Fisheries

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VOL 38 NO 1
JAN 2013

Hydraulic Fracturing: Will There Be Impacts?

What Hatchery Fish Don’t Remember

The World’s First Ecological Observatory

Fish? Why Fish?

New AFS Policy Statement!

AFS’s Role In Education

03632415(2013)38(1)

Pushing the Limits:
Using VIE to Identify Small Fish

Most tags just don't fit in small-bodied and early life stages of fish, but we still need to identify them, preferably without biasing our data. The options are further limited when many batches or individual identification is required. Visible Implant Elastomer^{TM} (VIE) is internally injected but remains externally visible, and because the size of a tag is controlled by the tagger, it is easily adapted to very small fish. Colors and tag locations can be combined to create a coding scheme.

VIE has been used to tag newly settled coral reef fishes as small as 8—10 mm (1,2) with high tag visibility and little mortality. Marking success was influenced by depth of subcutaneous tag injection, anatomical location of the tag, pigmentation of the skin, and investigator's experience with the technique. Long-bodied fish like eels and lamprey as small as 1 g are easily tagged with VIE (3, 4).

Techniques for tagging very small salmonids have been developed for VIE. Brown trout ≤26 mm can be tagged at the base of the fins and have been recovered during stream surveys up to 83 days later[5]. This technique worked well with Atlantic Salmon ≤30 mm, and has been used for monitoring in-stream movements through snorkel surveys[6]. The minimum size for tagging juvenile salmonids has been pushed down to 22 mm FL, and is possible to tag alevins in the yolk sac[7], and fry in the fins[8].

VIE is well-suited for tagging juveniles of many other species and is used world wide. Please contact us if we can help with your project.

Photos: A syringe is used to inject VIE into the fin of a juvenile salmonid (top). VIE is available in 10 colors (left), of which six fluoresce under a VI Light for improved visibility and tag detection (center). Tagging rainbow trout fry as small as 22 mm is possible with VIE (below). Leblanc & Noakes[7] used this to identify fish originating from larger eggs (top) or smaller eggs (bottom).

Photo courtesy C. Leblanc.

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[1] Frederick (1997) Bull. Marine Sci.; [2]Hoey & McCormick (2006) Proc. 10th Intern. Coral Reef Symp.; [3]Stone et al. (2006) N. Am. J. Fish. Manage.; [4]Simon & Dorner (2011) J. Appl. Ichthyology; [5]Olson &Vollestad (2001) N. Am. J. Fish. Manage.; [6]Steingrimsson & Grant (2003) Can. J. Fish. Aquat. Sci.; [7]Jensen et al. (2008) Fish. Manage. Ecol.; [8]Leblanc & Noakes (2012) N. Am. J. Fish. Manage.

Northwest Marine Technology, Inc.

www.nmt.us

Shaw Island, Washington, USA

Corporate Office
360.468.3375 office@nmt.us

Biological Services
360.596.9400 biology@nmt.us

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Photo Credits: foreground: Miles Luo; background: Alessandro Farsi

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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.

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Teach Your Children Well

John Boreman, President

AFS President Boreman may be contacted at: John.Boreman@ncsu.edu

This is an exciting time to be a member of the American Fisheries Society (AFS). Conservation laws, technology, and the questions being asked of fisheries professionals are changing rapidly, as well the nature of the fisheries discipline itself. In the past 20 years we have witnessed increased accountability requirements for those managing our fisheries resources, not only in the United States but also globally, putting more responsibility on the shoulders of fisheries professionals. We have seen the Internet and associated social media become a mainstay in communications among fisheries professionals and for keeping us in touch with decision makers and the public in general. We have seen computational power and associated data storage requirements increase by orders of magnitude, along with the development and use of sensors to measure the environment and its biota. Today's students (and many of today's faculty) were not yet born when our astronauts walked on the moon, when we used transistors in our radios, and spun 45s on our record players. I was shocked when none of the students in my class ever heard of FORTRAN. What's in store for fisheries professionals the next 20 years? Will we be able to adapt to changes in everything affecting our lives and livelihoods? Will we be adequately prepared to do so?

As a professional society, the AFS has a role to play in ensuring that people entering the future workforce will be prepared to tackle the issues that fisheries professionals will then be facing. This role is codified in the AFS Strategic Plan for 2010–2014:

> *Guide colleges and universities to maintain, modify, or develop curricula of the highest quality for both undergraduate and graduate students that provide an array of courses and experiences needed to effectively manage and conserve fisheries resources and meet the needs of employers.*

In keeping with my theme "Preparing for the Challenges Ahead," I have established an AFS Special Committee on Educational Requirements, chaired by AFS Second Vice President Ron Essig, to accomplish several tasks. First, the committee will assemble a list of North American colleges and universities currently offering undergraduate and graduate degrees in fisheries-related disciplines (e.g., fisheries science, fisheries biology, fisheries ecology, fisheries management, fisheries policy, and fisheries economics) and publish the list on the AFS website. Concurrently, the committee will oversee a survey of major employers that will be hiring graduates with degrees in fisheries-related disciplines in the next 5–10 years to determine what coursework those graduates will be expected to have taken that would be most germane to the positions being filled. The survey results, and an evaluation of their implications, should be published in *Fisheries*. When the list and survey are completed, the committee will compare the coursework expectations of the employers with the current coursework requirements of a selected subset of colleges and universities offering fisheries degrees. If the comparison indicates a misalignment, the committee will recommend ways in which an alignment can be made, which could range from giving simple advice to the colleges and universities to instituting an accreditation program administered by the AFS (or something in between). The recommendations could serve as the basis for discussion at an upcoming AFS Governing Board retreat.

I have also asked the special committee to compare coursework expectations resulting from the survey to degree requirements for certification as a fisheries professional, working with the Education Subcommittee of the AFS Board of Professional Certification, as well as to the U.S. Office of Personnel Management's educational requirements in the grade-level qualification standards for the 482 (Fish Biology) series. Based on the comparisons, the committee could recommend changes that would bring the degree requirements for certification and federal employment into alignment with employer expectations. The committee might also look at analogous requirements for federal employment of fisheries professionals in Mexico and Canada. These comparisons can be published as a series of articles in *Fisheries*.

Continuing education, which helps fisheries professionals shore up their level of skill, knowledge, and expertise as employment demands evolve, is also important in preparing the future workforce. To this end, I have charged the AFS Continuing Education Committee to assist AFS staff in expanding opportunities for distance education (i.e., education via the Internet) beyond virtual attendance at continuing education courses offered at the annual meeting. One option the Continuing Education Committee will be tackling through the AFS will be to pilot at least one half-day short course in the coming year to be offered via a webinar. The pilot short course could be offered for free to alleviate complications with registration and fees and allow the committee to focus evaluation of the pilot solely on the quality of the learning experience. Given successful delivery of the pilot course, the AFS could pursue, for example, a quarterly distance education webinar series that may or may not require

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Hydraulic Fracturing and Brook Trout Habitat in the Marcellus Shale Region: Potential Impacts and Research Needs

Maya Weltman-Fahs

New York Cooperative Fish and Wildlife Research Unit, and Department of Natural Resources, 120 Bruckner Hall, Cornell University, Ithaca, NY 14853. E-mail: mw482@cornell.edu

Jason M. Taylor

New York Cooperative Fish and Wildlife Research Unit, and Department of Natural Resources, 120 Bruckner Hall, Cornell University, Ithaca, NY 14853

ABSTRACT: *Expansion of natural gas drilling into the Marcellus Shale formation is an emerging threat to the conservation and restoration of native brook trout (*Salvelinus fontinalis*) populations. Improved drilling and extraction technologies (horizontal drilling and hydraulic fracturing) have led to rapid and extensive natural gas development in areas overlying the Marcellus Shale. The expansion of hydraulic fracturing poses multiple threats to surface waters, which can be tied to key ecological attributes that limit brook trout populations. Here, we expand current conceptual models to identify three potential pathways of risk between surface water threats associated with increased natural gas development and life history attributes of brook trout: hydrological, physical, and chemical. Our goal is to highlight research needs for fisheries scientists and work in conjunction with resource managers to influence the development of strategies that will preserve brook trout habitat and address Marcellus Shale gas development threats to eastern North America's only native stream salmonid.*

Ruptura hidráulica y el hábitat de la trucha de arrollo en la región de Marcellus Shale: impactos potenciales y necesidades de investigación

RESUMEN: El crecimiento de las actividades de perforación de gas natural en la formación Marcellus Shale es una amenaza emergente para la conservación y restauración de las poblaciones nativas de la trucha de arroyo (*Salvelinus fontinalis*). La perforación más eficiente y las tecnologías de extracción (perforación horizontal y ruptura hidráulica) han facilitado el rápido y extensivo desarrollo de esta industria a las áreas que comprende la región Marcellus Shale. La expansión de las rupturas hidráulicas representa múltiples amenazas a las aguas superficiales, que pueden estar asociadas a atributos ecológicos clave que limitan las poblaciones de la trucha de arroyo. En la presente contribución se expanden los modelos conceptuales actuales que sirven para identificar tres fuentes potenciales de riesgo entre las amenazas a las aguas superficiales asociadas al creciente desarrollo del gas natural y los atributos de la historia de vida de la trucha de arroyo; atributos hidrológicos, físicos y químicos. El objetivo de este trabajo es hacer notar las necesidades de investigación para los científicos pesqueros y trabajar junto con los manejadores de recursos para influir en el desarrollo de estrategias tendientes a preservar el hábitat de la trucha de arroyo; así mismo se atienden las amenazas que representa el desarrollo de la industria del gas natural para el único salmónido nativo de América del norte.

INTRODUCTION

Hydraulic Fracturing in the Marcellus Shale

Natural gas extraction from subterranean gas-rich shale deposits has been underway in the northeastern United States for almost 200 years but has expanded rapidly over the past decade within the Devonian Marcellus Shale formation (P. Williams 2008). This expansion has largely been driven by the development and refinement of the horizontal hydraulic fracturing process (United States Energy Information Administration 2011a). Horizontal gas drilling differs from the more traditional vertical drilling process because the well is drilled to the depth of the shale stratum and then redirected laterally, allowing for access to a larger area of subterranean shale (Figure 1). Drilling is followed by the hydraulic fracturing process, which involves injecting a chemically treated water-based fluid into the rock formation at high pressure to cause fissures in the shale and permit the retrieval of gas held within the pore space of the shale. The fissures are kept open by sand and other proppants, which allow gas to be extracted (Soeder and Kappel 2009; Kargbo et al. 2010). The hydraulic fracturing process was granted exemptions to the Clean Water and the Safe Drinking Water Acts under the Energy Policy Act of 2005. Drilling has since expanded rapidly in the Marcellus Shale deposit in portions of West Virginia and Pennsylvania (Figure 2), is expected to continue into Ohio and New York, and will likely continue to expand within these states to include the gas-bearing Utica Shale formation.

Brook Trout Status within the Marcellus Shale

Eastern brook trout are native to the Eastern United States, with a historic range extending from the southern Appalachians in Georgia north to Maine (MacCrimmon and Campbell 1969; Figure 2). Brook trout require clean, cold water (optimal tem-

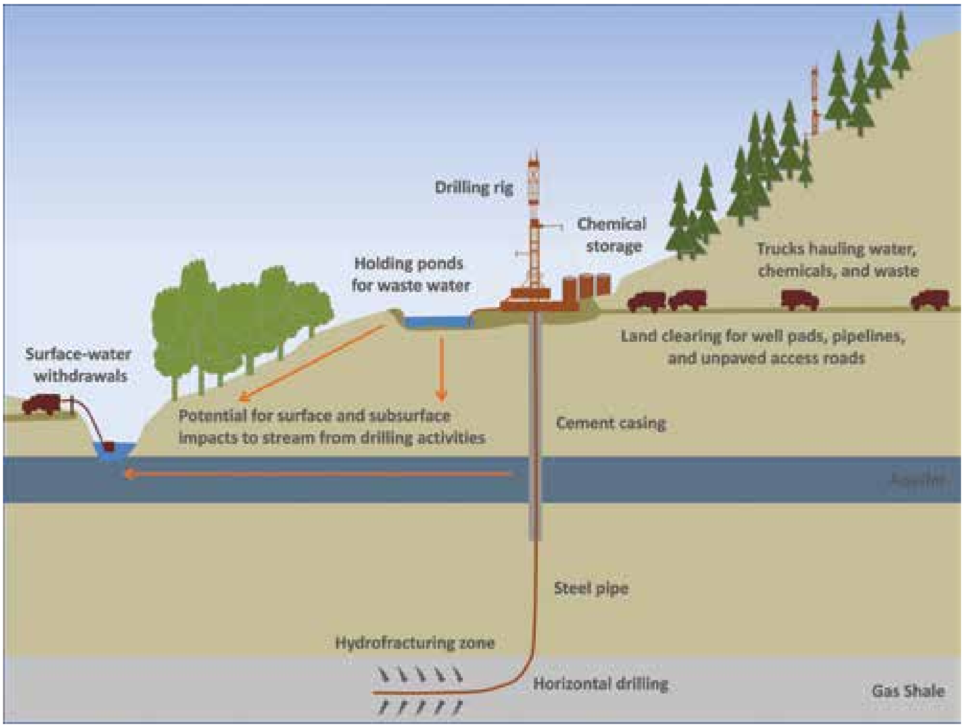

Figure 1. Conceptual diagram depicting the hydraulic fracturing process. A rig drills down into the gas-bearing rock and the well is lined with steel pipe. The well is sealed with cement to a depth of 1,000 ft. to prevent groundwater contamination. The well is extended horizontally 1,000 ft. or more into the gas-bearing shale where holes are blasted through the steel casing and into the surrounding rock. Sand, water, and chemicals are pumped into the shale to further fracture the rock and gas escapes through fissures propped open by sand particles and back through the well up to the surface. Supporting activities include land clearing for well pads and supporting infrastructure, including pipelines and access roads. Trucks use roads to haul in water extracted from local surface waters, chemicals, and sand. Recovered water is stored in shallow holding ponds until it can be transported by truck to treatment facilities or recycled to fracture another well. These activities may impact nearby streams through surface and subsurface pathways.

perature = 10–19°C), intact habitat, and supporting food webs to maintain healthy populations, making them excellent indictors of anthropogenic disturbance (Hokanson et al. 1973; Lyons et al. 1996; Marschall and Crowder 1996). Only 31% of subwatersheds (sixth level, 12-digit hydrological units [HUC12], as defined by the Watershed Boundary Dataset; U.S. Department of Agriculture, Natural Resources Conservation Service 2012) within the historic range of brook trout are currently expected to support intact populations (self-sustaining populations greater than 50% of the historical population; Hudy et al. 2008). Substantial loss of brook trout populations within their native range is due to anthropogenic impacts that have resulted in habitat fragmentation and reduction, water quality and temperature changes, and alteration of the biological environment through introduction and removal of interacting species (Hudy et al. 2008). Conservation efforts, including formation of the Eastern Brook Trout Venture (Eastern Brook Trout Joint Venture [EBTJV] 2007, 2011) and a shift by organizations such as Trout Unlimited (TU) to policies that oppose the stocking of nonnative hatchery-produced salmonids in native trout streams (TU 2011), are focused on maintaining and restoring brook trout populations in their native range. With these growing concerns about the future of native brook trout populations, natural gas well development within the Marcellus Shale region presents another potential threat to native brook trout populations.

Twenty-six percent of the historic distribution of brook trout habitat overlaps with the Marcellus Shale (Figure 2). The Pennsylvania portion of the Marcellus Shale has experienced the largest increase in natural gas development (Figure 2). Between January 1, 2005, and May 31, 2012, the cumulative number of Marcellus Shale well permits issued in Pennsylvania increased from 17 to 11,784 (Pennsylvania Department of Environmental Protection [PADEP] 2012a). Of these permitted wells, 5,514 were drilled during the same time period (PADEP 2012b; Figure 3A). Trends in drilled well densities among subwatersheds during the rapid expansion of drilling activity suggest that there have not been any extra protections granted during the well permitting process for subwatersheds that are expected to support intact brook trout populations (Figure 3B). Fifty-four of the 134 subwatersheds categorized as having intact brook trout populations within the Marcellus Shale region have already experienced drilling activity (Hudy et al. 2008). Overall, Marcellus drilling activity has expanded to 377 subwatersheds (mean area = 94.8 ± 1.9 km^2) in Pennsylvania (Figure 4).Within these 377 subwatersheds, patterns in well density over time show similar trends among subwatersheds varying in their current brook trout population status (Figure 3B). Though there is a significant difference in current well densities among the three subwatershed types (one-way analysis of variance [Type II], $F_{2, 292} = 4.14$, $P = 0.02$), mean well density does not differ between subwatersheds where brook trout are extirpated/unknown and those with intact brook trout populations (Tukey's multiple comparison test, $\alpha = 0.05$; Figure 3B). In fact, the two highest drilling densities include an extirpated/unknown subwatershed (16.7 wells/10 km^2) and a subwatershed expected to support intact brook trout populations (15.1 wells/10 km^2; Figure 4). These trends highlight that increasing hydraulic fracturing development is occurring not only in degraded subwatersheds but also in those that support an already vulnerable native species and valuable sport fish. This trend should be of concern to fisheries scientists, managers, and conservationists who work to maintain and improve the current status of this natural heritage species.

