registration	HHD	Plaza Foyer
8:00 AM	5:00 PM	Age and Growth Analyses with R	HHD	Directors Suite
8:00 AM	5:00 PM	AV Loading	OCC	D-129
8:00 AM	5:00 PM	Bayesian II: Intermediate BUGS for Fish Biologists	HHD	Studio Suite

9:00 AM	2:00 PM	American Institute of Fisheries Research Biologists (AIFRB), Board of Control Meeting	HHD	Skyline III
9:00 AM	3:00 PM	Introduction to Fisheries Improvement Projects Meeting	HHD	Forum Suite
9:00 AM	5:00 PM	NOAA Fisheries Quest Meeting	HHD	Council Suite
9:00 AM	5:00 PM	WDAFS Executive Committee Meeting	HHD	Executive Suite
12:00 PM	2:30 PM	Journal Editors' Luncheon	HHD	Skyline II
12:00 PM	4:00 PM	Monsters of Stock Assessment Meeting	HHD	Broadway I, II & III
1:00 PM	2:30 PM	Fisheries Administration Section Meeting	HHD	Galleria North
2:00 PM	4:00 PM	PNNL Bio-design and Evaluation of Hydro Turbines Discussion	HHD	Skyline IV
2:00 PM	6:00 PM	Trade Show Exhibitor Move-in	OCC	Exhibit Hall B & C
2:30 PM	3:30 PM	Fisheries Administration & Fisheries Management Joint Section Meeting	HHD	Galleria North
3:30 PM	5:00 PM	Fisheries Management Section Meeting	HHD	Galleria North
4:00 PM	6:00 PM	Estuaries and Marine Fisheries Joint Section Business Meeting	HHD	Skyline II
5:00 PM	7:00 PM	Education Section – Business Meeting	HHD	Broadway I & II
6:30 PM	9:00 PM	Welcome Networking Event	HHD	Galleria
TBD	TBD	Poster Session Set-up	OCC	Exhibit Hall B & C

Monday August 17

Time		Event	Location	Room
6:00 AM	11:55 PM	AV Storage	OCC	D-130
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	OCC	D-134
6:00 AM	11:55 PM	AFS 2015 Storage	OCC	C-128
7:00 AM	8:00 AM	Plenary Speakers Breakfast	OCC	D-131
7:00 AM	6:00 PM	Registration	OCC	
7:00 AM	6:00 PM	AV Loading	OCC	D-129
8:00 AM	12:00 PM	Plenary Session	OCC	Oregon Ballroom
11:30 AM	8:30 PM	Trade Show Open & Cyber Café	OCC	Exhibit Hall B & C
12:00 PM	2:00 PM	Plenary Speakers and Awards Luncheon	DTH	TBD
1:30 PM	3:30 PM	Fisheries Information and Technology Section – Annual Business Meeting	OCC	E-147
1:30 PM	5:30 PM	Concurrent Technical Sessions	OCC	
3:30 PM	5:30 PM	Journal Editorial Board Meeting	HHD	Council Suite
4:00 PM	5:00 PM	Hutton Oversight Committee Meeting	HHD	Directors Suite
5:00 PM	6:00 PM	Introduced Fish Section Meeting	OCC	B-110
5:00 PM	7:00 PM	Fish Culture Section Business Meeting	OCC	A-106
5:00 PM	11:00 PM	University of Washington, School of Aquatic and Fishery Science Reunion	HHD	Skyline II
5:30 PM	6:30 PM	Oregon Chapter Awards Ceremony	HHD	Skyline I
5:30 PM	6:30 PM	Genetics Section – Business Meeting	OCC	E-147
5:30 PM	7:00 PM	MSU Fisheries and Wildlife: Alumni and Friends	OCC	D-131
6:00 PM	8:30 PM	Trade Show and Poster Networking Event	OCC	Exhibit Hall B & C

Tuesday August 18

Time		Event	Location	Room
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	OCC	D-134
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
7:00 AM	5:00 PM	Registration	OCC	
7:00 AM	6:00 PM	AV Loading	OCC	D-129
8:00 AM	5:30 PM	Concurrent Technical Sessions	OCC	
8:00 AM	6:00 PM	Trade Show Open & Cyber Cafe	OCC	Exhibit Hall B & C
12:00 PM	1:30 PM	WDAFS Business Meeting	OCC	Portland Ballroom 251
12:00 PM	2:00 PM	Best Student Presentation Judges' Luncheon	OCC	A-103
12:00 PM	2:00 PM	Student Mentor Lunch and Career Fair	OCC	D-131
12:00 PM	2:00 PM	Past Presidents' Luncheon	HHD	Directors Suite
2:00 PM	3:00 PM	Student Subsection of the Education Section – Business Meeting	OCC	E-147
2:30 PM	3:30 PM	Book Editorial Advisory Meeting	HHD	Boardroom East
5:00 PM	7:00 PM	University of Idaho, Alumni Reception	HHD	TBD
5:00 PM	7:00 PM	Socioeconomics Section – Business Meeting	OCC	E-147
5:30 PM	6:30 PM	International Fisheries Section Meeting	OCC	A-103
5:30 PM	6:30 PM	Western Native Fishes Committee Meeting	OCC	B-116
5:30 PM	7:00 PM	Water Quality Section Annual Membership Meeting	OCC	A-108
5:30 PM	7:30 PM	Bioengineering Section Annual Business Meeting	OCC	D-135
5:30 PM	7:30 PM	VEMCO Networking Event	OCC	D-131
6:00 PM	OPEN	Fish Habitat Section	Off-site	Kell Irish Restaurant & Pub
6:30 PM	8:00 PM	International Fisheries Section Networking Event	DTH	Presidential Suite
6:30 PM	9:30 PM	Student Networking Event (Students Only)	*Portland Spirit*	