Linking Marcellus Shale Drilling Impacts to Brook Trout Population Health

Recent efforts to conceptualize horizontal hydraulic fracturing impacts have focused on stream ecosystems and regional

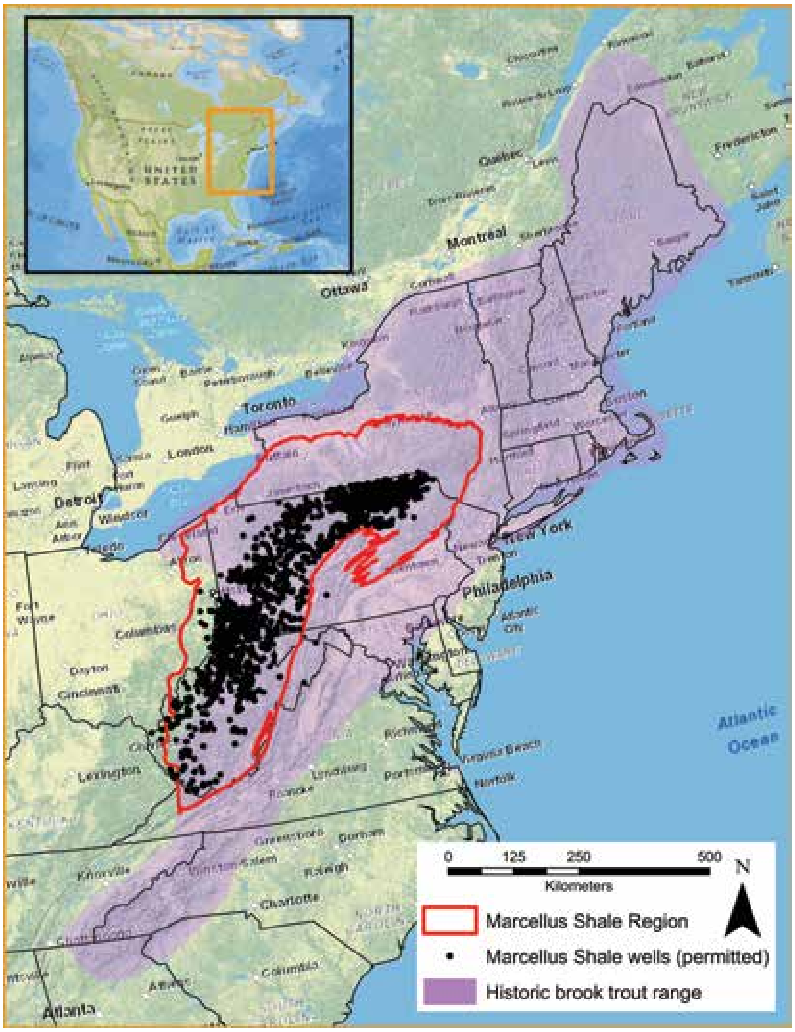

Figure 2. Overlay of the Marcellus Shale region of the Eastern United States (U.S. Geological Survey [USGS] 2011) and the historic distribution of eastern brook trout (Hudy et al. 2008) with permitted Marcellus Shale well locations, 2001–2011 (Ohio Department of Natural Resources 2011; West Virginia Geological and Economic Survey 2011; PADEP 2012a).

water supplies but not on potential pathways to particular target organisms. Herein, we integrate two existing conceptual models of potential natural gas development impacts to surface waters and link them to different brook trout life history attributes (Entrekin et al. 2011; Rahm and Riha 2012). Entrekin et al.'s (2011) conceptual model establishes connections between hydraulic fracturing activities and the ecological endpoint of stream ecosystem structure and function by way of potential environmental stressors from drilling activity sources. These stressors to stream ecosystems can be planned activities that must necessarily occur in the hydraulic fracturing process (deterministic events) or those that may occur unexpectedly (probabilistic events; Rahm and Riha 2012). Brook trout have different environmental requirements at the various stages of their life cycle and may be sensitive to potential impacts associated with the current expansion of hydraulic fracturing; thus, understanding the environmental stressors associated with hydraulic fracturing has implications for fisheries conservation, including maintenance and/or enhancement of native brook trout populations.

We delineated relationships between various stream ecosystem attributes that are potentially impacted by increased drilling activities and different aspects of the brook trout life cycle (Figure 5). A review of extant literature on the activities associated with natural gas drilling and other extractive industries and of the environmental changes known to directly influence brook trout at one or more of their life stages identified three primary pathways by which increased drilling will likely impact brook trout populations. The primary pathways include (1) changes in hydrology associated with water withdrawals; (2) elevated sediment inputs and loss of connectivity associated with supporting infrastructure; and (3) water contamination from introduced chemicals or wastewater (Entrekin et al. 2011; Rahm and Riha 2012). These three pathways may be considered natural gas drilling threats to brook trout populations that require study and monitoring to fully understand, minimize, and abate potential impacts.

PATHWAY #1: WITHDRAWALS → HYDROLOGY → BROOK TROUT

Two to seven million gallons of water are needed per hydraulic fracturing stimulation event; a single natural gas well can be fractured several times over its lifespan, and a well pad site can host multiple wells (Soeder and Kappel 2009; Kargbo et al. 2010). This large volume of water needed per well, multiplied by the distributed nature of development across the region, suggests that hydraulic fracturing techniques for natural gas development can put substantial strain on regional water supplies. This level of water consumption has sparked concern among hydrologists and aquatic biologists about the sourcing of the water, as well as the implications for available habitat and other hydrologically influenced processes in adjacent freshwater ecosystems (Entrekin et al. 2011; Gregory et al. 2011; Baccante 2012; Rahm and Riha 2012; Figure 5). Surface water is the primary source for hydraulic fracturing–related water withdrawals in at least one major basin intersecting the Marcellus Shale region (Susquehanna River Basin Commission [SRBC] 2010), but groundwater has been a major water source in other natural gas deposits such as the Barnett Shale region in Texas (Soeder and Kappel 2009). The cumulative effects of multiple surface and/or groundwater withdrawals throughout a watershed have the potential to effect downstream hydrology and connectivity of brook trout habitats (Rahm and Riha 2012; Petty et al. 2012).

Aquatic habitat is particularly limited by low-flow periods during the summer for fish and other aquatic organisms (Figure 6). Changes in temperature and habitat volume during summer low-flow periods are primary factors limiting brook trout populations (Barton et al. 1985; Wehrly et al. 2007; Xu et al. 2010). Brook trout rely on localized groundwater discharge areas within pools and tributary confluences to lower body temperature below that of the ambient stream temperature during warm periods, and groundwater withdrawals can alter these temperature refugia. Additionally, access to thermal refugia may be limited by loss of connectivity associated with reduced flows between temperature refugia (headwater streams, seeps, tributary confluences, groundwater upwellings) and larger stream habitats (Petty et al. 2012). Reduced flows, particularly coldwater inputs, may inhibit growth rates by reducing feeding activity of both juveniles and adults or inducing sublethal heat shock at temperatures above 23°C and lethal effects at 24–25°C (7-day upper lethal temperature limit; Cherry et al. 1977; Tangiguchi et al. 1998; Baird and Krueger 2003; Lund et al. 2003; Wehrly et al. 2007). Recovery from thermal stress responses (heat shock) can be prolonged (24–48 h) even if exposure to high stream temperatures is relatively short (1 h) but may be more than 144 h when exposed to high temperatures for multiple days (Lund et al. 2003). Adult abundance and biomass of brook trout in run habitats declines with flow reduction and carrying capacity is likely limited by available pool area during low-flow periods (Kraft 1972; Hakala and Hartman 2004; Walters and Post 2008).

Reduction in surface water discharge during summer months may also indirectly impact brook trout growth by decreasing macroinvertebrate prey densities (Walters and Post 2011) in small streams and lowering macroinvertebrate drift encounter rates for drift-feeding salmonids (Cada et al. 1987; Nislow et al. 2004; Sotiropoulos et al. 2006; Figure 5). Other indirect effects may include increasing interspecific competition through habitat crowding, especially with more tolerant competitor species such as brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*), due to decreased habitat availability and increased temperature during low-flow periods. Introduced brown trout tend to out-compete brook trout for resources and have higher growth rates in all but the smallest, coldest headwater streams (Carlson et al. 2007; Öhlund et al. 2008; Figure 5). Additionally, salmonids may be more susceptible to disease or infestation of parasites when the temperature of their environment is not consistent and adequately cool (Cairns et al. 2005), a problem that could be exacerbated by the crowding in pool habitats that can occur as a result of flow reductions (Figure 5). Sediment accrual in redds can limit recruitment (Alexander and Hansen 1986; Argent and Flebbe 1999), and adequate summer base flows coupled with occasional high flow pulses are important for preparing sediment free spawning redds (Hakala and Hartman 2004). DePhilip and Moberg (2010) demonstrated that the magnitude of withdrawals proposed by drilling companies in the Susquehanna River basin has the potential to impact summer and fall low flows, and in some cases, high-flow events (Q_{10}) in small streams.

Water withdrawals may also impact brook trout spawning activities and recruitment during higher flow periods (Figures 5 and 6). Brook trout peak spawning activity typically occurs at the beginning of November in gravel substrates immediately downstream from springs or in places where groundwater seepage enters through the gravel (Hazzard 1932). Withdrawals during the fall may dewater and reduce available spawning habitat, particularly during low-flow years. Additionally, stable base flows after spawning are necessary for maintaining redds during egg incubation throughout winter (Figure 6). Maintaining base flow in trout spawning habitats throughout the incubation period maintains shallow groundwater pathways, chemistry, and flow potentials in redds (Curry et al. 1994, 1995), which protect developing eggs from sedimentation (Waters 1995; Curry and MacNeill 2004) and freezing (Curry et al. 1995; J. S. Baxter and McPhail 1999). Thus, insuring that water withdrawals required for hydraulic fracturing do not interrupt stable winter base flows in small coldwater streams is an important consideration in protecting brook trout recruitment in the Marcellus Shale region (Figures 5 and 6).

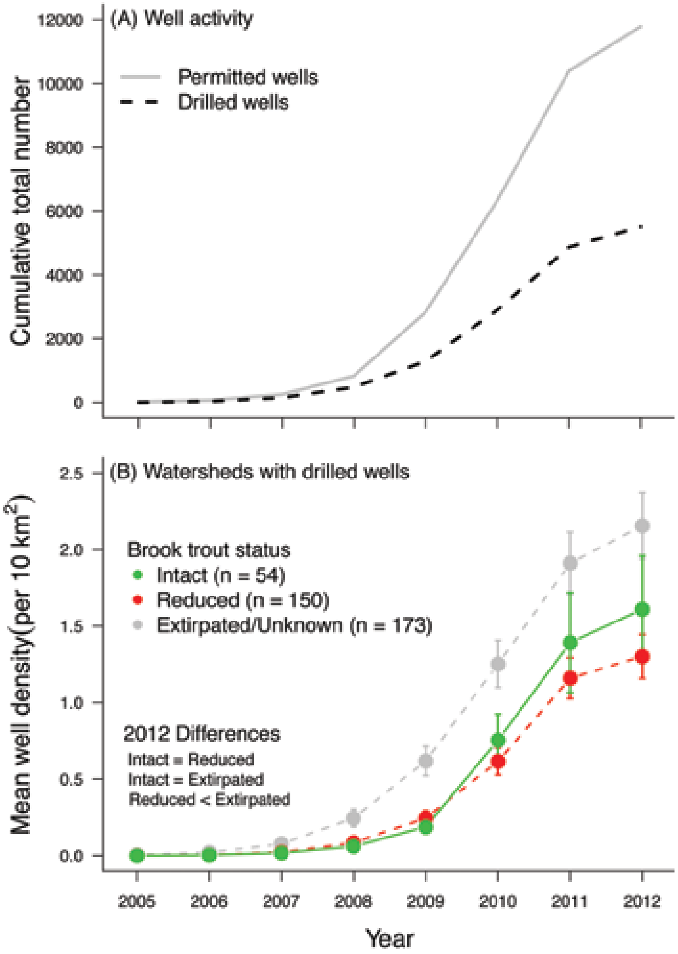

Figure 3. Well permitting and drilling in the Pennsylvania portion of Marcellus Shale from January 1, 2005, through May 31, 2012. (A) Cumulative number of permitted and drilled wells over time. (B) Mean well density (wells per 10 km²) over time for 377 actively drilled HUC12 subwatersheds, grouped by status of brook trout population (Hudy et al. 2008). Permitted and drilled Marcellus well data are from PADEP (2012a, 2012b), respectively.

PATHWAY #2: INFRASTRUCTURE → PHYSICAL HABITAT → BROOK TROUT

Natural gas extraction requires development of well pad sites and infrastructure for transportation and gas conveyance, which involves a set of activities that will likely have impacts on water quality and habitat quality for brook trout unless proper precautions and planning are implemented. These activities include, but are not limited to, construction of well pads, roadways, stream crossings, and pipelines; increased use of existing rural roadways for transportation of equipment, source water, recycled flow-back, and wastes associated with hydraulic fracturing activities; and storage of these same materials (Figure 1). Increased sediment loads and loss of stream connectivity are some of the stream impacts associated with these deterministic activities, which could reduce habitat quality and quantity needed for brook trout spawning success, egg development, larval emergence, and juvenile and adult growth and survival (Figure 5).

Brook trout are particularly sensitive to the size and amount of sediment in streams, with coarse gravel providing a more suitable substrate than fine particles (Witzel and MacCrimmon 1983; Marschall and Crowder 1996). Well pad site, access road, and pipeline corridor construction require land clearing, which can mobilize from tens to hundreds of metric tons of soil per hectare (H. Williams et al. 2008; Adams et al. 2011). Pipeline construction (Reid et al. 2004) and unpaved rural roadways (Witmer et al. 2009) crossing streams can trigger additional sediment inputs to streams. Road and well pad densities have been found to be positively correlated with fine sediment accumulation in streams (Opperman et al. 2005; Entrekin et al. 2011), which disrupts fish reproduction and can lead to mortality (Taylor et al. 2006). Overall, trout populations have been found to decline in abundance, even with small increases in stream sediment loads (Alexander and Hansen 1983, 1986). Sediment can impact all stages of trout life cycles, because turbidity reduces foraging success for adults and juveniles (Sweka and Hartman 2001), and sediment accumulation can cause oxygen deprivation in salmonid redds and reduce successful emergence of larvae from eggs (Witzel and MacCrimmon 1983; Waters 1995; Argent and Flebbe 1999; Curry and MacNeill 2004; Figure 5).

The spatial and temporal extent of sediment impacts to streams is linked to the scale and persistence of mobilizing activities. For example, localized events, such as construction of culverts

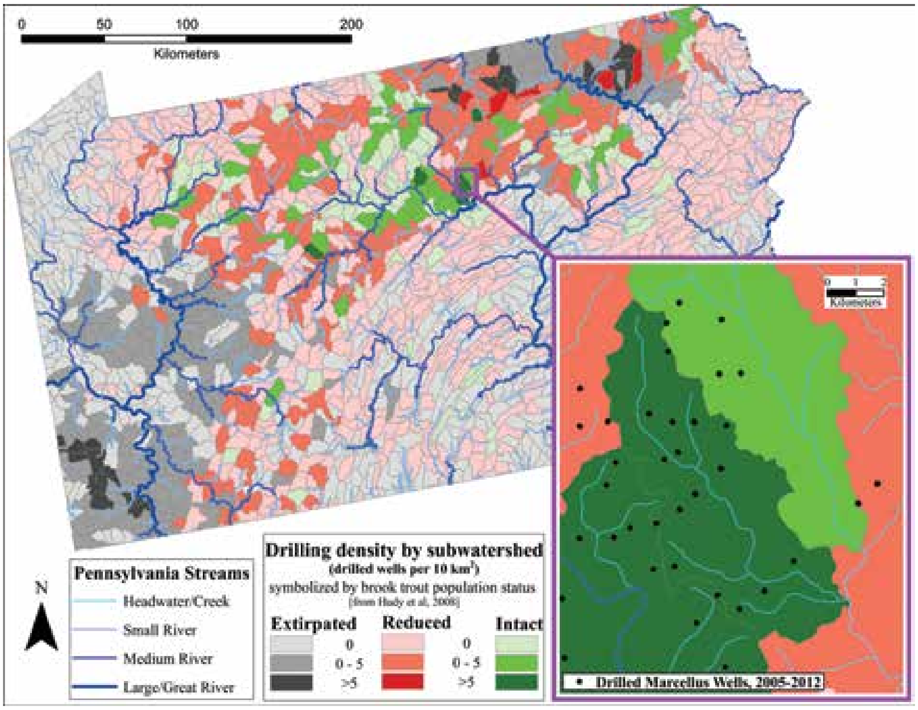

Figure 4. Density of wells drilled in the Pennsylvania portion of the Marcellus Shale by HUC12 subwatershed (well drilling locations from PADEP 2012b; 12-digit HUC subwatershed boundaries and areas from USGS Watershed Boundary Dataset; U.S. Department of Agriculture, Natural Resources Conservation Service 2012), symbolized by status of current brook trout population (Hudy et al. 2008). Inset: A subwatershed expected to support an intact brook trout population that currently has the second highest well density (15.1 wells/10 km2) of all drilled subwatersheds.

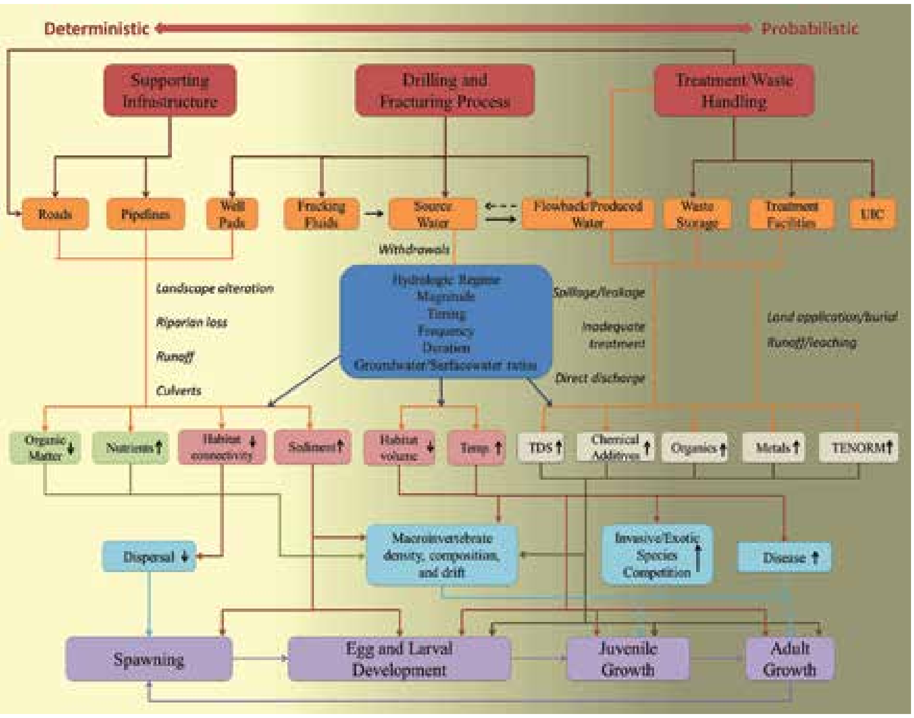

Figure 5. Conceptual model of relationships between hydraulic fracturing drilling activities and the life cycle of eastern brook trout (modified from conceptual models based on Entrekin et al. [2011] and Rahm and Riha [2012]).

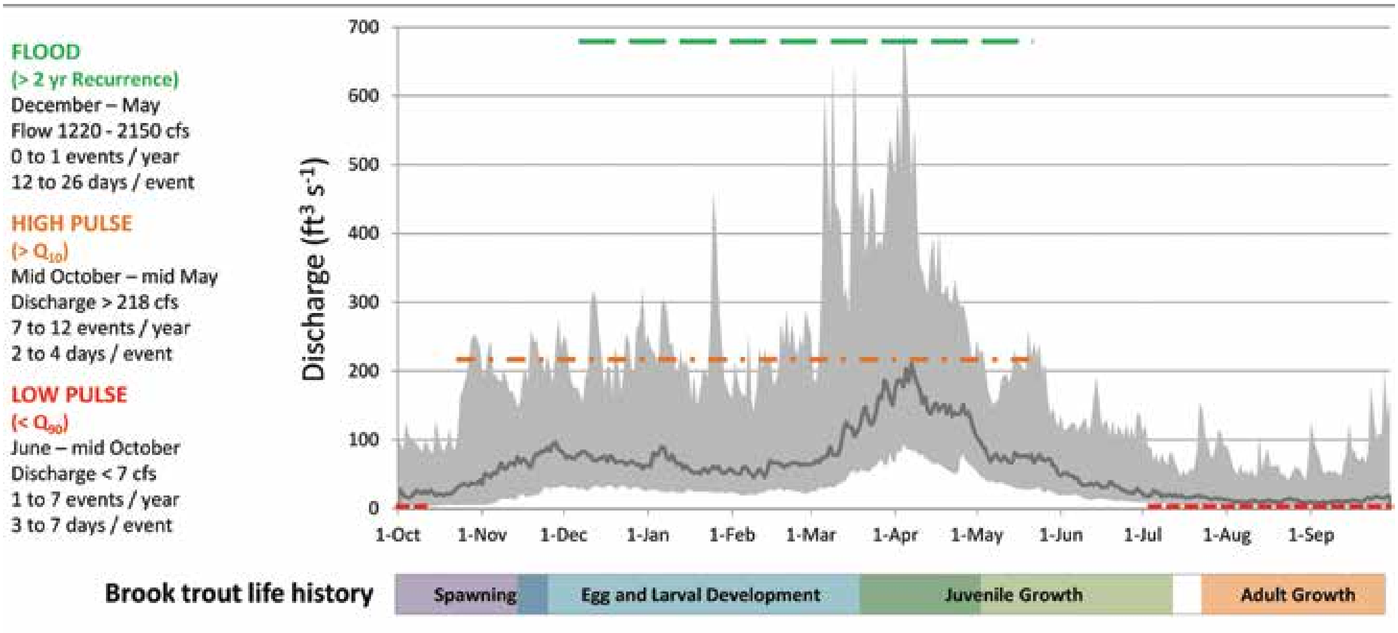

Figure 6. Hydrologic patterns for a trout supporting stream with relatively unaltered hydrology (Little Delaware River, USGS Gage 01422500, watershed area = 129 km2) in relation to timing of brook trout life history periods. Median (dark line), bounded by 10th and 90th percentile daily flows (grey) for 47 years of discharge data. Important flood, high-, and low-flow components were computed and described using Indicators of Hydrologic Alteration (The Nature Conservancy 2009).

at stream road crossings can increase sediment loads for up to 200 m downstream of the culvert over a 2- to 3-year period (Lachance et al. 2008). Conversely, the sediment loads associated with more diffuse land clearing activities and frequent and sustained access into rural areas by large vehicles can contribute to reductions in brook trout biomass and densities and shifts in macroinvertebrate communities that last approximately 10 years (VanDusen et al. 2005).

Sedimentation from drilling infrastructure development can further impact brook trout indirectly by reducing the availability of prey (Figure 5): high sediment levels reduce species richness and abundance of some aquatic macroinvertebrates (Waters 1995; Wohl and Carline 1996; VanDusen et al. 2005; Larsen et al. 2009), with high sediment environments generally experiencing a shift from communities rich in mayflies (Ephemoptera), stoneflies (Plectoptera), and caddisflies (Trichoptera) to those dominated by segmented worms (Oligochaeta) and burrowing midges (Diptera: Chironmidae; Waters 1995). Riparian clearing can also diminish food sources for brook trout populations, which tend to depend heavily on terrestrial macroinvertebrates (Allan 1981; Utz and Hartman 2007). However, shifts in the prey base from shredder-dominated communities that support higher brook trout abundance to grazer-dominated communities have been observed in recently logged watersheds due to higher primary productivity associated with increased sunlight from sparser canopy cover (Nislow and Lowe 2006). Consequently, land clearing and infrastructure development will likely increase sediment loads, culminating in changes in composition and productivity of the invertebrate prey base for brook trout, although not all of these changes will necessarily be negative for brook trout (Figure 5).

Conveyance of hydraulic fracturing equipment and fluids, and the extracted natural gas, into and out of well pad sites often necessitates crossing streams with trucks and pipelines. Culvert construction for roadway and pipeline stream crossings, if not properly designed, can create physical barriers that fragment brook trout habitat and disrupt their life cycle by preventing movement of adult fish into upstream tributaries for spawning and repopulation of downstream habitat by new juveniles (Wofford et al. 2005; Letcher et al. 2007; Poplar-Jeffers et al. 2009; Figure 5). Barriers to connectivity negatively impact fish species richness (Nislow et al. 2011), and habitat fragmentation without repopulation can cause local population extinction (Wofford et al. 2005; Letcher et al. 2007). Additionally, connectivity between larger stream reaches that provide food resources during growth periods and small headwater streams that may serve as temperature refugia during warmer months is important for overall population health (Utz and Hartman 2006; Petty et al. 2012). For these reasons, land clearing activities, road densities, and culvert densities can have a negative impact on trout reproductive activity and overall population size (Eaglin and Hubert 1993; C. V. Baxter et al. 1999).

PATHWAY #3: CHEMICAL WASTE → WATER QUALITY→ BROOK TROUT

Probabilistic events during the drilling process such as runoff from well pads, leaching of wastewater from holding ponds, or spills of hydraulic fracturing fluids during transportation to processing sites can affect the chemical composition of streams (Rahm and Riha 2012). Although the specific chemical composition of fracturing fluids is typically proprietary information, voluntary reporting of the content of fracturing fluids to the FracFocus Chemical Disclosure Registry (a partnership between the Ground Water Protection Council [GWPC] and Interstate Oil and Gas Compact Commission [IOGCC], supported the U.S. Department of Energy [USDOE]) has become more common (USDOE 2011). Fracturing fluids are generally a mix of water and sand, with a range of additives that perform particular roles in the fracturing process, including friction reducers, acids, biocides, corrosion inhibitors, iron controls, cross-linkers, breakers, pH-adjusting agents, scale inhibitors, gelling agents, and surfactants (GWPC and IOGCC 2012). The wastewater resulting from the hydraulic fracturing process is high in total dissolved solids (TDS), metals, technologically enhanced naturally occurring radioactive materials (TENORM), and fracturing fluid additives (U.S. Environmental Protection Agency [USEPA] 2012). Increased metals and elevated TDS from probabilistic spill events, or deterministic events including direct discharge of treated flow-back water into streams, will likely have negative effects on stream ecosystems that support brook trout populations (Figure 5).

Elevated concentration of metals causes decreased growth, fecundity, and survival in brook trout. In particular, aluminum has been shown to cause growth retardation and persistent mortality across life stages (Cleveland et al. 1991; Gagen et al. 1993; Baldigo et al. 2007), chromium reduces successful emergence of larvae and growth of juveniles (Benoit 1976), and cadmium can diminish reproductive success by causing death of adult trout prior to successful spawning (Benoit et al. 1976; Harper et al. 2008). Trout normally exhibit avoidance behaviors to escape stream reaches that are overly contaminated with heavy metals; however, because brook trout are so heavily reliant on low-temperature environs, they seek out refugia of cold groundwater outflow even if the water quality is prohibitively low (Harper et al. 2009). Thus, if groundwater is contaminated and the groundwater-fed portions of a stream are receiving a significant contaminant load, brook trout might be recipients of high concentrations of those contaminants.

Total dissolved solids represent an integrative measure of common ions or inorganic salts (sodium, potassium, calcium, magnesium, chloride, sulfate, and bicarbonate) that are common components of effluent in freshwaters (Chapman et al. 2000). Elevated TDS and salinity may have negative effects on spawning and recruitment of salmonids by decreasing egg fertilization rates and embryo water absorption, altering osmoregulation capacity, and increasing posthatch mortality (Shen and Leatherland 1978; Li et al. 1989; Morgan et al. 1992; Stekoll et al. 2009; Brix et al. 2010). There is also evidence from western U.S. lakes with increasing TDS concentrations that growth and survival of later life stages may be negatively impacted as well (Dickerson and Vinyard 1999). Elevated salinities can lower salmonid resistance to thermal stress (Craigie 1963; Vigg and Koch 1980), which may influence competition between brook trout and more tolerant brown trout (Öhlund et al. 2008). There is a growing body of evidence supporting associations between declines in macroinvertebrate abundance, particularly mayflies, and increased TDS or surrogate specific conductivity related to mining activities within the Marcellus Shale region (Kennedy et al. 2004; Hartman et al. 2005; Pond et al. 2008; Pond 2010; Bernhardt and Palmer 2011). Overall, changes in TDS associated with improper handling or discharge of flow-back water will likely impact brook trout through direct and indirect pathways including changes in macroinvertebrate communities that serve as the prey base and/or the alteration of environmental conditions to those more favorable for harmful invasive species (i.e., Golden algae; Renner 2009; Figure 5).

A FRAMEWORK FOR ADDRESSING RESEARCH NEEDS

Our examination of potential impacts of hydraulic fracturing for natural gas extraction in the Marcellus Shale on brook trout populations reveals three key pathways of influence: hydrological, physical, and chemical. These pathways originate from the various activities associated with the hydraulic fracturing method of natural gas extraction and may affect brook trout at one or more stages of their life cycle through direct and indirect mechanisms (Figure 5). The hydrological pathway is the broadest in that it is influenced by events at both the surface and groundwater levels and, subsequently, it influences brook trout both directly through flow regimes and indirectly by also influencing physical and chemical pathways. The primary drilling activity driving the hydrological pathway is the need for source water for the hydraulic fracturing process. The physical habitat pathway originates from the infrastructural requirements of the natural gas extraction industry, which can be expected to increase stream sedimentation and impede brook trout at all life phases. The consequences of infrastructural development further impact brook trout populations if road-building activities and poorly designed road-crossing culverts reduce connectivity between spawning areas, temperature refugia, and downstream habitats. Finally, the chemical pathway addresses the potential for contamination of streams by the hydraulic fracturing fluids and wastewater. This contamination can have direct consequences for brook trout and their food resources. The hydrological and physical pathways are expected to result from planned (deterministic) hydraulic fracturing activities, and the chemical pathway may be triggered by both unplanned spill and leak (probabilistic) events, as well as planned discharge of treated wastewater into streams or spreading of brines on roadways.

The delineation of these pathways identifies an array of immediate research priorities. The potential relationships identified in the conceptual model (Figure 5) provide a framework of empirical relationships between Marcellus Shale drilling activities, deterministic pathways, and brook trout populations that need to be tested and verified. There is currently variation in hydraulic fracturing density within the Marcellus Shale, ranging from extensive operations in Pennsylvania and West Virginia to a moratorium on the process in New York. Opportunities exist for researchers to develop studies that verify potential relationships between drilling activities and brook trout populations, such as examining sediment impacts and brook trout responses across watersheds representing a range of well densities (Entrekin et al. 2011) or over time in watersheds with increasing levels of drilling activity. Correlative studies should also be confirmed through experimental approaches that take advantage of paired watershed or before–after control-impact (Downes et al. 2002) designs. Tiered spatial analysis techniques can be used to assess the cumulative impacts of persistent drilling activity within nested drainage areas at a range of spatial scales (Bolstad and Swank 1997; MacDonald 2000; Strager et al. 2009). Additionally, risk assessment analyses based on biological endpoints are needed to characterize impacts of probabilistic events such as chemical spills and leaks (USEPA 1998; Karr and Chu 1997).

MOVING FROM RESEARCH TO MANAGEMENT AND CONSERVATION POLICY

Management of hydraulic fracturing activities in the Marcellus Shale is the responsibility of various permitting regulatory agencies with various scales of influence, including statewide (departments of environmental conservation/protection, departments of transportation, fish and game commissions, etc.) and regional (conservation districts, river basin commissions, etc.) entities. Though the individual policies are too numerous to describe in depth here, it is apparent that policies can be developed and refined with the support of research and monitoring programs that provide crucial data, such as a geographically finer scale understanding of brook trout distribution and population status, seasonal flow requirements for brook trout at their various life stages (Figure 6), identification and prioritization of high-quality habitat, and verification of the potential drilling impacts within the Marcellus Shale. These types of data are necessary for revising existing policies and developing new policies that are protective of brook trout populations and the stream ecosystems that support them in the face of increased Marcellus Shale drilling activities.

An example of science influencing policy that is protective of brook trout habitat is the current and proposed water withdrawal policies for the Susquehanna River Basin. The SRBC governs water withdrawal permitting for the Susquehanna River Basin region, and its policies have the potential to influence the degree to which hydrologic impacts of Marcellus Shale drilling may influence brook trout populations (SRBC 2002). The SRBC currently enforces minimum flow criteria for water withdrawals for hydraulic fracturing in coldwater trout streams to prevent low-flow impacts (Rahm and Riha 2012). The SRBC requires that water withdrawals must stop when stream flow at withdrawal sites falls below predetermined passby flows and cease until acceptable flow returns for 48 h. For small streams (<100 mile^2), passby flows are determined based on instream flow models (Denslinger et al. 1998) and are designed to prevent more than 5% to 15% change in trout habitat, depending on the amount of trout biomass the stream supports. A more general 25% average daily flow requirement is used as the passby flow for larger coldwater trout streams (SRBC 2002). This policy is expected to prevent water withdrawals from impacting habitats during low flows in summer. However, analyses of hypothetical withdrawals within the range of proposed water withdrawal permits suggest that water needs associated with Marcellus Shale drilling will impact seasonal flow needs (not just summer low flow) of small streams likely to support brook trout (DePhilip and Moberg 2010; Rahm and Riha 2012). Additionally, multiple upstream withdrawal events occurring on the same day within the same catchment may culminate in stream flows falling below the passby flow requirement. Though there is considerable uncertainty around water withdrawal estimates, accounting for cumulative withdrawal-induced low-flow effects can increase the number of days that are expected to fall below passby requirements for smaller streams by as much as approximately 100 days within an average year (Rahm and Riha 2012). Consequently, the SRBC has released new proposed low-flow protection regulations for public comment (SRBC 2012b, 2012c), based primarily on recommendations from a cooperative project between The Nature Conservancy, staff from the SRBC, and its member jurisdictions (DePhillip and Moberg 2010). The proposed SRBC flow policy uses a tiered approach to flow protection that prevents withdrawals or puts more stringent requirements in extremely sensitive or exceptional quality streams such as small headwater streams that support reproducing brook trout populations (SRBC 2012b, 2012c). This proposed policy would also provide significant flow protection for trout streams by incorporating seasonal or monthly flow variability into passby flow criteria rather than based on a single average daily flow criterion (Richter et al. 2011; Figure 6) and assessing proposed withdrawal impacts within the context of cumulative flow reductions associated with existing upstream withdrawals (Rahm and Riha 2012). However, the SRBC's proposed policy has received considerable critique from stakeholders, including the natural gas industry (SRBC 2012a). It is unclear what protections a revised water withdrawal policy will provide to streams that support brook trout habitat.

The SRBC policy is only one example of a regulatory body using scientific data to improve and refine a management policy that directly relates to potential drilling impacts on trout populations. It is crucial that policies governing hydraulic fracturing activities be likewise dynamic and subject to adaptation based on updated scientific knowledge. For example, the Pennsylvania *Oil and Gas Operators Manual* provides technical guidance for infrastructure development by identifying best management practices for sediment and erosion control and well pad, road, pipeline, and stream-crossing designs and delineates preventative waste-handling procedures to avoid unexpected probabilistic events like spills and runoff (PADEP 2001). These practices should be amended and updated as new studies refine methods to minimize impacts (e.g., Reid et al. 2004) and strategically protect or restore habitat quality or connectivity (e.g., Poplar-Jeffers et al. 2009). Furthermore, water quality data from monitoring efforts, like TU's Coldwater Conservation Corps (one of many stream survey programs that train and equip volunteers to conduct water quality testing in local streams; TU 2012) can alert regulatory agencies to failures in the probabilistic event prevention strategies that may help better characterize risks and improve waste transport and disposal procedures. For expansion of drilling in new areas, such as into New York State, regulatory agencies including the New York State Department of Environmental Conservation (NYSDEC), which is currently evaluating potential impacts of hydrologic fracturing activities and developing a corresponding set of proposed regulations (NYSDEC 2011), should utilize the most up-to-date and complete scientific data possible from active monitoring efforts to develop best management practices that are optimally protective of natural flow regimes, habitat conditions, and water quality in high-quality streams.

Spatial analysis and visualization of well density (Figure 4) can be combined with refined understanding of brook trout habitat and population status from stream surveys and ground-truthing to prioritize and geographically focus conservation efforts. Currently the Pennsylvania Fish and Boat Commission's Unassessed Waters Program in conjunction with Trout Unlimited and other partner organizations is conducting intensive assessments of streams with unknown brook trout status: to date, this program has identified an additional 99 streams that support wild populations (Weisberg 2011). Similar efforts are being spearheaded in New York by the NYSDEC and TU (2011). Furthermore, the efficacy of regulatory policy can be bolstered by data from monitoring and research efforts that define highest priority watersheds for conservation of brook trout. Various trout-focused organizations have identified key watersheds for protection and restoration. Trout Unlimited has updated their existing Conservation Success Index (J. E. Williams et al. 2007) with a targeted analysis for Pennsylvania to integrate new data on brook trout streams and natural gas drilling threats (TU 2011b). Likewise, the EBTJV has identified an extensive set of action strategies that identify priorities on a state-by-state basis (EBTJV 2011). Results from these types of analyses can be used to identify and direct conservation efforts to key areas where Marcellus Shale drilling activities are likely to have the greatest impacts by disturbing habitat for the highest quality remaining brook trout populations.

In summary, expedient efforts to develop strategies that minimize negative impacts of Marcellus Shale drilling activities on brook trout habitat are needed. Horizontal drilling and hydraulic fracturing for natural gas extraction is likely to increase and expand from Pennsylvania and West Virginia into unexploited areas with growing pressure related to economic incentives from the oil and gas industry and the need for cheap domestic energy sources. Natural gas drilling is expected to persist in the region for several decades due to the extent of the Marcellus Shale natural gas resource and the presence of the gas-rich Utica Shale below it (P. Williams 2008). Consequently, development of adequate management and conservation strategies based on science and enforcement of policies that conserve and protect stream ecosystems supporting brook trout populations and other aquatic organisms are needed to balance energy needs and economic incentives with environmental and brook trout conservation concerns.