Wednesday August 19

Time		Event	Location	Room
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	OCC	D-134
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
7:00 AM	9:00 AM	Spawning Run	Waterfront Park	
7:00 AM	9:30 AM	*Fisheries* Magazine Meeting	HHD	Cabinet Suite
7:00 AM	6:00 PM	AV Loading	OCC	D-129
8:00 AM	2:00 PM	Trade Show Open & Cyber Cafe	OCC	Exhibit Hall B & C
8:00 AM	5:00 PM	Registration	OCC	
8:00 AM	5:00 PM	Cutthroat Trout Taxonomy	DTH	TBD
8:00 AM	5:30 PM	Concurrent Technical Sessions	OCC	
12:00 PM	2:00 PM	Equal Opportunities Section - Business Meeting and Luncheon	OCC	D-131
12:00 PM	2:00 PM	World Council of Fisheries Societies Luncheon Meeting (Invitation Only)	DTH	TBD
2:00 PM	4:00 PM	Trade Show Take-down	OCC	Exhibit Hall B & C
4:10 PM	5:30 PM	AFS Business Meeting	OCC	Oregon Ballroom 203
6:00 PM	11:55 PM	Grand Networking Event	South Park Blocks	
TBD	TBD	Poster Session Take-down	OCC	Exhibit Hall B & C

Thursday August 20

Time		Event	Location	Room
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	OCC	D-134
6:00 AM	11:55 PM	Media Room	HHD	Senate Suite
6:00 AM	11:55 PM	AFS 2015 Organizing Committee Office	HHD	Boardroom West
7:00 AM	8:30 AM	Incoming Governing Board Breakfast	HHD	Broadway I & II
7:00 AM	5:00 PM	AV Loading	OCC	D-129
7:00 AM	7:00 PM	AFS Headquarters Office	OCC	A-101
8:00 AM	12:00 PM	Registration	OCC	
8:00 AM	12:00 PM	Cutthroat Trout Taxonomy	OCC	A-103
8:00 AM	5:30 PM	Concurrent Technical Sessions	OCC	
12:00 PM	2:00 PM	Portland-Kansas Handoff Luncheon (Invitation Only)	TBD	
3:00 PM	4:30 PM	National Fish Habitat Partnership - Science and Data Committee Meeting	OCC	D-131
5:30 PM	7:00 PM	Closing Networking Event	HHD	Pavilion East

Photo credit: Travel Portland.

IN MEMORIAM

C. LAVETT SMITH, JR.

The highly respected ichthyologist, Clarence Lavett Smith, Jr. (Smitty), passed away on February 10, 2015, in Fort Collins, Colorado, at the age of 87. The majority of Smith's career (35 years, until 1997) was spent as a curator at the American Museum of Natural History (AMNH). Particularly newsworthy during his time at AMNH was his dissection with colleagues in 1975 of a coelacanth *Latimeria* spp., making the surprising discovery that these ancient fish were livebearers.

Smith was raised in Hamburg in western New York and obtained his B.S. degree from Cornell University, M.S. degree from Tulane University, and Ph.D. from the University of Michigan. While being schooled, Smith worked under the direction of such ichthyological stalwarts as Ed Raney and Reeve Bailey. Drafted by the Army in 1954 while working on his doctoral degree, he served in the Army Medical Corps at Walter Reed Hospital in Washington, D.C. and the Tropical Medical Research Laboratory in San Juan, Puerto Rico. In Puerto Rico, he discovered a love for the tropics and, in his spare time, even managed to describe two new species of blennies.

In his career, Smith taught at a number of universities in the New York City region, in the south and midwest United States, and in Hawaii and Guam. Most of his summers were spent teaching or conducting research at biological stations, including Ohio State's F.T. Stone Lab on Lake Erie, the AMNH Lerner Marine Laboratory at Bimini in the Bahamas, and the Smithsonian's Research Station on Carrie Bow Cay, Belize.

Smith wrote more than 100 scientific books and journal articles on fish, plus some popular works, including in 1994, *Fishwatching: An Outdoor Guide to Freshwater Fishes*. Though interested in anything ichthyological, Smith's primary research focuses were the biodiversity and community and behavioral ecology of coral reef fishes, especially in the Caribbean and Pacific, and the zoogeography and life histories of the freshwater fishes of New York State. However, he also published on many other topics, including classical comparative taxonomy and fossil and larval fishes. Although Smith was not truly a theorist, he did publish a useful primer on cladistics in the AFS *Fisheries* magazine in 1988 titled, "Minnows First, Then Trout," as that approach to taxonomic classification became predominant.