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Adaptive Forgetting: Why Predator Recognition Training Might Not Enhance Poststocking Survival

Grant E. Brown

Department of Biology, Concordia University, 7141 Sherbrooke St. West, Montreal, QC, H4B 1R6, Canada. E-mail: grant.brown@concordia.ca

Maud C. O. Ferrari

Department of Biomedical Sciences, Western College of Veterinary Medicine, University of Saskatchewan, 52 Campus Drive, Saskatoon, SK, S7N 5B4, Canada

Douglas P. Chivers

Department of Biology, University of Saskatchewan, 112 Science Drive, Saskatoon, SK, S7N 1E2, Canada

ABSTRACT: *The success of current fish restocking efforts is often hampered by poor poststocking survival of hatchery-reared juveniles. As a result of hatchery selection, combined with a lack of ecologically relevant experience, hatchery-reared fishes often fail to recognize and respond to potential predators following stocking into natural waterways. One commonly proposed method to enhance potential poststocking survival is to condition hatchery-reared fishes to recognize predators prior to stocking. However, despite a wealth of laboratory and field studies demonstrating predator recognition learning in fishes, only a handful of studies have attempted to assess potential poststocking benefits, and these suggest mixed results. Our goal is to highlight possible causes of this apparent contradiction. A survey of the behavioral ecology literature highlights the exceptional degree of sophistication of predator recognition learning among prey fishes. Moreover, an emerging body of literature suggests that how long prey retain learned predator recognition is as important as what prey learn. This highly plastic retention (memory window) may confer adaptive benefits under variable conditions. Hatchery selection may result in phenotypes leading to reduced learning and/or retention of learned information. We conclude by proposing several avenues of investigation aimed at improving the success of prestocking conditioning paradigms.*

Olvido adaptativo: por qué el entrenamiento para reconocer depredadores puede no incrementar la supervivencia después del repoblamiento

RESUMEN: El éxito de los esfuerzos de repoblamiento de peces suele disminuir debido a condiciones desfavorables para la supervivencia de juveniles, provenientes de cultivo, tras prácticas de repoblamiento. Como resultado de la selección en cultivo, en combinación con la falta de experiencia en temas de ecología, los peces de cultivo a veces fallan en reconocer y responder potenciales depredadores después de haber sido introducidos, con fines de repoblamiento, a cuerpos de agua. Un método comúnmente propuesto para aumentar la supervivencia post-repoblamiento es condicionar a los juveniles de peces cultivados a que reconozcan a sus depredadores antes de la translocación. Sin embargo, pese al buen equipamiento de los laboratorios y a los trabajos en campo que demuestran la capacidad de aprendizaje de los peces para reconocer depredadores, solo unos pocos estudios se han enfocado en evaluar los beneficios potenciales post-repoblamiento y dichos estudios muestran resultados encontrados. Nuestro objetivo es subrayar las posibles causas de esta aparente contradicción. Un sondeo bibliográfico acerca de ecología conductual destaca la extraordinaria sofisticación del proceso de aprendizaje en peces para reconocer a sus depredadores. No obstante, otra parte de la literatura reciente sugiere que el tiempo que los peces retienen el patrón de reconocimiento del depredador es igualmente importante que lo aprendido por el individuo. Esta retención altamente flexible (ventana de memoria) puede conferir beneficios adaptativos ante condiciones variables. La selección mediante el cultivo puede resultar en fenotipos caracterizados por una reducida capacidad y/o poca retención de la información aprendida. Concluimos proponiendo distintas líneas de investigación cuyo propósito es aumentar el éxito del acondicionamiento previo al repoblamiento.

Hatchery-reared (HR) fishes, especially salmonids, are routinely stocked into natural waterways as part of population enhancement, recovery programs, and conservation efforts (C. Brown and Laland 2001; Salvanes and Braithwaite 2006; Fraser 2008). These recovery programs, however, are often met with limited success. Though some studies have shown that HR fish have similar poststocking survival rates as do their wild counterparts (e.g., Johnson et al. 2010), many studies point toward reduced survival among HR populations (e.g., Olla et al. 1994; Shively et al. 1996; Salvanes and Braithwaite 2006). A reduced survival may be due, in part, to the maladaptive behavioral phenotypes of HR fish, compared to their wild counterparts (C. Brown and Day 2002; Fraser 2008; Fernö et al. 2011). A growing body of research shows that hatchery-rearing, even over a little as one to two generations, is sufficient to induce significant differences in foraging (Fernö et al. 2011), growth rates (Tymchuck et al. 2007), risk-taking behavioral tactics (Sundström et al. 2004), and predator avoidance behaviors (Shively et al. 1996; Houde et al. 2010; Jackson and Brown 2011) between HR salmonids and their wild counterparts. Such differences in behavioral phenotypes may lead to stocked fish having reduced growth rates, increased predation risk, and/or reduced fitness (Huntingford 2004; Fernö et al. 2011).

Maladaptive behavioral phenotypes may arise from one of two possible mechanisms or, more likely, a combination of the two. Initially, under hatchery conditions, juvenile HR fishes lack experience with natural foraging conditions, microhabitat variability, and predation threats (Olla et al. 1998; C. Brown and Day 2002; Fernö et al. 2011). As a result of the unnatural hatchery environment, juvenile HR fishes might suffer from a lack of opportunity to learn through direct or indirect experience (Fernö et al. 2011), resulting in poorly developed or context-inappropriate behavioral phenotypes (C. Brown and Day 2002). Secondly, behavioral differences between hatchery and wild populations may be the result of genetic divergence resulting from either inadvertent selection for traits that are beneficial under hatchery conditions or the relaxation of natural selection pressures under hatchery conditions (Huntingford 2004; Fraser 2008). Jackson and Brown (2011) directly tested this hypothesis under natural conditions with juvenile Atlantic salmon (Salmo salar) originating from the same population. They compared the predator avoidance behavior of wild-caught juvenile Atlantic salmon with that of the offspring of wild-caught parents (F_1) and the offspring of parents that had spent one full generation under hatchery conditions (F_2). Jackson and Brown (2011) found the strongest predator avoidance response to a standardized predation cue among wild-caught salmon and the weakest response among F_2 salmon. Curiously, the response of the F_1 group was intermediate, suggesting that both hatchery selection and a lack of ecologically relevant experience contribute to the maladaptive behavior patterns among HR salmon.

A commonly advocated solution in a wide range of taxonomically diverse prey populations reared under artificial conditions is "life skills training" (Suboski and Templeton 1989; G. E. Brown and Smith 1998; C. Brown and Laland 2001). The idea that HR fish can be taught to recognize potential predators prior to stocking is attractive because it could allow for increased poststocking survival. Such enhanced survival would reduce the costs associated with stocking programs and potentially increase the effectiveness of population recovery efforts (Salvanes and Braithwaite 2006). However, despite considerable effort to demonstrate learning under laboratory conditions (reviewed in G. E. Brown et al. 2011a), only a few studies have attempted to demonstrate the potential benefits of prestocking predator recognition training efforts on the poststocking survival of commercially important species. These studies have provided, at best, mixed results. For example, Berejikian et al. (1999) found that though Chinook salmon (*Oncorhynchus tshawytscha*) could be conditioned to avoid the odor of an ecologically relevant predator (adult cutthroat trout, *Oncorhynchus clarki*) under laboratory conditions, this did not result in enhanced poststocking survival. Likewise, Hawkins et al. (2007) conditioned 1+ Atlantic salmon (*Salmo salar*) to recognize northern pike (*Esox lucius*) as a potential predator. Conditioned salmon survived no better when stocked into lakes where pike were the dominant predator. Conversely, D'Anna et al. (2012) conditioned white seabream (*Diplodus sargus*) prior to release and found a near doubling of poststocking survival. Likewise, Hutchinson et al. (2012) demonstrated two- to fourfold increases in poststocking survival of juvenile Murray cod (*Maccullochella peelii*) but not for juvenile silver perch (*Bidyanus bidyanus*). Thus, we are left with the question of why this type of learning may not translate to enhanced survival.

Here, we provide an overview of recent work examining chemically mediated predator recognition mechanisms in aquatic prey species and highlight the incredible degree of sophistication involved in these learning mechanisms. In addition, we examine the poorly understood aspect of retention of learned information. Finally, we conclude with some potential avenues to address the question of why prestocking training might not work to increase poststocking survival. The extent to which hatchery effects (selection + differential experience) will impact the poststocking survival and learning ability of fishes clearly depends upon the holding and breeding practices employed within hatcheries. For example, Beckman et al. (1999) found that differences in prestocking growth rate of hatchery-reared Chinook salmon was related to the likelihood of stocked smolts returning as adults. Likewise, habitat enrichment within hatchery-rearing tanks is known to enhance natural foraging patterns, possibly increasing poststocking survival (Roberts et al. 2011). For simplicity, we refer to the dichotomy of hatchery-reared vs. wild-stock fishes within the context of predator-recognition learning. Our goal here is to bring to light recent advances in the study of ecologically relevant learning mechanisms and to bridge the gap between the behavioral ecological literature and possible fisheries applications.

THE SOPHISTICATION OF PREDATOR RECOGNITION LEARNING IN FISHES

Learning, in the broadest sense, can be defined as the ability to modify behavioral response patterns based on experience (G. E. Brown and Chivers 2005). The ability to reliably assess local predation threats allows prey (including juvenile salmonids) to balance the often conflicting demands of predator avoidance and a suite of behavioral activities such as foraging and territorial defense (Lima and Dill 1990; Kim et al. 2011). This is especially difficult under conditions of variable predation risk and/or foraging opportunity (Sih 1992; Dall et al. 2005). Learning to recognize potential predators allows prey to respond only to ecologically relevant threats and to avoid expending time and energy responding to irrelevant cues. In addition, learned recognition has been shown to increase survival during staged encounters with live predators (Mirza and Chivers 2000; Darwish et al. 2005; Vilhunen 2006). Thus, under conditions of variable predation risks, learning is argued to allow prey to optimize the trade-off between predator avoidance and other fitness-related activities (G. E. Brown and Chivers 2005; Dall et al. 2005; G. E. Brown et al. 2011a).

A large body of research has investigated the mechanisms of predator recognition learning in fishes (Ferrari et al. 2010a; G. E. Brown et al. 2011c). A well-documented mechanism of learning is the so-called chemically mediated learning. Damage-released chemical alarm cues are a common feature in freshwater and marine fishes (Ferrari et al. 2010c), which are released following mechanical damage incurred during an attack by a predator. Given the mechanism of release, these chemosensory cues are reliable indicators of predation threats (Chivers et al. 2007, 2012; Ferrari et al. 2010c). When released into the water column and detected by nearby conspecifics and/or heterospecifics, these cues may elicit dramatic, short-term increases in species-specific antipredator behavior (Ferrari et al. 2010c). Recent studies demonstrate that alarm cues convey a surprising amount of information regarding local predation threats. For example, the response intensity of many prey fishes appears to be proportional to the concentration of alarm cue detected (e.g., Dupuch et al. 2004; G. E. Brown et al. 2006, 2009). Similarly, detecting alarm cues at concentrations below that needed to elicit an observable antipredator response are known to increase the use of secondary cues (i.e., visual information; G. E. Brown et al. 2004).

When paired with the visual and/or chemical cues of a novel predator, these alarm cues can facilitate the learned recognition of a novel predator (G. E. Brown et al. 2011a). For example, when juvenile rainbow trout are presented with the paired stimuli of a conspecific alarm cue (innate unconditioned stimulus) and the odor of a novel predator (conditioned stimulus), the trout will exhibit a strong increase in predator avoidance toward the alarm cue. However, when later presented with the predator odor, the trout will increase predator avoidance, demonstrating a learned response to the previously novel predator cue (G. E. Brown and Smith 1998). Following a single conditioning trial, these learned responses may persist for several weeks (G. E. Brown and Smith 1998). Control trials, in which the predator odor is paired with distilled water, fail to elicit any evidence of learning (G. E. Brown and Smith 1998).

A wealth of studies has demonstrated that this type of direct learning is common among aquatic prey species (reviewed in G. E. Brown et al. 2011a). Recent studies have shown that juvenile Atlantic salmon are capable of such chemically mediated learning under fully natural conditions (Leduc et al. 2007). More impressive, however, is the exceptional degree of sophistication present in this learning system. For example, fathead minnows (*Pimephales promelas*) are capable of learning threat-sensitive responses (i.e., the intensity of the behavioral response is directly proportional to the level of risk; G. E. Brown et al. 2006) via this mechanism. When paired with a low concentration of alarm cue (hence low risk), prey will exhibit a similarly low-intensity response to pike odor. However, when the pike odor is paired with a high concentration of alarm cue (hence high risk), the minnows learn to exhibit a high-intensity response (Ferrari et al. 2005). Recent experiments with HR rainbow trout extend these findings, showing that when conditioned to recognize pumpkinseed (*Lepomis gibbosus*) as predation threats, trout can generalize the learned response to the odors of predators that are taxonomically related to pumpkinseed (i.e., longear sunfish, *Lepomis megalotis*) but not to those of more distantly related predators (i.e., yellow perch, *Perca flavescens*; Brown et al. 2011c). Finally, when glowlight tetras (*Hemigrammus erythrozonus*) are conditioned with a conspecific alarm cue paired with the combined odor of largemouth bass (*Micropterus salmoides*), convict cichlids (*Amatitlania nigrofasciata*), and common goldfish (*Carassius auratus*), they are capable of exhibiting increased antipredator behavior in response to individual predator odors but not the odor of a predator not included in the cocktail (yellow perch; Darwish et al. 2005). Moreover, this cocktail learning was shown to increase survival during staged encounters with live predators (Darwish et al. 2005).

Learned predator recognition may also occur via indirect learning mechanisms. Initially, predator recognition can be facilitated via the mechanism of social or observational learning. Social learning may occur when prey acquire the recognition of novel predator cues in the absence of any direct experience (Mathis et al. 1996); simply observing an experienced conspecific (or heterospecific) prey respond to a predator cue can provide sufficient information to allow learning to occur. Such social learning may allow for the rapid transmission of recognition of novel predator cues within populations (G. E. Brown et al. 1997) and has been employed under hatchery conditions to enhance the learning of context-appropriate foraging patterns (C. Brown et al. 2003; Rodewald et al. 2011). Secondly, predator diet cues may also facilitate learning. For example, fathead minnows exposed to northern pike fed a diet of minnows learn to recognize the visual cues of pike (i.e., will respond to the sight of the predator), whereas minnows exposed to pike fed an unknown diet do not respond to the sight of the pike (Mathis and Smith 1993). Likewise, the response of juvenile Arctic charr (*Salvelinus alpinus*) to predator odors is enhanced when the predators have been fed charr versus when they are food deprived (Vilhunen and Hirvonen 2003). Finally, age of individuals seems to influence their ability to learn novel predator recognition. For example, Hawkins et al. (2008) demonstrated that juvenile Atlantic salmon exhibit age-specific sensitivity to novel predator odors. Under laboratory conditions, 10- to 15-week posthatching salmon were more responsive to pike odor than were younger or older conspecifics. Moreover, 16- to 20-week posthatching salmon were better able to learn to recognize novel predator odors than were younger salmon. Hutchison et al. (2012), however, found that whereas Murray cod fingerlings can learn to recognize novel predators, subadults exhibited no evidence of learning. Combined, these findings suggest a critical ontogenetic constraint on the timing of predator recognition learning.

Together, these studies demonstrate that chemically mediated predator recognition learning is a highly sophisticated and complex mechanism allowing for an incredible degree of behavioral plasticity. Under conditions of uncertain predation threats, the ability to modify predator avoidance responses based on recent experience likely confers significant fitness advantages (Dall et al. 2005; G. E. Brown et al. 2011a). However, if learning is so critical to the survival of wild prey populations, why should prestocking conditioning not confer increased survival benefits? The answer to this question might lie in the emerging question of retention of learned information (i.e., memory).

RETENTION OF LEARNED INFORMATION

Though there is a very large body of literature demonstrating the learning abilities and ecological constraints on learning in prey organisms (reviewed in G. E. Brown and Chivers 2005; G. E. Brown et al. 2011a), surprisingly little is known about the retention of learned information. The retention of learned predator recognition varies widely among prey fishes (Ferrari et al. 2010a). For example, following a single conditioning event, HR rainbow trout conditioned to recognize a novel predator will retain a detectable response for up to 21 days (G. E. Brown and Smith 1998), though the intensity of the response wanes after approximately 10 days (Mirza and Chivers 2000). Conversely, after a single conditioning, fathead minnows retained their learned response to a novel predator cue for at least 2 months with little evidence of a decrease in response intensity (Chivers and Smith 1994). Similar studies have shown that learned foraging preferences also vary within and between populations (Mackney and Hughes 1995).

Recently, Ferrari et al. (2010a) proposed a model of "adaptive forgetting," suggesting that the retention (how long prey will exhibit an observable response) to learned information is flexible and dependent on the certainty of this information. Under natural conditions, prey must balance the need to detect and avoid predation threats and to maximize foraging and reproduction (Lima and Dill 1990). The ability to balance these trade-offs depends on the availability of accurate and reliable information regarding risk associated with potential predators (Dall et al. 2005). In turn, the reliability of learned information should impact the duration of its retention (Ferrari et al. 2010a). For example, prey may outgrow gape limits of potential predators, reducing the value of learned recognition. Exhibiting an increased predator avoidance response toward this previously learned cue would represent a cost in the form of lost energy intake. However, if the prey were still at risk to the predator, failure to respond might result in death.

Ferrari et al. (2010a) suggested a number of intrinsic (i.e., prey growth rate, behavioral tactics) and extrinsic (i.e., predictability of predation threats, predator risk level) factors that would be expected to influence the retention of learned information. This model is particularly relevant to the issue of prestocking predator recognition training because hatchery selection may influence the very factors that shape the retention of learned information. Next, we will discuss several relevant examples from our recent work.

RETENTION AND THE EFFECTS OF HATCHERY SELECTION

Personality and Retention

A growing body of literature demonstrates consistent behavioral tactics, often referred to as "shy" vs. "bold" phenotypes, in a wide range of fishes (including salmonids; Budaev and Brown 2011). Generally speaking, individuals with bold phenotypes are more likely to continue foraging under the risk of predation, return to foraging sooner following an attack from a predator, and spend more time away from shelter compared to shy conspecifics (Budaev and Brown 2011). According to the framework of adaptive forgetting (Ferrari et al. 2010a), we might expect bold individuals to retain learned predator recognition less effectively than shy conspecifics due to the reduced value placed on predator avoidance (Tymchuk et al. 2007). This is relevant to the prestocking paradigm, because hatchery-reared fish generally exhibit bolder behavioral tactics (i.e., brown trout, *Salmo trutta*; Sundström et al. 2004) and attenuated stress responses than do wild-caught conspecifics (Lepage et al. 2000), leading to potentially maladaptive behavior patterns.