Smith was involved with many scientific and natural history societies, and he served in leadership and board positions with a number of Hudson River-related and other environmental organizations. His time spent living underwater as part of the Tektite Program and Hydrolab earned him membership in the exclusive New York Explorer's Club. While at AMNH, he also participated in themed tours for the public, leading snorkeling excursions on tropical coral reefs.

Smith had numerous other passions, such as the history of canal systems, woodworking, boat building, and writing fiction. After retirement from AMNH, Smith moved with his wife Marjorie to Colorado Springs, Colorado, to be nearer family.

Clarence Smith's famous coelacanth dissection in 1975. Smith is on the right. Photo credit: AMNH.

Smith and wife Marjorie in lower left with his various students circa 1987. Photo credit: Moses Chang.

I had the privilege of earning two graduate degrees under Smith's mentorship. Smith loved engaging graduate students, especially when piling us into his van and spending a day chasing spawning Sea Lampreys *Petromyzon marinus* just for the joy of it or a week in the field seining and electrofishing to collect specimens and contribute site data for his landmark 1986 publication, *The Inland Fishes of New York State*. As a student, I spent a good deal of time in his laboratory, which doubled as his office. With Smith's high visibility as an AMNH curator, I often heard him field telephone calls with all kinds of questions about fish from the public or reporters. After finishing such a phone conversation, he'd sometimes lean back in his chair, ruminate for awhile, and then say "You know John, life is an ichthyology exam." If so, then Smith passed with the highest of grades.

– John Waldman

FROM THE ARCHIVES

We now recognize about six hundred species of fishes as found in the fresh waters of North America, north of the Tropic of Cancer, these representing thirty-four of the natural families. As to their habits, we can divide these species rather roughly into four categories proposed by Professor Cope, or, as we call them-

(1) Lowland fishes; as the bow-fin, pirate perch, large-mouthed black bass, sunfishes and some catfishes.

(2) Channel fishes; as the channel catfish, the moon-eye, gar-pike, buffalo-fishes and drum.

(3) Upland fishes; as many of the darters, shiners and suckers, and the small-mouthed black bass.

(4) Mountain fishes; as the brook trout, and many of the darters and minnows.

Prof David S. Jordan (1888): The Distribution of Freshwater Fishes, Transactions of the American Fisheries Society, 17:1, 6.

Urban Land Use, Water Quality, and Biological Conditions in the Lower Mississippi River Basin Bayous

Yushun Chen
Institute of Hydrobiology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan, Hubei 430072, China.
E-mail: yushunchen@ihb.ac.cn

Kathryn Herzog, Sagar Shrestha, Daniel Grigas, John Farrelly, Christopher Laskodi, and Matthew Skoog
Aquaculture and Fisheries Center, University of Arkansas–Pine Bluff, Pine Bluff, AR 71601

Yushun Chen is currently President-Elect of AFS Water Quality Section

BASIN AND URBAN LAND USE

The lower Mississippi River Basin (LMRB) or lower Mississippi River Hydrologic Unit includes parts of Arkansas, Louisiana, Mississippi, Tennessee, Kentucky, and Missouri along the lower Mississippi River. The land use in this hydrologic unit is primarily row crop soybean, wheat, rice, cotton, and corn plus remnant bottomland hardwood forest (Stanturf et al. 2000). Within this large agricultural landscape, urban land uses do exist, and small-sized (i.e., area < 60 km^2, population < 20,000) to medium-sized (i.e., area > 60 km^2, population between 20,000 and 100,000) communities are common. In the LMRB, land use changes along a gradient of urbanization, from urban (downtown areas) to suburban (primarily residential areas), and then sharply to agriculture (farmland areas) as one proceeds further outside of the towns. Thus, streams often flow from urban head watersheds into lower-order agricultural watersheds or from agricultural head watersheds into urban watersheds and then back to agricultural watersheds. Such complexities confound studies of watershed land use effects, as does the scarcity of forested reference watersheds.

BAYOUS

Bayous are unique ecological systems in the LMRB. They are essentially slow-moving streams running across flat lowlands (Figures 1a–1c). These streams are static compared with high-gradient streams in other regions, and during most of the year, no detectable velocity is apparent in them. Urban bayous are located in the downtown areas of cities and towns where roads, commercial buildings, parking lots, and residential houses surround them (Figure 1a). Some of these bayous are artificially straightened or "channelized" for storm water conveyance purposes. Suburban bayous are located in suburban areas of cities and towns and are bordered by residential houses, scattered woods, and pastures (Figure 1b). During the dry season (e.g., June–August), some of these bayous are hydrologically disconnected from upstream and downstream reaches. Conversely, during the wet season (e.g., December–March), most of these bayous attain bank-full flow quickly. Due to a higher percentage of impervious surfaces, urban bayous usually experience very "flashy" flows during the wet seasons. To the contrary, suburban bayous experience longer, steady flows throughout the wet seasons due to infiltration and groundwater recharge. In reference conditions of the basin, streams are surrounded by natural forest with higher canopy cover and without direct anthropogenic disturbance, and fish habitats such as brush, logs, and debris and multiple substrates are common in these streams (Figure 1c).

WATER QUALITY

These bayous or lowland streams have naturally lower dissolved oxygen (DO) than those in upland streams. For instance, some of the least-disturbed sites can reach DO below 2.5 mg/L due to organic decomposition and lack of aeration, and sources of the DO impairment in some of these streams are natural (Justus et al. 2014). In the LMRB, most cities and towns have their own sewage wastewater treatment facilities, but some have central treatment facilities. These facilities receive sewage from residential houses and some from industries. However, some cities and towns have experienced sewage line failures that place adjacent water bodies at risk of episodic peaks in ammonia and total fecal coliform, especially after storms (Arkansas Department of Environmental Quality [ADEQ] 2010). Moreover, in this region, many cities and towns lack storm water treatment facilities or even environmentally friendly conveyance systems. In most situations, urban storm water enters adjacent bayous directly, which contributes to high levels of conductivity, turbidity, total suspended solids, nutrients, and trace metals (ADEQ 2010). In a recent base flow water quality assessment (i.e., June–December 2011) in a southeast Arkansas urban watershed (i.e., upper Bayou Bartholomew Watershed, with an area around 120 km^2), we found higher mean conductivity (130 uS/cm) and temperature (20.0C) in the urban than suburban streams (93 uS/cm, 18.3C) due to differences in riparian canopy cover, although other measured water quality parameters did not differ during the monitoring period (Y. Chen, unpublished data).

BIOLOGICAL CONDITIONS

Biological communities are closely related to physical and chemical conditions in the bayous. In reference conditions of the basin, stream fish assemblages are distinctively dominated by families of Centrarchidae (30%), Cyprinidae (17%), Percidae (11%), Ictaluridae (9%), and Catostomidae (4%; Keith 1987). Environmentally sensitive fish species make up less than 0.2% of the relative abundance value in reference stream assemblages in the basin (Keith 1987). Some darter species (Percidae) such as River Darter *Percina shumardi*, Logperch *P. caprodes*, Swamp Darter *Etheostoma fusiforme*, Cypress Darter *E. proeliare*, and Mud Darter *E. asprigene* are abundant in some reference habitats (Keith 1987; Baker and Killgore 1994; Buchanan 1997). Urban-impacted bayous generally have less diverse fish assemblages and a higher proportion of tolerant species. For instance, in a recent fish sampling (i.e., October 2011) in the above-mentioned urban watershed, we collected 207 fish specimens and recorded 9 species from the urban streams ($n = 4$) compared to 353 specimens and 15 species from the suburban streams ($n = 4$; Y. Chen, unpublished data). The urban stream fish assemblages were dominated by Mosquitofish *Gambusia affinis*; 58%, Bluegill *Lepomis macrochirus*; 20%, Green Sunfish *L. cyanellus*; 8%, Warmouth *L. gulosus*; 5%, and Longear Sunfish *L. megalotis*; 4%. The suburban stream fish assemblages were dominated by Bluegill (70%), Longear Sunfish (9%), Warmouth (5%), Green Sunfish (5%), Mosquitofish (3%), and Blackspotted Topminnow *Fundulus olivaceus*; 3%; Y. Chen, unpublished data. In some sampling events, however, due to longer periods of hydrological disconnection, suburban bayous have fish abundances less than urban bayous. Abnormal and skin-affected fish specimens also were occasionally collected in urban bayous, though the exact causes are unknown. Overall, the impaired habitats and water quality in the urbanized bayous are still supporting fisheries but mostly in an altered form (ADEQ 2010).

EXPECTATIONS

In the LMRB, adopting more environmentally friendly storm water management measures may be the first step to improve urban stream ecological conditions. Rehabilitation and remediation of these urban bayous would also improve these unique ecosystems and increase ecosystem services such as fishing and clean water (Hughes et al. 2014).

An urban bayou (a), a suburban bayou (b), and a forested reference bayou (c) of the lower Mississippi River Basin in southeast Arkansas.

ACKNOWLEDGMENTS

Gregg Lomnicky, Robert Hughes, Michael Eggleton, Steve Lochmann, and Jeffrey Schaeffer provided constructive comments and revisions on an earlier draft of this article.

FUNDING

Preparation of this article is partially funded by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) Mississippi River Basin Healthy Watersheds Initiative (MRBI) program and the state of Arkansas.

REFERENCES

ADEQ (Arkansas Department of Environmental Quality). 2010. Integrated water quality monitoring and assessment report. Arkansas Department of Environmental Quality, North Little Rock, Arkansas.