Recently, we directly tested this prediction with HR juvenile rainbow trout. Juvenile trout were classified as shy vs. bold based on their latency to escape from an opaque chamber into a large test arena (a reliable method of assessing behavioral tactics; C. Brown et al. 2005; Wilson and McLaughlin 2007) and conditioned to recognize a novel predator cue (pumpkinseed odor). When tested for recognition of the conditioned cue 24 h later, there was no difference in the intensity of the learned antipredator response (Figure 1). However, when tested 9 days postconditioning, we found that bold trout no longer exhibited any evidence of retention of the learned response. Shy trout exhibited strong responses, similar to those of the day 2 testing (Figure 1). These data suggest that though it is possible to condition HR fish to recognize predators, they simply may not retain the information long enough to gain a functional benefit due to their bold behavioral phenotypes (G. E. Brown et al. in press).

Growth Rates and Retention

Another common trait within hatchery settings is increased growth rates associated with both the reliable availability of food and the relaxation of competitive pressures (C. Brown and Laland 2002; Saikkonen et al. 2011). Ferrari et al. (2010a) suggested that increased growth rates should reduce the rela-

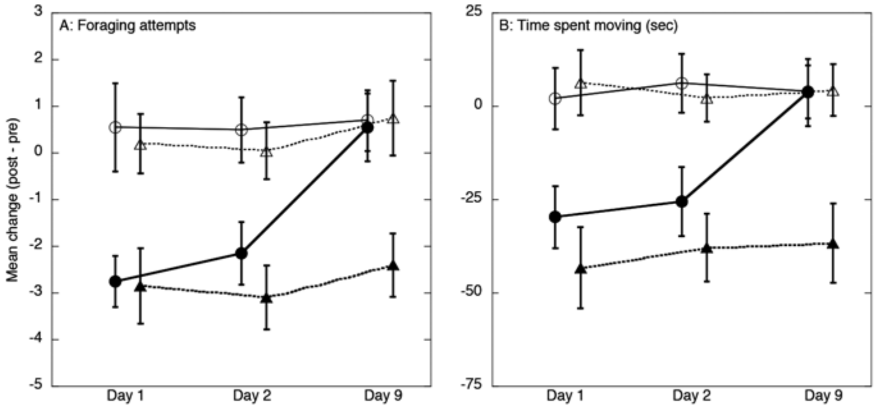

Figure 1. Mean (±SE) change in foraging attempts (A) and time moving (B) for shy (solid triangles) vs. bold (solid circles) rainbow trout conditioned to recognize pumpkinseed as a predation threat on day 1 and subsequently tested for recognition of pumpkinseed odor alone on day 2 and day 9. Shy phenotype trout exhibited significantly longer retention when compare to bold phenotype trout. Open symbols represent pseudoconditioned controls. Modified from G. E. Brown et al. (in press).

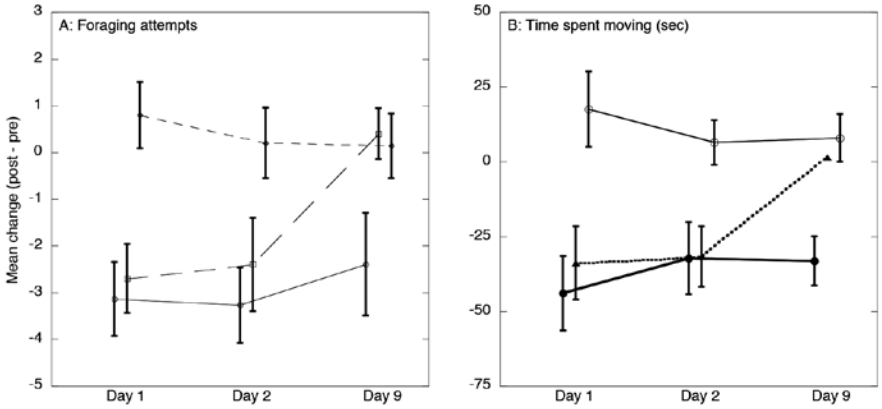

Figure 2. Mean (±SE) change in foraging attempts for juvenile rainbow trout conditioned to recognize pumpkinseed odor as a predation threat (circles) or pseudoconditioned (control; triangles) and subsequently exposed to pumpkinseed odor either 24 h postconditioning (day 2) or 8 days postconditioning (day 9). Panel A depicts results where groups of trout of similar initial mass were fed a high food (5% mbw day−1) or a low food (1% mbw day−1) ration the duration of the study. Panel B depicts results where trout of different initial masses were fed the same food ration (1% mbw day−1). Modified from G. E. Brown et al. (2011c).

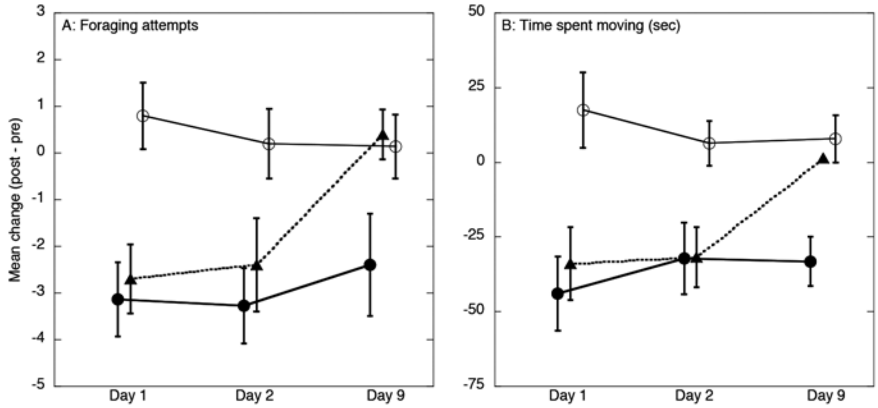

Figure 3. Mean (±SE) change in foraging attempts (A) and time moving (B) for juvenile rainbow trout conditioned with a high risk cue (circles), a low risk cue (triangles) or pseudoconditioned (squares) to recognize pumpkinseed odor as a predator cue. Modified from Ferrari et al. (2010b).

tive value of learned information. G. E. Brown et al. (2011b) tested this hypothesis under laboratory conditions with HR rainbow trout. Juvenile trout, matched for size, were reared on 1% or 5% mbw day^{-1} diets of standard trout chow for 7 days and then conditioned (or pseudoconditioned) to recognize a novel pumpkinseed predator. They were then either tested 24 h postconditioning (day 2) or held on the same 1% or 5% diet for an additional 8 days and then tested for recognition. The results suggest that though there was no difference in the intensity of the learned response between high and low food rations on day 2, only trout reared on the low food ration (low growth rate) showed any evidence of retention when tested on day 9. The observation that response intensity among conditioned trout on day 2 did not differ precludes the possibility that the observed differences on day 9 were due to hunger levels. Trout reared on the high growth rate ration were not different from pseudoconditioned controls (Figure 2A). These results were further supported by a companion study in which small (~0.6 g) and larger (~1.8 g) trout were fed the same 1% mbw day^{-1} rations and tested as above (Brown et al. 2011b). Despite a threefold difference in size, retention was similar between small and large trout (Figure 2B). Combined, these results demonstrate that growth rate at the time of conditioning influences the value of the learned information, leading to differential retention times.

Strength of Initial Conditioning

Several authors have shown that the strength of the initial conditioning event influences the overall intensity of learned predator recognition (Vilhunen and Hirvonen 2003; Ferrari et al. 2005; Zhao et al. 2006). For example, fathead minnows exhibit concentration dependent response intensities to conspecific alarm cues. Ferrari et al. (2005) found that the learned response to novel predator odors matched the intensity of the response during the initial conditioning event. More recently, Ferrari et al. (2010b) found that HR rainbow trout exhibited threat-sensitive retention of learned predator cues. Trout were conditioned to a high or low concentration of conspecific alarm cues (simulating high- vs. low-risk conditions) paired with the odor of pumpkinseeds (or pseudoconditioned) and tested for recognition. When tested for recognition 24 h postconditioning, they found that conditioned trout exhibited learned responses toward the predator cue but the intensity of response did not differ between those conditioned to high vs. low risk cues. However, when tested 8 days postconditioning, those initially exposed to the low risk cue did not retain the learned response (Figure 3).

Ontogenetic Constraints on Learning

Thought it has not been directly tested, it is possible that ontogenetic stage may also play an important role in the retention of learned predator recognition. As mentioned above, Hawkins et al. (2008) and Hutchison et al. (2012) have demonstrated age-specific propensities for chemically mediated learning in juvenile Atlantic salmon and Murray cod. Moreover, as salmonids undergo smoltification, they incur considerable physiological stress (Järvi 1990). This, combined with increased standard metabolic rates in smolts vs. nonsmolting conspecifics (Seppänen et al. 2010), might lead to a reduction in the value of learned predator recognition in favor of increased foraging demands. Several studies (Damsgård and Arnesen 1998; Skilbrei and Hansen 2004) showed a short-term reduction in growth rate and foraging during the smoltification phase but this is typically followed by an extended period of rapid growth. Such a shift in the value of predator avoidance vs. foraging benefits could lead to a reduction in retention (Ferrari et al. 2010a, 2010b).

However, size (ontogeny) has been shown to significantly influence risk-taking tactics in juvenile coho salmon (*Onchorhynchus kisutch*). Reinhardt and Healey (1999) compared the latency to resume foraging (as a measure of antipredator response intensity) among small (~1.5 g) vs. large (~3.5 g) coho salmon reared on similar food rations. Given that maximum potential growth rate is size dependent, larger fish will be capable of realizing a higher percentage of potential growth compared to smaller conspecifics during peak growing seasons (Reinhardt and Healey 1999). Reinhardt and Healey (1999) found that among the small-sized cohort, prior growth rate had a significant positive relationship with the latency to resume foraging following exposure to a standardized predation threat, suggesting that those with lower realized potential growth were more willing to accept increased risk in order to continue foraging in accordance with the asset protection model (Clark 1994). However, they found no effect of prior growth on the risk-taking tactics of the larger cohort. According to Ferrari et al. (2010c), prey that are more willing to accept risk in order to continue foraging (i.e., bold) should show reduced retention periods compared to more risk averse individuals. Thus, potential for growth influencing risk-taking tactics (asset protection) rather than actual growth (G. E. Brown et al. 2011b) may also shape retention.

Photo 1. Behavioral observations of juvenile Atlantic salmon in the Catamaran Brook, New Brunswick. The orange markers (upper left) indicate foraging territories of individual salmon. Photo Credit: G. E. Brown.

Photo 2. Mesh enclosures anchored in the Catamaran Brook, New Brunswick. Enclosures can be stocked with tagged salmon and allow for long-term studies of behavior under natural conditions. Photo Credit: C. K. Elvidge.

Implications for Prestocking Conditioning

Taken together, we see that the mechanism of chemically mediated predator recognition learning is an incredibly complex and sophisticated system, allowing for the acquisition of complex, context-specific behavioral response patterns within a wide variety of aquatic prey species. Moreover, an emerging field of research suggests that the question of how long to retain learned information is just as important to prey species as is the question of what to learn. Clearly, both learning and retention are highly plastic processes, shaped by environmental variability. If predator recognition learning is to result in increased poststocking survival, as suggested by a variety of authors (Suboski and Templeton 1989; C. Brown and Laland 2001; Fernö et al. 2011), we should revisit the design of prestocking conditioning paradigms in light of the results presented above. Next, we suggest a number of possible avenues for future studies. Many of the topics discussed below have previously been considered in the context of hatchery practices with an aim to enhance growth, quality, and survival, as well as the effectiveness of hatchery practices as a conservation tool (i.e., Sharma et al. 2005; Paquet et al. 2011). Thus, we limit our discussion to the relevance toward life skills training. Any findings must be considered in light of current best practices within the hatchery setting.

POSSIBLE AVENUES FOR FUTURE RESEARCH

One possibility to overcome this potential retention issue associated with prestocking conditioning would be to increase the strength of the initial conditioning event. Increasing the number of conditioning events may strengthen the initial learning and hence extend the retention of prestocking conditioning. Vilhunen (2006) found that HR Arctic charr exposed to four sequential conditioning events exhibited stronger learned responses than those conditioned a single time. Moreover, multiple conditioning events enhanced survival during staged encounters with predators. Typically, prestocking training studies have actively conditioned HR salmonids once or twice. It is possible that multiple conditioning events would extend the duration of retention, allowing for increased poststocking benefits. Likewise, based on the findings of Ferrari et al. (2010a), increased concentrations of alarm cues, indicating higher risks, should increase the strength of the initial conditioning. A recent study by Ferrari et al. (2012) demonstrated that woodfrog tadpoles (*Rana sylvatica*) that have been conditioned to recognize a novel predator odor four times retained their learned response longer than those conditioned once. This could combine with the potential benefits of social learning (C. Brown et al. 2003; Vilhunen et al. 2005).

A potential difficulty associated with repeated conditioning might be that HR fish may habituate to the predator odor. Though Vilhunen (2006) found that repeated conditionings enhanced the strength of learning, Berejikian et al. (2003) suggested that HR Chinook salmon may habituate to repeated exposures to the predator odor. There are, however, several differences between these two studies, the most relevant of which include the fact that Berijikian et al. (2003) tested Chinook salmon that were roughly twice the size as the Arctic charr tested by Vilhunen (2006). The observed differences could be related to species-specific differences in learning abilities or ontogenetic effects. Additional work is needed to examine the potential limitations associated with habituation.

A second potential avenue would be to reduce the latency between conditioning and stocking. In-stream or near-shore enclosures could be used to hold stocked fish prior to release. Such enclosures would expose HR salmonids to natural flow and drift regimes and would allow for acclimation prior to release. Large groups could then be conditioned and released. Recent work by Olson et al. (2012) suggested that mass conditioning may allow for the effective prestocking conditioning of HR fishes. Enclosure conditioning could also take advantage of potential social learning (C. Brown et al. 2003; Vilhunen et al. 2005; D'Anna et al. 2012). Vihunen et al. (2005) demonstrated that the effectiveness of social predator recognition learning is greatest when a relatively small number of experienced prey are housed with naïve prey.

Third, as described above, growth rate at the time of conditioning appears to influence retention of acquired predator recognition in at least one HR salmonid. Studies are needed to determine the potential effectiveness of placing HR salmonids on a restricted food ration prior to stocking. For example, HR stocks fed with on-demand feeders could be switched to fixed-ration feeders. Limiting the available foraging opportunities for a short time frame (a few days) may have an impact on retention without increasing stress or competition among stock populations (Ashley 2007).

Fourth, a limited number of studies examining the potential benefits of prestocking conditioning on postrelease survival have been conducted on smolts. Additional studies focused on presmolt life history stages are needed. Though it is clear that under laboratory conditions, smolts can indeed acquire recognition of novel predators (i.e., Berejikian et al. 1999), the increased physiological stress associated with smoltification and migration (Järvi 1990) may function to reduce the value of learned information. It is possible that young-of-the-year fry would exhibit longer retention periods, allowing for potential poststocking survival benefits.

Fifth, as mentioned earlier, HR fish may exhibit maladaptive or poorly developed foraging behavior in addition to impaired predator recognition. Several authors (i.e., Brown and Laland 2002; Rodewald et al. 2011) have successfully employed social learning and/or environmental enrichment to encourage context-appropriate foraging behavior in HR fishes prior to stocking. Under natural conditions, prey must balance the need to forage and avoid predators (Lima and Dill 1990). As such, there is a strong interaction between the two suites of behaviors. Combining context-appropriate foraging and predator recognition into an overall life skills training approach (C. Brown and Laland 2001) may further enhance the poststocking survival of HR fishes. In addition, as described above, prey can be conditioned to recognize multiple predators simultaneously (i.e., Darwish et al. 2005) and can generalize learned recognition across predators (i.e., G. E. Brown et al. 2011c). Learning multiple predators' cues at the same time or generalizing across ecologically relevant predators would further increase the ability of HR fishes to balance foraging—predator-avoidance tradeoffs—and may enhance poststocking survival.

The final issue that needs careful consideration is the habitat characteristics of both the conditioning environment and the place where the fish are to be released. Interactions between habitat characteristic and learning are at their infancy, but there are a few noteworthy studies that should provide us with issues to consider. For example, Gazdewich and Chivers (2002) conditioned minnows to recognize yellow perch as a predator and then staged encounters in two different habitat types. There was a clear effect of the predator training on prey survival, but this was only evident when the encounters were staged in one habitat type. Considering the pre- and postconditioning environment may be crucial for the success of training programs. In another study, Smith et al. (2008) conditioned rainbow trout to recognize a novel predator odor at either pH 6.0 or 7.0. A week later, the fish that were tested for recognition of the odor at the pH used during conditioning displayed antipredator responses, whereas those tested at the other pH did not. This study points to the need to consider the water quality parameters of the water body in which the fish are released. A simple change in pH may render learning ineffective and the training programs a waste of valuable resources.

Taken together, the research described in our review suggests that more research is needed to investigate the potential benefits associated with prestocking predator recognition training. The behavioral ecology literature suggests that learning is an adaptive phenotype that confers significant benefits under conditions of variable predation risk. Moreover, this literature suggests that the question of how long learned information is retained is equally as important as what information is learned.

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W.F. Thompson Award for Best Student Paper Published in 2011

Nominations are open for the W.F. Thompson Award, which will be given by the American Institute of Fishery Research Biologists (AIFRB) to recognize the best student paper in fisheries science published during 2011. The award will consist of a check for $1000, a certificate, and a one-year membership in AIFRB at an appropriate level. The requirements for eligibility are as follows:

(1) the paper must be based on research performed while the student was a candidate for a Bachelor's, Master's, or Ph.D degree at a college or university in the Western Hemisphere;

(2) the results of the research must have been submitted to the recognized scientific journal in which it was eventually published, or to the editor of the book in which it was eventually published, within three (3) years of termination of student status;

(3) papers that are considered for the award must be concerned with freshwater or marine biological resources;

(4) the paper must be in English; and

(5) the student must be the senior author of the paper.

Nominations may be submitted by professors or other mentors, associates of the students, or by the students themselves.

The deadline for receipt of nominations is January 31, 2013. The nominations should be sent to the Chairman of the W.F. Thompson Award Committee, Dr. Frank M. Panek, USGS-Leetown Science Center, 11649 Leetown Rd, Kearneysville, WV 25430 (email: fpanek@usgs.gov).