Baker, J. A., and K. J. Killgore. 1994. Use of a flooded bottomland hardwood wetland by fishes in the Cache River System, Arkansas. U.S. Army Engineer Waterways Experiment Station, Technical Report WRP-CP-3, Vicksburg, Mississippi.

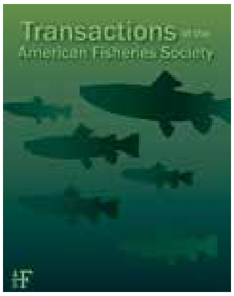
Buchanan, T. M. 1997. The fish community of Indian bayou, a coastal plain stream of remarkable species richness in the lower White River drainage of Arkansas. Journal of the Arkansas Academy of Science 51:55–65.

Hughes, R. M., S. Dunham, K. G. Maas-Hebner, J. A. Yeakley, C. Schreck, M. Harte, N. Molina, C. C. Shock, V. W. Kaczynski, and J. Schaeffer. 2014. A review of urban water body challenges and approaches: (1) rehabilitation and remediation. Fisheries 39(1):18–29.

Justus, B. G., S. V. Mize, J. Wallace, and D. Kroes. 2014. Invertebrate and fish assemblage relations to dissolved oxygen minima in lowland streams of southwestern Louisiana. River Research and Applications 30:11–28.

Keith, W. E. 1987. Distribution of fishes in reference streams within Arkansas' ecoregions. Proceedings of Arkansas Academy of Science 41:57–60.

Stanturf, J. A., E. S. Gardiner, P. B. Hamel, M. S. Devall, T. D. Leininger, and M. E. Warren, Jr. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry 98(8):10–16. AFS



Journal Highlights

TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Volume 144, Number 3, May 2015

Effect of Tides, River Flow, and Gate Operations on Entrainment of Juvenile Salmon into the Interior Sacramento–San Joaquin River Delta. *Russell W. Perry, Patricia L. Brandes, Jon R. Burau, Philip T. Sandstrom, and John R. Skalski. 144: 445-455.*

Migratory Characteristics and Passage of Paddlefish at Two Southeastern U.S. Lock-and-Dam Systems. *Brandon L. Simcox, Dennis R. DeVries, and Russell A. Wright. 144: 456-466.*

Fish Community Response to a Small-Stream Dam Removal in a Maine Coastal River Tributary. *Robert S. Hogg, Stephen M. Coghlan Jr., Joseph Zydlewski, and Cory Gardner. 144:467-479.*

Spatial Structure of Morphological and Neutral Genetic Variation in Brook Trout. *David C. Kazyak, Robert H. Hilderbrand, Stephen R. Keller, Mark C. Colaw, Amanda E. Holloway, Raymond P. Morgan II, and Tim L. King. 144:480-490.*

Diel Cycle and Effects of Water Flow on Activity and Use of Depth by Common Carp. *Josep Benito, Lluís Benejam, Lluís Zamora, and Emili García-Berthou. 144:491-501.*

Translocation of Humpback Chub into Tributary Streams of the Colorado River: Implications for Conservation of Large-River Fishes. *Jonathan J. Spurgeon, Craig P. Paukert, Brian D. Healy, Melissa Trammell, Dave Speas, and Emily Omana-Smith. 144:502-514.*

Consequences of Actively Managing a Small Bull Trout Population in a Fragmented Landscape. *Robert Al-Chokhachy, Sean Moran, Peter A. McHugh, Shana Bernall, Wade Fredenberg, and Joseph M. DosSantos. 144: 515-531.*

Effect of Exhaustive Exercise on the Swimming Capability and Metabolism of Juvenile Siberian Sturgeon. *L. Cai, D. Johnson, P. Mandal, M. Gan, X. Yuan, Z. Tu, and Y. Huang. 144:532-538.*

The Spawning Success of Early Maturing Resident Hatchery Chinook Salmon in a Natural River System. *Michael Ford, Todd N. Pearsons, and Andrew Murdoch. 144:539-548.*

Fine-Scale Pathways Used By Adult Sea Lampreys during Riverine Spawning Migrations. *Christopher M. Holbrook, Roger Bergstedt, Noah S. Adams, Tyson W. Hatton, and Robert L. McLaughlin. 144: 549-562.*

Diel Patterns and Temporal Trends in Spawning Activities of Robust Redhorse and River Redhorse in Georgia, Assessed Using Passive Acoustic Monitoring. *Carrie A. Straight, C. Rhett Jackson, Byron J. Freeman, and Mary C. Freeman. 144:563-576.*

Variation in Juvenile Steelhead Density in Relation to In-stream Habitat and Watershed Characteristics. *Knut Marius Myrvold and Brian P. Kennedy. 144:577-590.*

Shortnose Sturgeon and Atlantic Sturgeon in the Kennebec River System, Maine: a 1977–2001 Retrospective of Abundance and Important Habitat. *Gail S. Wippelhauser and Thomas S. Squiers Jr. 144:591-601.*

Phenotypic Shifts in Life History Traits Influence Invasion Success of Goldfish in the Yarlung Tsangpo River, Tibet. *Chunlong Liu, Yifeng Chen, Julian D. Olden, Dekui He, Xiaoyun Sui, and Chengzhi Ding. 144:602-609.*

Brown Trout Removal Effects on Short-Term Survival and Movement of *Myxobolus cerebralis*-Resistant Rainbow Trout. *Eric R. Fetherman, Dana L. Winkelman, Larissa L. Bailey, George J. Schisler, and K. Davies. 144:610-626.*

Abundance, Survival, and Life History Strategies of Juvenile Chinook Salmon in the Skagit River, Washington. *Mara S. Zimmerman, Clayton Kinsel, Eric Beamer, Edward J. Connor, and David E. Pflug. 144:627-641.*

Can Conservation Stocking Enhance Juvenile Emigrant Production in Wild Atlantic Salmon? *P. J. Bacon, I. A. Malcolm, R. J. Fryer, R. S. Glover, C. P. Millar, and A. F. Youngson. 144:642-654.*

CALENDAR

To submit upcoming events for inclusion on the AFS website calendar, send event name, dates, city, state/province, web address, and contact information to sgilbertfox@fisheries.org. (If space is available, events will also be printed in *Fisheries* magazine.) More events listed at www.fisheries.org

July 12–17, 2015

AFS 39th Annual Larval Fish Conference | Vienna, Austria | larvalfishcon.org

July 13–15, 2015

AFS AFS Fish Health Section Annual Meeting | Ithaca, New York | afs-fhs.org

July 13–17, 2015

3rd International Conference on Fish Telemetry (ICFT) | Halifax, Canada | 2015icft.org

July 26–31, 2015

World of Trout | Bozeman, Montana | Facebook > The World of Trout - 1st International Congress

August 16–20, 2015

AFS 145th Annual Meeting of the American Fisheries Society | Portland, Oregon | 2015.fisheries.org

October 21–23, 2015

6th International Oyster Symposium | Falmouth, Massachusetts | oystersymposium.org

October 25–30, 2015

The Second Mississippi-Yangtze River Basins Symposium | Wuhan, China | news.fisheries.org/the-second-mississippi-yangtze-river-basins-symposium

October 27–29, 2015

The 4th International Conference on Members of the Genus *Flavobacterium* | Auburn, Alabama | flavobacterium.com

January 24–27, 2016

76th Midwest Fish & Wildlife Conference | Grand Rapids, Michigan | midwestfw.org

February 17–21, 2016

AFS Southern Division Spring Meeting | Wheeling, West Virginia | sdafs.org

May 21, 2016

2nd World Fish Migration Day | www.worldfishigrationday.com

May 23–27, 2016

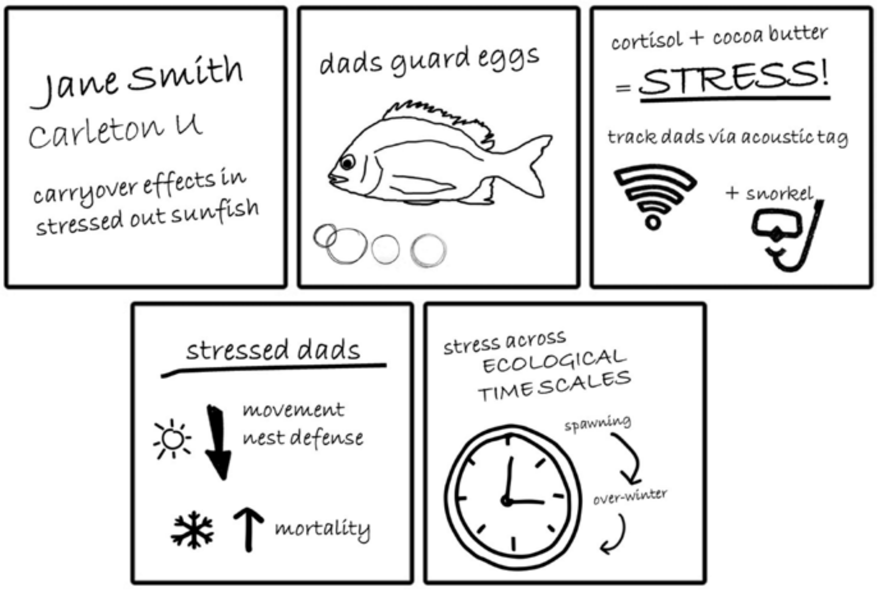
7th World Fisheries Congress | Busan, South Korea | wfc2016.or.kr

BACK PAGE

Try This! Sketch Your Conference Notes

Natalie Sopinka
AFS Contributing Writer
E-mail: natsopinka@gmail.com

With the 2015 Annual Meeting only a month away, it's time to start preparing. T-shirt with fish pattern packed, check. Presentation saved to a USB stick, check. Pad of blank paper, a black Sharpie, and a favorite colored pencil to sketch symposium talks, check! This year, why not try sketching your conference notes?



Example of a five-frame sketch.