Each nomination must be accompanied by a copy of the paper (unless it is easily available on the internet) and a résumé.

The papers will be judged by knowledgeable subject matter reviewers selected by the Chairman and members of the Committee on the basis of contribution to fisheries science, originality, and presentation.

The National Ecological Observatory Network: An Observatory Poised to Expand Spatiotemporal Scales of Inquiry in Aquatic and Fisheries Science

Ryan M. Utz,* Michael R. Fitzgerald, Keli J. Goodman, Stephanie M. Parker, Heather Powell, and Charlotte L. Roehm

The National Ecological Observatory Network, 1685 38th St. Suite 100, Boulder, CO 80301.

***E-mail: rutz@neoninc.org**

ABSTRACT: *Large spatiotemporal-scale fisheries research amid pervasive environmental change requires scientific resources beyond the capabilities of individual laboratories. Here we introduce the aquatics program within a novel institution, the National Ecological Observatory Network (NEON), poised to substantially advance spatiotemporal scales of inquiry in fisheries research. NEON will collect high-quality data from sites distributed throughout the United States, including Alaska, Hawaii, and Puerto Rico, for 30 years. Data products will include hundreds of metrics that comprehensively quantify the biological, chemical, and hydrogeomorphic attributes of streams, lakes, and rivers in the observatory network. Coupling observations from NEON terrestrial, atmospheric, and airborne programs will facilitate unique inquiries in ecohydrology. All NEON-generated data will be rigorously quality controlled and posted to an entirely open-access web portal. Proposals that expand the observatory scope through additional observations, sites, or experiments are encouraged. Thus, NEON represents an unprecedented and dynamic resource for fisheries researchers in the coming decades.*

La red del Observatorio Ecológico Nacional: un sistema listo para expandir la escala espacio-temporal de la investigación en la ciencia acuática y pesquera

RESUMEN: La investigación pesquera en grandes escalas espacio-temporales, dentro de un ambiente cambiante, requiere de recursos científicos que van más allá de las capacidades de laboratorios individuales. En la presente contribución se introduce el programa “aquatics” concebido en el seno de una institución de reciente formación, el Observatorio Ecológico Nacional (NEON) que fue diseñado para mejorar de forma sustancial la escala de investigación espacio-temporal de las ciencias pesqueras. NEON recolectará datos de alta calidad, dentro de un periodo de 30 años, de distintos sitios distribuidos a lo largo de los Estados Unidos de Norteamérica, incluyendo Alaska, Hawái y Puerto Rico. Los datos incluirán cientos de medidas que cuantifican los atributos biológicos, químicos e hidrogeomorfológicos de arroyos, lagos y ríos que abarca el observatorio. El acoplamiento de observaciones de los programas terrestres, atmosféricos y aéreos de NEON facilitará la investigación eco-hidrológica. Todos los datos generados por NEON pasarán por un riguroso control de calidad y serán puestos a disposición del público en general en un portal de internet. Se exhortan aquellas propuestas que, a través de la adición de observaciones, sitios o experimentos, estén encaminadas a expandir el ámbito del observatorio. Así, NEON representa un recurso, dinámico y sin precedentes, para los investigadores pesqueros en las próximas décadas.

INTRODUCTION

Understanding the multiscaled spatial and temporal processes that structure aquatic ecosystems is a fundamental challenge in fisheries management and conservation. For example, the suite of physical controls that shape habitat templates in rivers operate with observable signatures spanning approximately 15 orders of magnitude across time and space (Minshall 1988), whereas processes occurring among and within interacting populations of organisms exhibit an arguably equivalent degree of spatiotemporal heterogeneity (Fausch et al. 2002). Complicating matters further, freshwater and terrestrial ecosystems are inexorably linked through nutrient (Marcarelli et al. 2011), prey (Wipfli and Baxter 2010), and water subsidies also operating at variable spatiotemporal scales. Finite resources inevitably limit the spatial and temporal extent of virtually all ecological studies, resulting in a high likelihood of overlooking or mischaracterizing important patterns and processes (Cooper et al. 1998). Such knowledge gaps inevitably lead to uncertainties when developing science-informed management decisions.

Applying broad-scale spatiotemporal data often proves to be an effective means of addressing such challenges. For instance, long-term data sets from widely distributed locations have been recently used to highlight greater than expected phenological responses of plants to climate change (Wolkovich et al. 2012), demonstrate spatially pervasive trends of rising water temperatures in streams and rivers (Kaushal et al. 2010), and evaluate the current status of marine fisheries on a global spatial scale (Worm et al. 2009). Yet the information resources that led to such findings represent the exception in ecology, with the majority of collected data within the field remaining proprietary and inaccessible despite the clear need for openness in such a collaborative, interdisciplinary science (Reichman et al. 2011). Furthermore, even when data are freely available, poorly documented metadata, incomplete provenance, and/or inconsistent methodology can render comparability among locations or across time spans impossible (Peters 2010).

Fortunately, several recently initiated large-scale environmental observatories will soon expand scales of inquiry in disciplines with ties to fisheries science for all researchers. Such networks aim to freely provide multidecadal data records collected using standardized methodology to allow trend comparisons among widely dispersed sites. For instance, the National Science Foundation (NSF)-supported Ocean Observatory Initiative will begin publishing 25 years worth of open-access multivariate oceanographic data from a network of deepwater and coastal arrays dispersed throughout the western hemisphere starting in 2015 (Cowles et al. 2010). Another NSF-funded initiative, the Critical Zone Observatory (CZO; http://www.criticalzone.org), freely publishes hydrologic, chemical, and physical data from the vadose zones of seven locations throughout the United States and Puerto Rico (Anderson et al. 2008; Lin et al. 2011). Lake ecologists may access an unprecedented catalog of information amassed by the Global Lake Ecological Observatory Network (GLEON; gleon.org), a grassroots network of scientists integrating scalable environmental data from lakes around the world (Hanson 2008; Kratz et al. 2006).

Here we introduce an observatory poised to become a valuable resource for fisheries scientists: the National Ecological Observatory Network (NEON). The observatory is an NSF-funded project currently being constructed by an independent 501(3)(c) nonprofit corporation (NEON, Inc.; headquartered in Boulder, Colorado). The explicit mission of NEON is to enable continental-scale ecological forecasting (i.e., identifying broad-scale patterns across North America and using these to help predict future trends) by providing infrastructure and high-quality, standardized data collected throughout the United States, including Alaska, Hawaii, and Puerto Rico. Specifically, NEON was explicitly designed to address Grand Challenge questions in the environmental sciences put forth by the National Research Council (NRC 2001). NEON-generated data are thus strategically intended to provide standardized observations and experimental data to increase understanding of how (1) climate change, (2) land use change, and (3) invasive species interact to impact (1) biogeochemical cycles, (2) biodiversity, (3) ecohydrological processes, and (4) the spread of infectious diseases (Figure 1; NEON 2011).

During the scheduled 30 years of operation, NEON will archive and provide open access to more than 600 data products. Parameters will range from standard descriptive field measurements, such as indicators of water quality (e.g., NO_3 concentrations, total organic matter, and acid neutralizing capacity) to complex metrics derived from multiple variables (e.g., stream metabolism, fish biodiversity, NO_3 flux). Each measurement will be subjected to a rigorous quality assurance/quality control check. All observatory-generated data will be posted to an open-access web portal for research community and general public use. NEON will operate in 60 sites distributed among 20 ecoclimatic domains selected to maximize objective representation of

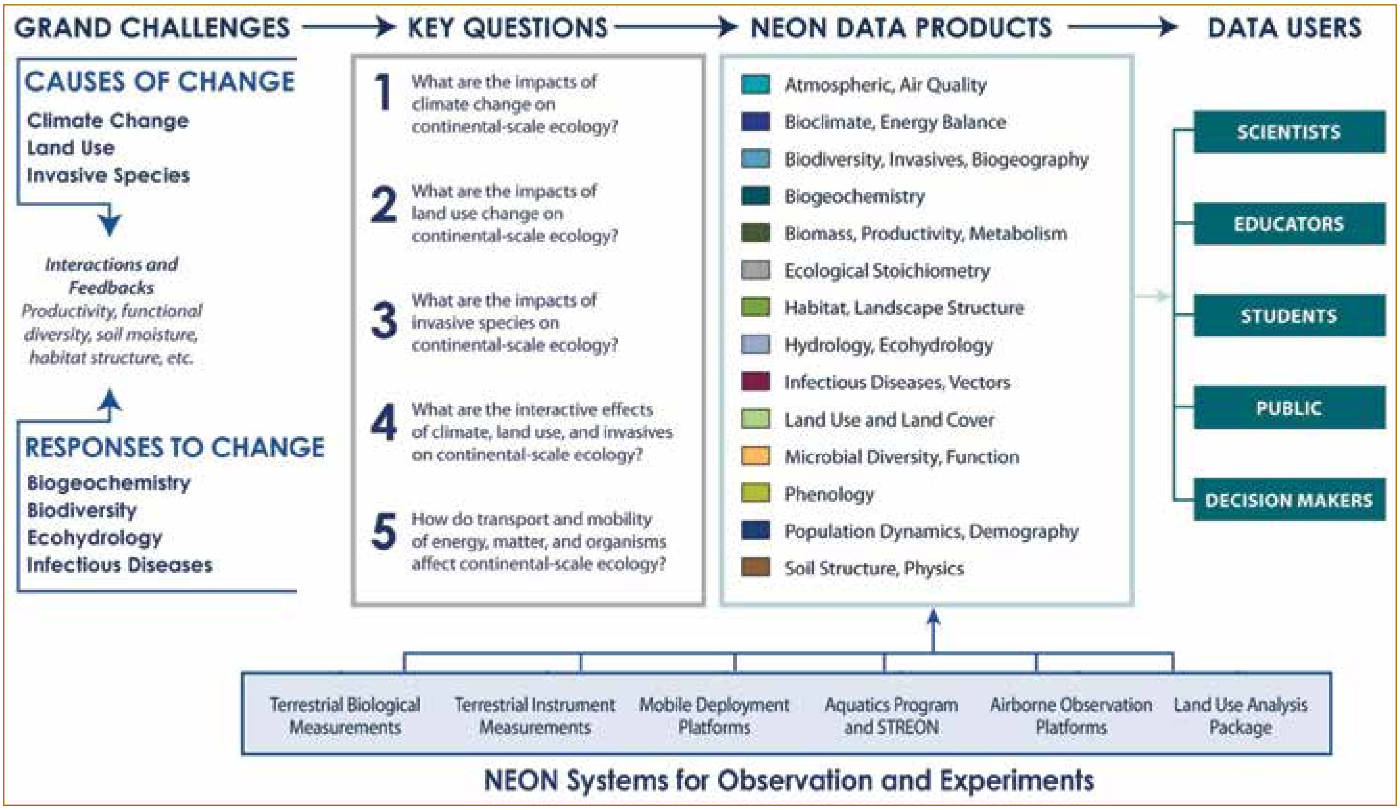

Figure 1. The theoretical basis of the NEON observatory. National Resource Council (NRC) Grand Challenges in environmental sciences have alluded to key questions that NEON data products are meant to help multiple communities address.

continental-scale environmental variability (Keller et al. 2008). The observatory is also a platform upon which researchers identifying an impetus for additional data or seeking to use NEON infrastructure for novel experiments are encouraged to apply for external funding to support their work.

Within NEON, an Aquatic Program will implement a sampling regime for 212 data products from 36 wadable streams, nonwadable rivers, and lakes throughout the United States. The Aquatic Program within NEON aims to address NRC-posited Grand Challenges in aquatic ecosystems with the exception of infectious disease dynamics. Aquatic data will include quantitative metrics characterizing diversity among multiple biological assemblages (fish, invertebrates, macrophytes, algae, and periphyton) and comprehensive biogeochemical, hydrologic, and geomorphic data. The following sections provide an overview of the data products to be derived by the NEON Aquatic Program and how they stand to benefit fisheries scientists. Because of the number of parameters to be collected, a comprehensive description of all planned data products would reach beyond the scope of this article. However, a full, descriptive list of planned data products may be freely accessed online (Keller 2010; Keller et al. 2010).

BIOLOGICAL DATA

Providing comprehensive data that enable the detection of long-term trends in biological assemblages among North American ecosystems represents a fundamental NEON goal. Data products derived from NEON biological collections in aquatic sites will include the diversity, richness, relative abundance, and spatial distribution of microbes, algae, aquatic plants, macroinvertebrates, and fishes. Individual weights and lengths of fishes will also be quantified, with the exception of sensitive species or populations that prohibit such handling. NEON field crews will collect microbial biofilm, algal, and benthic macroinvertebrate community samples two to three times per year and fish sampling will occur once per year in streams and lakes. Zooplankton samples will also be collected in all lakes. Sampling regimes for fish will consist of electrofishing, gill netting, and/or minnow traps depending on site characteristics. During the 30-year period of NEON operations, special attention will be paid to invasive species and data will denote when organisms are not native. Riparian vegetation surveys will be undertaken at each site once per year during peak leaf out. Finally, phenologically important dates associated with riparian vegetation (leaf out, fall, and senescence) that dictate patterns in evapotranspiration and associated trends in stream hydrology will be recorded at each site.

In addition to biological data collected using conventional methodology, NEON will help advance molecular techniques that catalog species and improve biomonitoring efforts. NEON will work with existing partners, including the United States Environmental Protection Agency and Barcode of Life Datasystems, to develop novel DNA barcode databases (Hajibabaei et al. 2007) for select aquatic and terrestrial taxonomic groups that are morphologically difficult to distinguish and speciose. In aquatic ecosystems, a subset of benthic macroinvertebrates will be targeted for DNA barcoding. Though the initial target aquatic taxa for DNA barcoding has yet to be determined, the group will likely possess difficult taxonomic attributes, a ubiquitous distribution and significant potential for biomonitoring applications, such as nonbiting midges (Chironomidae; Raunio et al. 2011).

CHEMICAL AND BIOGEOCHEMICAL DATA

Water quality in aquatic ecosystems is strongly integrated with surrounding terrestrial and atmospheric environments through multiple spatiotemporally heterogeneous processes (Williamson et al. 2008). Such relationships influence fish habitat, water quality, and ecosystem services, though fish may simultaneously shape water chemistry through nutrient transport, via ecosystem engineering (Moore 2006), and by creating biogeochemical hotspots (McIntyre et al. 2008). NEON will provide continuous and discrete chemical data of surface water (up to 35 parameters) at aquatic sites via in situ sensors and water samples collected up to 26 times per year. At lake sites, NEON water chemistry samples will span locations across lake surfaces and at multiple depths to quantify epilimnetic and hypolimnetic processes. These observations will help to define the seasonality of chemical parameters such as total and dissolved nutrients, cations, and anions. Isotopic ratios (i.e., δN^{15}, O^{18}, S^{34}, and C^{13}) in detritus, surface and subsurface water, particulate organic matter, and primary producer samples will also be collected to structure food webs and quantify links between chemical and biological processes and among environments. Because benthic zone sediments act as source, sink, or transformation centers of biogeochemical cycles, NEON will quantify sediment chemistry (up to 23 parameters including dissolved nutrients, cations, and anions) at least annually at all aquatic sites. Complementary metrics pertaining to grain size and structure will help determine sorption and oxygen depletion potentials. At sites where the likelihood of metal contamination is considered significant, NEON will measure sediment and water column metal concentrations. In addition to data derived from grab samples, continuous monitoring sensors will measure parameters such as turbidity, pH, conductivity, dissolved oxygen, temperature, and select nutrients, providing valuable real-time information on the chemical dynamics that affect aquatic organisms.

Aquatic chemistry parameters will also include in-house calculations of high-order biogeochemical metrics. NEON will produce measurements of whole-stream metabolism in wadable streams, which is a key indicator of processes that couple aquatic, terrestrial and atmospheric environments (Carpenter et al. 2005). Changes in land use and subsequent nutrient export from surrounding ecosystems can influence metabolism in receiving waters, ultimately impacting primary production and biological oxygen demand (Mulholland et al. 2001). In some cases, excessive nutrient inputs elevate primary productivity to rates that induce eutrophication, oxygen depletion, and fish kills (Dybas 2005). Given the value of metabolism as an integrator of environmental change, NEON will continuously quantify metabolism in wadable stream sites using a two-stage oxygen-depletion method. Associated data products will include relationships between discharge and stream reaeration rate coefficients, which will enable the calculation of continuous rates of gross primary production and ecosystem respiration per unit channel area and length. Other high-order biogeochemical metrics to be quantified by NEON include flux estimates for nitrogen, phosphorus, and carbon.

HYDROLOGIC, GEOMORPHIC, AND GROUNDWATER DATA

Climate models indicate that global changes in hydrologic cycles are imminent and will significantly affect aquatic ecosystems worldwide. In northeastern North America, heavy precipitation events are predicted to occur more frequently, whereas in the arid southwest precipitation is anticipated to decrease (Solomon et al. 2009). Severe precipitation events may induce water quality degradation in small streams and lakes, because greater fractions of water budgets could potentially be transmitted via overland flow. Such events impact the thermal attributes of aquatic ecosystems: groundwater infiltration is thermally consistent, whereas the temperature of water delivered during events as overland flow may be highly variable (Brown and Hannah 2008). Pulse- and press-dynamic changes in precipitation, water temperature fluctuations, and hydrology associated with climate change will impact the reproductive success of many fishes (Daufresne and Boët 2007). NEON will continuously record stream stage and calculate instantaneous discharge at all wadable stream sites. Additionally, aquatic sites (including lakes) will be instrumented with a network of up to eight riparian monitoring wells (≤30 m deep) to quantify local groundwater contributions at locations where such infrastructure is feasible. Sensors deployed in wells will provide near-continuous data on groundwater level, temperature, and conductivity. The well network will be spatially designed to capture coverage of influent–effluent groundwater chemistry, hydraulic gradients, and flow directions. Coupling NEON biological and biogeochemical attributes with sensor-derived groundwater well, in-stream surface water, and atmospheric/meteorological station data will allow researchers to conduct unprecedented analyses in ecohydrology.

Morphology surveys will be conducted annually to monitor changes in aquatic site physical attributes. At each stream and river site, NEON typically secures access to conduct research within a 1,000-m reach, and morphology surveys will cover this entire extent. Morphological data products in wadable stream systems will include channel attributes such as slope, sinuosity, and the relative linear extent of specific habitat types (i.e., pools, riffles, and runs). Features will be mapped with respect to fixed coordinate systems to assess questions such as whether and how channel attributes evolve over time. Additionally, the abundance, location, and mobility of large woody debris (fundamentally important to aquatic ecosystems; Gregory et al. 2003) will be quantified during morphology surveys. In lakes, detailed bathymetry surveys will be conducted using acoustic technology with high-precision differential Global Positioning Systems.

ATMOSPHERIC, TERRESTRIAL, AND REMOTELY SENSED DATA

NEON data collected outside of aquatic systems will likely also prove a valuable resource in many fisheries science applications. Terrestrial NEON data products consist of physical, chemical, and biological data, including soil metrics, evapotranspiration, phenological attributes (such as leaf senescence and emergence), and biochemical vegetation parameters. Such characteristics directly influence hydrologic cycles and water quality; thus, NEON data will enable investigative efforts relating terrestrial dynamics to hydrogeomorphic attributes in aquatic ecosystems. NEON will quantify stable isotope data signatures from multiple biotic and abiotic components of terrestrial and atmospheric environments. Consequently, stable isotope-based modeling of energy and material subsidies between terrestrial and aquatic food webs, an important phenomenon in both systems (Paetzold et al. 2005; Wipfli and Baxter 2010), will be possible across the network. NEON will collect a comprehensive suite of high-resolution data on atmospheric parameters from tower infrastructures, including total and photosynthetically active solar radiation, deposition, and wind speed/direction. These data may be used to quantify atmospheric controls on the physicochemical attributes of NEON aquatic ecosystems. Additionally, the NEON tower infrastructure will measure the chemical composition of dust and precipitation, thereby facilitating studies investigating deposition impacts on primary productivity in lake and marine ecosystems (Miller et al. 2007; Elser et al. 2009).

Data products will also include remotely sensed information derived from an Airborne Observation Platform (AOP). NEON will collect spectroscopic, photogrammetric, and light detection and ranging (LiDAR) data from flights deployed once annually over all sites in each domain. AOP observations will be converted to multiple high-order data products, such as land cover, canopy moisture, chemistry and structure, and disturbance metrics. These remotely sensed data are meant to bridge scales between satellite and terrestrially derived data. Integrating such information with aquatic and terrestrial observations should facilitate unprecedented analyses in watershed science.

STREON—THE FIRST NEON NETWORK EXPERIMENT

As mentioned above, NEON encourages proposals submitted by external scientists who use observatory facilities to conduct novel experiments. The first among these will be the Stream Experimental Observatory Network (STREON), an experimental program that will serve as a long-term assessment of stream ecosystem responses to drivers of environmental change (eutrophication and the extirpation of large-bodied organisms). STREON will consist of two treatments: (1) the nutrient most likely limiting local primary production (nitrogen or phosphorous) will be enriched by 5× ambient concentrations and (2) large-bodied organisms such as fish and amphibians will be electrically excluded from patches of benthic habitat (sediment baskets) during an annual 8- to 12-week period (Figure 2). Additionally, the likely nonlimiting nutrient (nitrogen or phosphorus) will be chronically added at an N:P ratio of 20:1. Nutrient enrichment treatments will be applied immediately downstream of the regular aquatic NEON reach in 10 sites (Table 1, Figure 2), and consumer exclusion apparatuses (and control replicates) will be deployed in both reaches. Data associated with STREON will include all standard NEON aquatic site measurements collected in both reaches. Additionally, sediment baskets linked to the consumer exclusion treatment will be incubated in closed recirculation chambers to quantify benthic metabolism and nutrient uptake.

Past chronic nutrient enrichment experiments have demonstrated distinct temporal thresholds of whole-ecosystem effects and elevated fish growth rates in treatment reaches (Benstead et al. 2007), and studies similar to the consumer exclusion component have revealed how fishes and other large-bodied organisms induce trophic cascades and/or serve as ecosystem engineers (Greathouse et al. 2006). What renders STREON unique from past efforts is the scope: the experiment will run over a 10-year period in 10 geoclimatically distinct streams across the continent. STREON will operate using standardized data quality assurance procedures to ensure that the experiment is as consistent as possible among sites. As with all NEON-generated information, STREON data will be open access, quality assured/quality controlled and available to the public via a web portal.

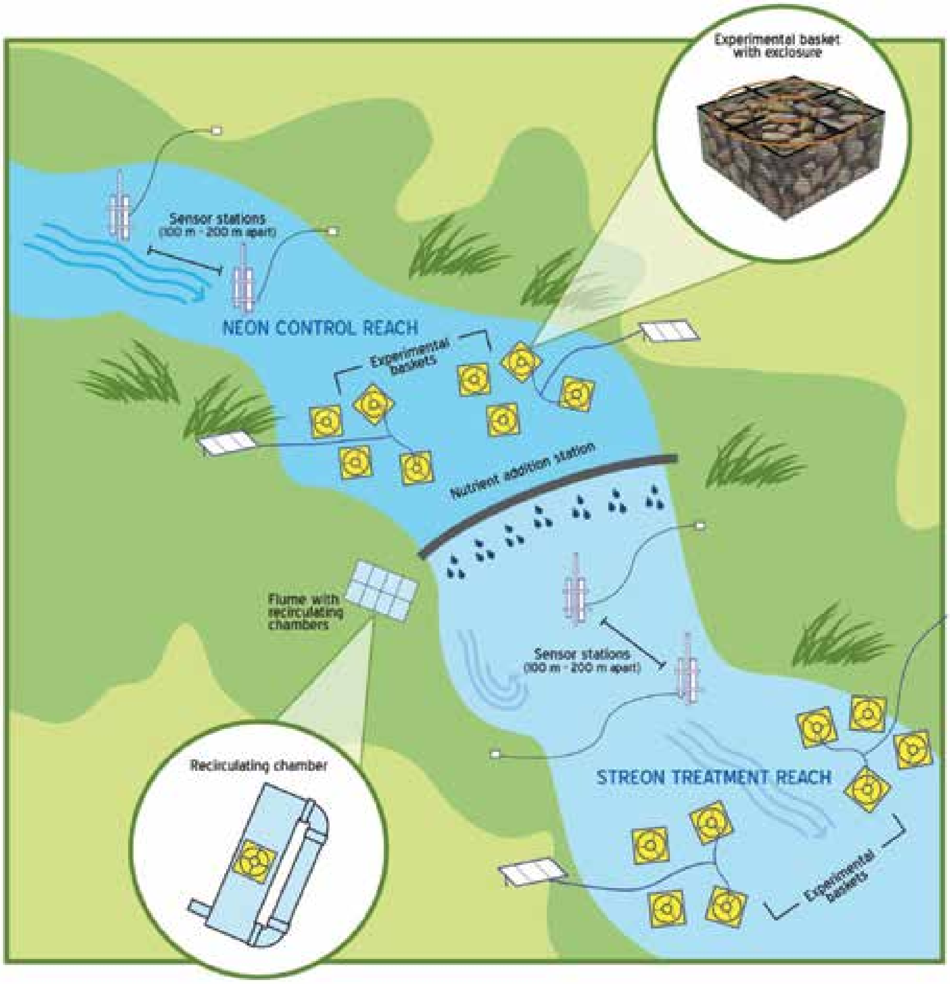

Figure 2. Experimental design of the STREON program at a typical site.

Metric and Protocol Development

The metrics to be collected and posted by NEON were specifically selected to help address NRC Grand Challenges in the environmental sciences and were identified during the planning and design phases of NEON development. From 2005 to 2011, NEON held multiple workshops and meetings intended to solicit recommendations on metric selection from external researchers in various subdisciplines of ecology. The resulting comprehensive suite of data products to be collected may be found in Keller (2010) and Keller et al. (2010). However, the NEON suite of data products will not necessarily remain static during the 30 years of operations: researchers may apply for funding (through agencies external to NEON) to expand the scope of data products that NEON collects (explained further in The NEON Structure: Current and Future section below).

For each NEON-generated data product, including all described in the preceding sections, specific protocols defining field and laboratory procedures will be written by NEON staff ecologists and peer-reviewed by active members in the research community. Protocol methodology will attempt to outline the best-known sampling practices for NEON field technicians. Preliminary protocol drafts are distributed to a voluntary working group of scientists external to NEON for review. Working group members possess the expertise required to assess such protocols and include scientists from academia, government agencies, and nonprofit organizations. For example, the aquatics technical working group reviews all aquatics program protocols and is comprised of 18 aquatic ecologists from nine universities or colleges, three federal agencies, and two nonprofit research institutions (currently active members of all working groups are listed on the NEON website). Finalized protocols will be made available to the community as open-access online resources so that researchers wishing to apply NEON methodology to maximize the comparability of data they collect may do so.

Protocols are developed to maximize data comparability among sites. Wherever possible, NEON personnel will apply identical methodology across sites. Procedures applied will represent those most appropriate for the setting where local environmental conditions significantly affect the efficacy of a certain method. For instance, when sampling benthic macroinvertebrates, Surber samplers will be used in mid- to high-gradient streams with hard substrates, whereas sites with sandy or silty substrates will be sam-

TABLE 1. NEON candidate aquatic sites and examples of fish species found in these water bodies. Sites listed are pending land use agreements (for site updates visit the NEON website). Numbers in the first column correspond to those illustrated in Figure 4. Italicized stream names denote sites in the STREON program.

Site	Name, State	Watershed area (km2; lotic systems) or surface area (ha; lakes)	Fish community attributes at site
1	West Branch Bigelow Creek, MA	0.3	No fishes present
2	Sawmill Brook, MA	4.0	No fishes present
3	*Baisman Run, MD*	1.7	Six species including brook trout (Salvelinus fontinalis), rosyside dace (Clinostomus funduloides), and longnose dace (Rhinichthys cataractae)
4	Posey Creek, VA	2.2	Currently unknown, but likely mottled sculpin (Cottus bairdi), creek chub (Semotilus atromaculatus), and blacknose dace (Rhinichthys atratulus)
5	Suggs Lake, FL	31.5	Fourteen recorded species, including spotted gar (Lepisosteus oculatus), bowfin (Amia calva), and warmouth (Lepomis gulosus)
6	Barco Lake, FL	10.1	Warmouth, largemouth bass (Micropterus salmoides), and bluegill (Lepomis macrochirus)
7	Ichawaynochaway Creek, GA	2,683.2	Fifty recorded species including goldstripe darter (Etheostoma parvipinne), shoal bass (Micropterus cataractae), and spotted bullhead (Ameiurus serracanthus)
8	*Río Cupeyes, PR*	11.3	American eel (Anguilla rostrada), mountain mullet (Angonostomus monticola), and bigmouth sleeper (Gobiomorus dormitor)
9	Río Guillarte, PR	11.9	Currently unknown; likely similar to Río Cupeyes
10	Lake Clara, WI	27.4	At least five species characteristic of north-temperate lakes, including yellow perch (Perca flavescens), largemouth bass, and northern pike (Esox lucius)
11	Pickerel Creek, WI	34.9	Currently unknown
12	*Kings Creek, KS*	12.4	Twenty recorded species including orangethroat darter (Etheostoma spectabile), orangespotted sunfish (Lepomis humilis), and shorthead redhorse (Moxostoma macrolepidotum)
13	McDowell Creek, KS	214.4	Thirty-six recorded species, including carmine shiner (Notropis percobromus), southern redbelly dace (Phoxinus erythrogaster), and longnose gar (Lepisosteus osseus)
14	LeConte Creek, TN	9.1	Brook trout and mottled sculpin (Cottus bairdi)
15	*Walker Branch, TN*	0.4	Creek chub and western blacknose dace (Rhinichthys obtusus)
16	Black Warrior River, AL	15,159.3	One hundred twenty-six recorded species including Tuskaloosa darter (Etheostoma douglasi), redeye bass (Micropterus coosae), and black redhorse (Moxostoma duquesnei)
17	Lower Tombigbee River, AL	47,102.4	One hundred twenty-one recorded species, including paddlefish (Polyodon spathula), river redhorse (Moxostoma carinatum), and crystal darter (Ammocrypta asprella)
18	*Mayfield Creek, AL*	17.0	Currently unknown, but could include >25 species. Supports populations of Tombigbee darter (Etheostoma lachneri), least brook lamprey (Lampetra aepyptera), and bluehead chub (Nocomis leptochephalus)
19	Prairie Pothole, ND	11.0	Currently unknown; likely supports populations of brook stickleback (Culea inconstans) and black bullhead (Ameirus melas)
20	Prairie Lake, ND	30.0	Currently unknown; likely similar to Prairie Pothole lake
21	Arikaree River, CO	2,874.9	Nineteen species, including brassy minnow (Hybognathus hanksinsoni), northern plains killifish (Fundulus kansae), and orangethroat darter
22	South Pond, OK	0.8	No fishes present
23	Pringle Creek, TX	18.1	Currently unknown; likely supports populations of mimic shiner (Notropis volucellus), blackstripe topminnow (Fundulus notatus), and logperch (Percina caprodes)
24	Bozeman Creek, MT	48.7	Currently unknown
25	Blacktail Deer Creek, WY	38.9	Brook trout
26	Fool Creek, CO	2.4	Currently unknown
27	Como Creek, CO	4.8	Greenback cutthroat trout (Oncorhynchus clarki stomias)
28	*Sycamore Creek, AZ*	345.0	Longfin dace (Agosia chrysogaster) and desert sucker (Pantosteus clarki)
29	Red Butte Creek, UT	16.7	Bonneville cutthroat trout (O. clarki utah)
30	East Branch Planting Creek, OR	1.6	Currently unknown; likely supports populations of coastal cutthroat trout (O. clarki clarki)
31	*McRae Creek, OR*	5.2	Coastal cutthroat trout
32	Providence Creek, CA	1.3	No fishes present
33	*Convict Creek, CA*	52.1	Brook trout (Salvelinus fontinalis), brown trout (Salmo trutta), rainbow trout (Oncorhynchus mykiss)
34	Toolik Lake, AK	146.7	At least five species including lake trout (Salvelinus namaycush), Arctic grayling (Thymallus arcticus), and round whitefish (Prosopium cylindraceum)
35	*Oksrukuyik Creek, AK*	73.5	Arctic grayling and slimy sculpin (Cottus cognatus)
36	*Caribou Creek, AK*	30.7	Arctic grayling and slimy sculpin

pled using hand corers. Posted data will specify methodological approaches, and the open-access protocols used to collect the data will allow interested researchers to determine the rationale concerning methodological decisions. Sample collection timing will also be coordinated to maximize data comparability among sites. NEON will identify periods where maximum biological diversity is expected for each target assemblage using externally collected historical data from each domain.

NEON Site Selection Process and Aquatic Sites

Sites in the NEON network are chosen to simultaneously maximize representation among major North American ecosystems and allow researchers to address environmental questions of regional concern. To distribute sites throughout major ecological gradients of North America, NEON used multivariate geographic clustering (Hargrove and Hoffman 1999) to partition the continental United States, Alaska, Hawaii, and Puerto Rico into 20 ecoclimatic domains. All domains (excluding Hawaii) include one to three aquatic sites that fall into two categories: core sites, which will remain fixed in place during the entire 30 years of NEON operations, and relocatable sites, which are intended to move approximately every 5 years to capture variation within a domain and address regional questions of interest. Sites were selected to represent the greatest degree of characteristic ecological attributes of the corresponding domains. Core sites typically consist of ecosystems that are minimally impacted by anthropogenic stressors. Relocatable sites may be in areas impacted by anthropogenic stressors and are usually paired with either core sites or other relocatables to allow contrasting measurements between impacted and relatively intact ecosystems. The data collected from all sites may be used to extrapolate relationships that identify the driving causes of long-term ecological changes to areas not sampled but where partial, extensively sampled, or gridded information is available.

Currently, the candidate aquatic sites in the NEON network include 26 wadable streams, three nonwadable rivers, and seven lakes representing characteristic aquatic ecosystems among a majority of North American ecoregions (Table 1, Figures 3 and 4). Sites are considered as candidates until a land use agreement is obtained. NEON aquatic site selection is informed by external scientific input from those familiar with the respective domain and follows the same criteria of terrestrial and atmospheric site selection: core sites are situated in relatively intact watersheds, whereas relocatable sites may be anthropogenically impacted. Wherever possible, aquatic sites are located adjacent to (i.e., <5 km) NEON tower and terrestrial sites to help couple data among ecosystems. NEON lotic ecosystem sizes range from small, first-order, fishless streams to large rivers that support highly diverse fish communities. The network of sites in Domain 8, the Ozarks Complex, may prove particularly valuable for fisheries and aquatic ecosystem science because they consist of three sites with nested catchments of various sizes within a large river watershed. Domain 8 sites were specifically selected to span the river continuum (Vannote et al. 1980) of the Tombigbee River watershed and include reaches with more than 100 recorded fish species.

The NEON Structure: Current and Future

NEON is an NSF-funded project managed and maintained by an independent, nonprofit corporation (NEON, Inc.) implemented through the Large Facilities Office (LFO). Examples of well-known observatories managed under this program include the Arecibo and Gemini Satellite Observatories. Programs implemented through the LFO typically undergo a multiyear review process with incremental developmental steps prior to operations termed the major research equipment and facilities construction (MREFC) process. Construction funds were awarded in fiscal year 2011; a 5-year construction phase (where sites are fitted with sensors and data collection begins) followed by a 30-year operations phase is now set to ensue. Within each domain, NEON crews stationed in local offices will perform field operations. Central NEON headquarters is located in Boulder, Colorado.

All data will be posted on an open-access, NEON-maintained Internet portal. The portal system will include comprehensive search interfaces, filtering capabilities (e.g., searching within regional and/or date criteria), and decision-support functions to help investigators become fully aware of all available data pertinent to their inquiries. The data acquisition portal is currently under development and many design specifications have yet to be finalized. However, NEON will collaborate with several existing data management initiatives, such as the National Water Quality Monitoring Council and BioOne, to assist with portal development. External researchers will also be consulted to help maximize data portal functionality. Regardless of the final design, an open-source metadata structure and provenance process will ensure that users understand where and how all data are derived. All data will undergo stringent quality assurance/quality control product definition, statistical, and modeling analysis to ensure the identification of erroneous readings. Wherever possible, data will be cross-checked using related sensors or measurements among the NEON data streams. Researchers and the public will be able to access NEON-derived design and protocol documents using the web portal to ensure data comparability and methodological repeatability outside of the observatory. For instance, the standardized, peer-reviewed field protocol applied for fish sampling will be downloadable so that reliably comparable data may be collected elsewhere.