But I Can't Draw

Science and natural history illustrator Bethann Merkle (commnatural.com; @CommNatural on Twitter) begs to differ. "You *can* draw," she says. Sketching, like pipetting, fly-fishing, and coding in R, requires practice, but we all have the capacity to do it. Professional science scribe Perrin Ireland's (@experrinment) favorite rule for sketching, "is that it has very little to do with whether you can draw." Conference sketching does, however, involve adjusting the way we listen and how we mentally store what we heard and what we are hearing.

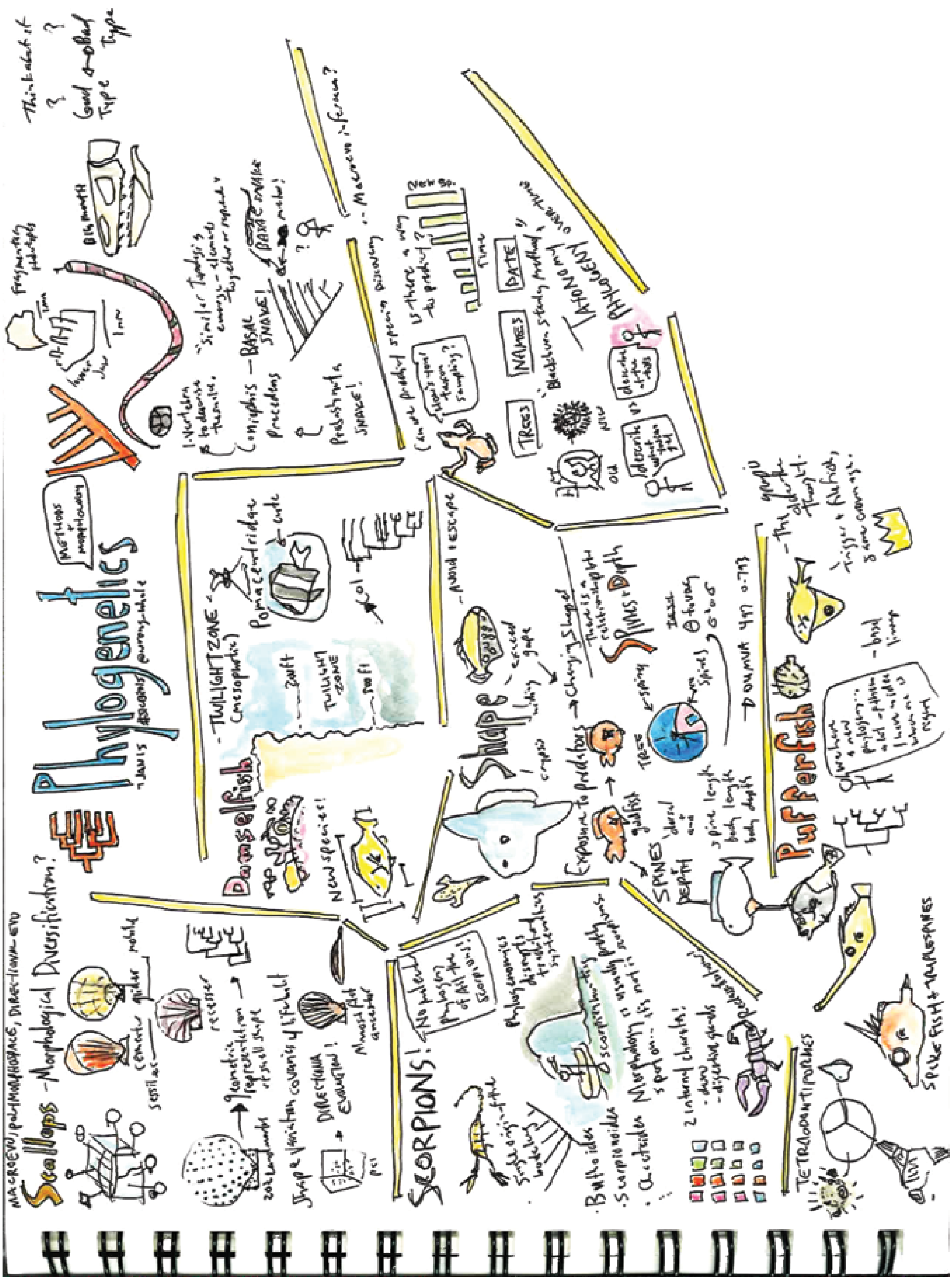
What happens when a speaker has transitioned to the study results while you're still sketching the methods? Ireland has developed a strategy of placing talk content in "holding spots in [her] brain." While sketching what you heard, try visualizing sketches of what is being said. Real-time conference sketching is an adventure in creativity. You may miss a speckle or fin while sketching a trout, but as Merkle explains, sketching is "never perfect for anyone."

You'll Thank Yourself Later

Drawings help with memorization. "I had a hard time recalling talks looking back at my scribbled notebooks," said Shayle Matsuda (@wrong_whale). A graduate student at California Academy of Sciences, Matsuda now sketches symposium presentations in watercolor to create "a visual story." Transforming what he heard into a sketch gave Matsuda "a deeper understanding of the material and helped [him] remember." Visual representations of scientific conferences are also appreciated by the research community as a whole; both Merkle and Ireland now host sketching workshops at conferences.

Pro Tips for Conference Sketching

1. Try it once. Enjoy the process? Sketch a second, third, or fourth talk.
2. Get your colleagues and lab mates involved. Conference sketches can adorn office walls and bulletin boards, and "safety in numbers" definitely applies to sketching in public.
3. Bring your gear: a pad of blank paper, a black felt-tip pen or marker, and an accent color (e.g., colored pencil, crayon, highlighter, or marker). A single accent color can be used to emphasize key components of your sketch. When using two colors, choose complementary pairings such as blue and orange or purple and yellow.
4. Follow a template. The structure of conference talks lends itself well to sketching in frames. Five-frame sketches can include (1) the name of the speaker and title of the talk, (2) talk introduction, (3) methods, (4) results, and (5) conclusions (See above image). Try out this template, or let your sketch free-flow.
5. Keep it simple. Use symbols, shapes, lines, and basic outlines of plants, animals, and landscapes.
6. Share your work. Tweet your #SciArt notes to @AFS2015, and post your sketches on the AFS Facebook page.
7. Have fun and happy doodling!



Shayle Matsuda's conference sketches. Image credit: Shayle Matsuda.


LAKE


CREEK


OCEAN

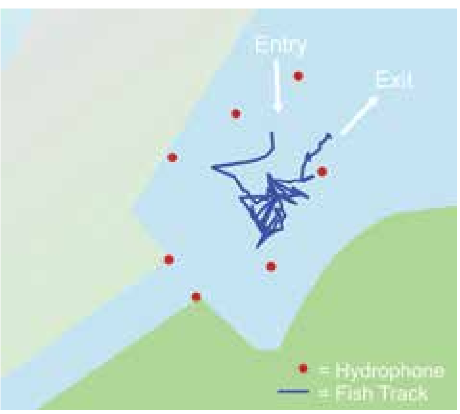

RIVER

Larinier Fish Pass entrance with hydropower active.

Larinier Fish Pass entrance with hydropower inactive.

Fish pass & side-of-fish-pass ascent routes, downstream.

Example of a fish passage track.



Example of a fish non-passage track.

Investigating Passage: Behavioural Studies of Upstream Moving Salmonids on the Yorkshire Esk, Ruswarp, UK

In an effort to improve understanding of how low-head hydropower may potentially impact migrating salmonids, the Environment Agency (EA) and The University of Hull International Fisheries Institute (HIFI) came together with North York Moors National Park to track the behaviour of adult salmonids at Ruswarp Weir on the River Esk in North Yorkshire, England.

The overall aim of the study was to investigate the behaviour of upstream migrating salmonids at a head-of-tide hydropower scheme that included a co-located fish passage facility, to identify any impact of the hydropower scheme on fish passage and to help address one of the "evidence gaps" in knowledge about migratory behaviour around these structures. A secondary aim is to investigate fish fine-scale behaviour in relation to hydrodynamic, hydraulic and environmental cues that attract and guide fish at fish passes, in order to improve best practice guidance on fish pass design and improve fish passage rates.

The fish were tracked using both a fixed 2D Acoustic Tracking System (ATS) to determine fine-scale behaviour in the vicinity of a Larinier fish pass entrance, and three mobile hydrophones situated at key locations around the weir and fish release location. Tagging and tracking a number of fish would provide the basic metrics needed (attraction efficiency and overall passage efficiency with behavioural context). Two years of post-installation monitoring have been reported presenting telemetry data for 94 acoustically tagged sea trout and salmon around Ruswarp Weir. The three mobile hydrophones were located downstream of the release point (to determine downstream migration), at the downstream end of weir (to confirm arrival at the obstacle) and above the weir (to confirm passage via routes other than the Larinier pass).

Data from the three mobile hydrophones were used to elucidate the behaviour of tagged fish and their potential fates and to provide context to interpret their detailed behaviours recorded on the ATS. In many cases fish exhibited both rapid initial movements up to the weir and downstream movements before passage and in some cases passage occurred an appreciable length of time after release whilst re-ascending the river under spate conditions. The use of the mobile hydrophones allowed estimates of predation/straying (or tag loss), more precise determination of the number of potential migrants, and therefore refined estimates of fish passage metrics. The fine-scale behaviour study demonstrated clear hot-spots of residence time in areas of the pool below the structure.

> ***"It's a confusing environment for migrating sea trout down there, with all kinds of competing and distracting flows! But examining the micro-scale behaviour of fish to these multiple stimuli is really helping us understand and improve fish passage at these structures."***
>
> \- Dr. Jon Hateley, Environment Agency

HTI is honoured to work closely with the fisheries team at the EA and HIFI in support of their efforts. To receive more information about this study, read the full reports at www.HTIsonar.com/publications.html or email HTI about the technology used at support@HTIsonar.com.

With Special Thanks to:

Environment Agency

University of Hull

HTI