Educational resources and tools are being developed at NEON to ensure that observatory-generated information, including data, is accessible and usable for all interested users. In partnership with stakeholder communities, NEON will employ a variety of approaches to engage communities in the scientific process. Planned educational activities include social media applications, online learning modules, citizen science projects, student research and internship programs, short courses, and workshops to help individuals at all levels of professional development effectively use observatory-generated data. Graduate students from any institution will be able to participate in a competitive field and data analysis course to help familiarize themselves with NEON resources. The NEON web portal will be an interface to many educational resources, including online learning modules for students hoping to use NEON data. Citizen science programs will enable participants to collect, contribute, interpret, and visualize scientific data that may significantly contribute to scientific inquiry. Project Budburst, the first among such initiatives (comanaged by the Chicago Botanical Garden and NEON), provides an interface for amateur botanists to report the dates of phenological events such as leaf out and senescence at any location. Interested researchers may now access thousands of phenological event data recorded across the country over the past 4 years.

NEON aims to be a dynamic and valued resource by actively encouraging the scientific community to develop research projects that leverage NEON data, facilities, and infrastructure. Currently, the NSF Macrosystems Biology program, supporting research on biological systems at regional to continental scales, is a principal avenue for fostering scientific collaboration with NEON. Other NSF funding programs that have encouraged NEON collaboration to date include the Research Coordination Networks and Campus Cyberinfrastructure–Network Infrastructure and Engineering Program. New collaborative efforts that leverage NEON may also be funded by agencies other than NSF or nongovernmental institutions. Proposals that include the use or leveraging of NEON assets may be submitted by universities, nonprofit institutions, non-academic organizations, or federal agencies. Decisions regarding the use of NEON assets in novel work will be assessed for technical and logistical feasibility by NEON staff in accordance with policies and procedures currently in development and subject to NSF approval. Quantitative, interdisciplinary, and systems-oriented research on biological processes and their interactions with environmental change at continental scales will be particularly encouraged. Smaller scale initiatives, including new technology testing and implemention, will also be possible and promoted through collaborations with NEON scientists. Finally, collaborative research may be fostered through student internships with individuals mentored by both external and NEON scientists.

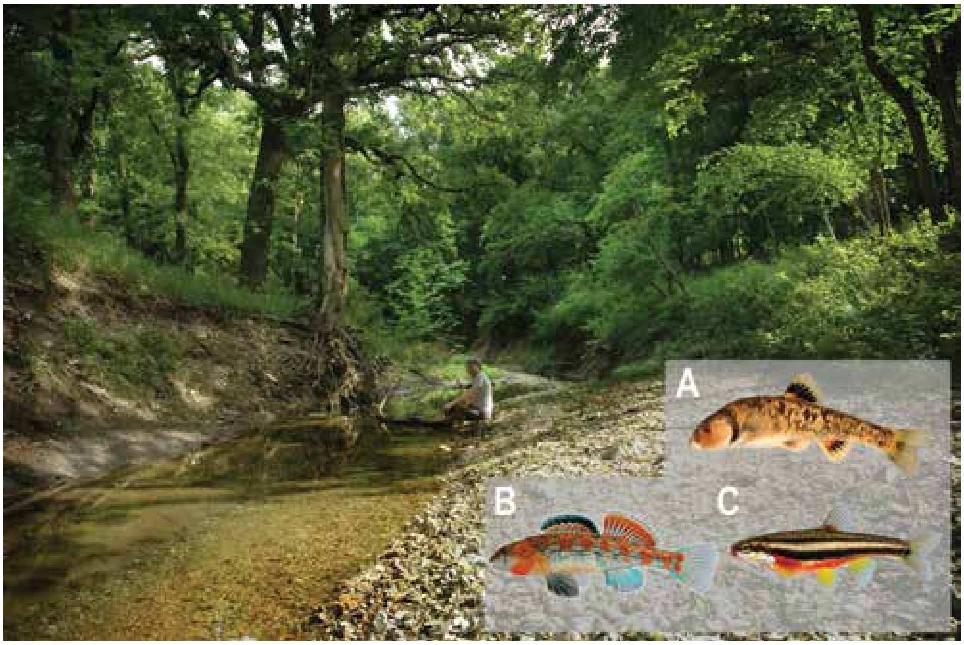

Figure 3. Kings Creek, a NEON candidate core aquatic and STREON site located within the Konza Prairie Biological Station near Manhattan, Kansas. NEON will collect population estimates of fishes, including (A) central stoneroller, (B) orangethroat darter, and (C) southern redbelly dace in Kings Creek for 30 years. Additionally, data from the STREON experiment will allow any interested researcher to explore how populations of these fishes respond to chronic nutrient enrichment and how their extirpation might impact ecological processes in the benthic zone.

Figure 4. Map of NEON North American domains and locations of aquatic sites in the observatory. Site numbers correspond to those listed in Table 1.

Successful analyses and forecasting in fisheries science at broad scales amid pervasive global environmental change will require unprecedented scientific resources. NEON aims to become a transformative tool in the ecological sciences by providing high-quality, nonproprietary, and comprehensive data across spatiotemporal scales beyond the capabilities of individual laboratories. The combined suite of aquatic, terrestrial, and atmospheric data generated by NEON will particularly enhance investigations of material and energy exchanges across apparent ecosystem boundaries, which are increasingly recognized as critically important in aquatic ecosystems (Lamberti et al.

2010). To learn more about NEON, including the observatory structure, data products, working group members, and construction updates, please visit the NEON website (neoninc.org).

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SIUC Subunit Blends Research and Service in Pursuit of Professional Development

Carlin Fenn, Jeffrey Hillis, and Jesse Trushenski

Center for Fisheries, Aquaculture and Aquatic Sciences, Southern Illinois University Carbondale, Carbondale, IL 62901.

Members of the Southern Illinois University Carbondale (SIUC) Subunit of the Illinois Chapter of the American Fisheries Society take a multi-faceted approach to promote the conservation of aquatic resources through personal, professional, and community development. From teaching youths about aquatic ecology and fish identification, to the development of the inaugural "Carp-A-Thon" for area anglers, the SIUC IL-AFS Subunit serves as an important community resource. This past year alone, members planned and participated in well over a dozen fisheries-related outreach events, including the Illinois Department of Natural Resources' Urban Fishing program, where members had the chance to introduce youngsters to the joys of angling and the importance and value of the great outdoors.

Opportunities abound for Subunit members to develop their fisheries and interpersonal skills by electrofishing area lakes, generating stock assessment reports, and presenting their findings to anglers and members of the community. This year, members experienced a unique opportunity to culture freshwater prawn as part of an SIUC-sponsored research project. At the end of the summer, the tasty crustaceans were harvested and sold to students and faculty of SIUC and greater Southern Illinois community as a fundraiser for the Subunit. Additionally, members gained pond-culture experience, learned about prawn biology, and collected data for a bioenergetics study.

The next few months are an exciting time for the SIUC IL-AFS Subunit, as members are currently developing monthly workshops to give new students out-of-the-classroom learning opportunities in electrofishing, lab and culture techniques, pond management, and boat maintenance, safety, and operation. These opportunities build professional skill sets, human and resource networks, and a sense of camaraderie among both new and old members of the fisheries community at SIUC. The SIUC Subunit also serves as an important means of mentoring undergraduate students by incorporating real field and lab experiences to supplement traditional classroom-style learning. Graduate students benefit from undergraduate assistance that is always available. This relationship is important to the growth of the program and describes the Subunit's mission. Encouraging academic excellence, robust research productivity, and community service are the focus of the SIUC IL-AFS Subunit. In addition to serving locally, the Subunit also has a history of helping the Illinois Chapter and AFS Sections at various levels. Through the Subunit, members feel a connection to our local cadre of fish-heads, as well as AFS and the broader fisheries community.

To learn more about the SIUC IL-AFS Subunit, please visit their website at http://fishstudent.rso.siu.edu. For more information on establishing a Student Subunit at your college or university, contact your state AFS Chapter.

(Left): SIUC IL-AFS member Jake Norman instructs beginning anglers on how to properly cast a rod and reel during the 2012 Illinois Department of Natural Resources' Urban Fishing program. Through this vital community resource, many children had the opportunity to catch their first fish, thus generating a newfound enthusiasm for fishing within the youngest members of the Southern Illinois community. (Center): From May through September 2012, SIUC IL-AFS members cultured freshwater prawn in SIUC-provided ponds. Members harvested the prawn in late September, and sold them by the pound as a fundraiser for the Subunit. Not only did Subunit members witness how tasty freshwater prawn are, but they also gained experience on data collection for a bioenergetics study and learned about prawn biology and pond culture techniques. Above, SIUC IL-AFS member and prawn fundraiser organizer Bonnie Mulligan holds a "blue claw" male prawn during the harvest. (Right): SIUC IL-AFS member and past-president John Bowzer holds a contestant's carp entry for the 1st annual Southern Illinois "Carp-A-Thon". The fishing tournament was sponsored in part by the SIUC IL-AFS, and served as both a platform to both raise awareness of the Bighead and Silver carp infiltration of local waterways and a fundraiser for the Subunit. Prizes were awarded to the anglers for "Biggest Carp" and "Top Ten Heaviest Fish."

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American Fisheries Society Adopts New Policy, Encourages Efforts to Understand and Limit Effects of Lead in Sport Fishing Tackle on Fish and Wildlife

Jesse Trushenski and Paul Radomski

American Fisheries Society, Resource Policy Committee

In October of 2012, the American Fisheries Society (AFS) voted to adopt a new policy statement on "Lead in Sport Fishing Tackle." Like all AFS policies, this document represents the collective voice of the oldest, largest, and most influential professional organization dedicated to the fisheries sciences. The new policy draws attention to the negative effects of lead in the environment and encourages scientists, regulatory authorities, tackle manufacturers, the sport fishing community, and other stakeholders to work together to understand and limit any negative effects of lead-based tackle (e.g., sinkers, jigs) on fish and other organisms.

Lead is a naturally occurring but toxic element. Because of its negative effects on human and animal health, lead is banned in products such as gasoline, paint, and solder in many countries. However, lead is still commonly used in fishing tackle because it is readily available, dense, malleable, and inexpensive. Though lost fishing tackle can remain intact and relatively stable for decades or centuries in aquatic systems, if ingested by animals, the lead in these products becomes more biologically available and can result in lethal exposures. The effects of ingesting such tackle were established in waterbirds in the 1970s and 1980s, following lead poisoning events in localized populations of loons and swans. Although population-level effects have not been unequivocally demonstrated and lost tackle represents a relatively small fraction of the total amount of lead found in the environment (surface runoff, atmospheric deposition, and mining activities are more significant sources), given the likelihood of ingestion and the magnitude of organism-level effects of exposure following ingestion, it would seem prudent to assess, understand, and limit the negative effects of lead in sportfishing tackle on fish and other aquatic organisms.

This issue was reviewed by members of the AFS Resource Policy Committee (RPC), under the principal leadership of Paul Radomski, Tom Bigford, and Jesse Trushenski. In cooperation with a special committee established by then AFS President Wayne Hubert, Radomski and the other members of the RPC prepared a draft policy statement. Following review by the AFS RPC, governing board, and membership at large, the Society adopted the policy, calling for stakeholders to address the potential effects of lead in sportfishing tackle on fish populations.

Accordingly, the policy of the AFS, in regard to lead in sport fishing tackle, is to

1. Recognize that lead has been known for centuries to be toxic to biological organisms. Thus, the loss and subsequent ingestion of lead sinkers and jigheads by aquatic animals and the potential ramifications of lead ingestion is a natural resource management issue.
2. Understand that the impact of ingested lead on individuals of certain waterfowl species is generally accepted, but population-level impacts on fish and wildlife species are not well documented. Although conclusive scientific proof of these effects is not currently available, actions to inform, educate, and encourage sportfishing tackle manufacturers, users, and researchers to reduce future introductions of lead into aquatic ecosystems appears advisable. Accordingly, collaborate with fish and wildlife professionals, tackle manufacturers, anglers, policy makers. and the public to encourage the use of non-lead forms of small fishing sinkers and jigheads that are protective of potentially affected fish and wildlife populations.
3. Encourage scientifically rigorous research on lead tackle aimed at generating toxicological and environmental chemistry data including bioavailability assessments; support monitoring and modeling of exposure and effects on at-risk populations; encourage studies predicting consequences of exposure and long-term population-level effects of different tackle material; and encourage studies on reducing the economic and social barriers to nontoxic fishing tackle development and use.
4. Recognize that the hunting and angling communities can be important advocates and forces of change regarding natural resources issues and support educational efforts to promote greater public awareness and understanding of the consequences of lead exposure in wildlife species and the potential gains in environmental quality from use of lead-free fishing tackle.
5. Update policy language as focused research provides additional data on lead tackle-related impacts.

To read the full text of the new policy statement or any of the society's current policies, please visit the American Fisheries Society online at http://fisheries.org/policy_statements.

Fisheries 2013 Guide for Authors

MISSION STATEMENT

Fisheries is the monthly peer-reviewed membership publication of the American Fisheries Society (AFS). Its goal is to provide timely, useful, and accurate information on fisheries science, management, and the fisheries profession for AFS members. Some types of articles which are suitable for *Fisheries* include fishery case histories, review or synthesis articles covering a specific issue, policy articles, perspective or opinion pieces, essays, teaching case studies, and current events or news features. We particularly encourage the submission of short-form (under 5 typeset pages) "mini-review" articles. Our goal is to move towards four science-based papers in each issue. We will waive page charges for even shorter articles (under 2 typeset pages) on such articles as current events in fisheries science, interviews with fisheries scientists, history pieces, informative how-to articles, etc. We also encourage articles that will expose our members to new or different fields, and that recognize the varied interests of our readers. Research articles may be considered if the work has broad implications or applications and the subject matter can be readily understood by professionals of a variety of backgrounds. *Fisheries* is the Society's flagship publication and is the mostly widely read fisheries science publication in the world. Accordingly, content submitted for consideration should appeal broadly to fisheries professionals and speak to the interests of the AFS membership. Lengthy, highly technical, or narrowly focused research articles are better suited to the AFS technical publications, and we encourage authors to consider the other AFS journals as venues for these works.

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***IMPORTANT**

The maximum length of articles accepted in *Fisheries* is 10 typeset pages (including photos, figures, tables, pull quotes, titles, translations, etc.). One full page of article text with absolutely no figures, tables, pull quotes, titles, headers, translations, or photos is approximately 880 words or 6100 characters including spaces. Please adhere to this standard, taking figures and other non-text content into consideration, when preparing manuscripts for submission to *Fisheries*.

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We encourage submission of topical manuscripts of broad interest to our readership that address contemporary issues and problems in all aspects of fisheries science, management, and policy. Articles on fisheries ecology and aquatic resource management; biology of fishes, including physiology, culture, genetics, disease, and others; economics and social issues; educational/administrative concepts, controversies, techniques, philosophies, and developments; and other general interest, fisheries-oriented subjects will be considered. Policy and issue papers are welcome, particularly those focusing on current topics in fisheries policy. As noted above, we are particularly interested in mini-reviews, which should concisely but comprehensively summarize a topic under 5 typeset pages or less. Papers are judged on scientific and professional merit, relevance, and interest to fisheries professionals. Features and perspectives generally should not exceed 4,500 words (excluding references and tables) and should not cite more than 40 references. Please consult the managing editor PRIOR to submission for a length or reference limit exemption for review articles or articles of Society-wide significance.

Please submit your manuscript online using our manuscript tracking website at http://mc.manuscriptcentral.com/fisheries. If you cannot submit your manuscript online, please e-mail or phone the managing editor, Sarah Fox, for instructions: sgilbertfox@fisheries.org or 301-897-8616 x220 (for fastest response, please e-mail).

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Essays are thought-provoking or opinion articles based upon sound science. Essays may cover a wide range of topics, including professional, conservation, research, AFS, political, management, and other issues. Essays may be submitted in conjunction with a full feature article on the same topic. Essays can be up to 2,000 words, may include photographs or illustrations, and should not cite more than eight references. However, essays should provide scientific documentation, unlike unreviewed opinion pieces (below). Essays are peer-reviewed based on the following criteria: contribution to the ongoing debate, logical opinion based on good science, persuasiveness, and clarity of writing. Reviewer agreement with the opinion of the views expressed is not a criterion. Essays do not have page charges or abstracts. Essays should be formatted and submitted online as described above.

Fisheries Education

Fisheries will consider publication of case studies and other articles specifically intended as teaching tools. These articles, including case studies or short topical summaries, should be formatted to be used for teaching aids for courses taught at the undergraduate level. Fisheries Education articles should be readily understood by undergraduate students with basic training in biological/ecological sciences, and include background information, discussion questions, teaching notes, and references. Peer review of teaching case studies and educational topics will be handled by a special committee of the AFS Education Section.

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- Authors are strongly encouraged to submit a word processing file in either Word or plain text format.
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- The cover letter should explain how your paper is innovative, provocative, timely, and of interest to a broad audience. It should also include a list of potential reviewers who can provide an unbiased, informed, and thorough assessment of the manuscript. The cover letter can also be used to provide further explanation, if part of the information has been published or presented previously.
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- Leave at least a 1-in margin on all sides. Indent all paragraphs. Number pages sequentially and use continuous line numbering,
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- The first mention of a common name should be followed by the scientific name in parentheses. Our standard is C*ommon and Scientific Names of Fishes from the United States, Canada, and Mexico, 7th edition*.
- Define abbreviations the first time they are used in the text.
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- Avoid footnotes by including the information in the text.

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- Tab between column items — DO NOT "space" between columns.
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Calendar items should include, in this order: the date, event title, location, and contact information (including a website, if there is one), and should be sent to the editor at sgilbertfox@fisheries.org.

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University of Victoria,
PO Box 3020, Station CSC,
Victoria, BC, V8W 3N5
Canada.
Tel: (250) 721-6227.
E-mail: juanes@uvic.ca

QUESTIONS?

Sarah Fox, Managing Editor
American Fisheries Society
5410 Grosvenor Lane, Suite 110
Bethesda, MD 20814-2199
301-897-8616, ext.220
sgilbertfox@fisheries.org
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The Four Fs of Fish: Communicating the Public Value of Fish and Fisheries

Abigail J. Lynch and William W. Taylor

Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824-1222.
E-mail: lynchabi@msu.edu, taylorw@msu.edu

"Fish? Why fish?!" This is a common question we are often asked by those outside our field upon learning our profession. They are curious as to why we devote our lives to the study, conservation, restoration, and propagation of fish and associated habitats. This question can come anywhere and at any time. Though it is a common inquiry, do we, as professionals and as a profession, have a good answer?

Effectively demonstrating the value of fish and the fisheries supply chain they create is as important for the future of our own profession as for the fish. This, however, is no easy task. The average American eats approximately 15.8 pounds of fish and shellfish per year (NOAA 2010) and less than 14% of adult Americans report that they participate in recreational fishing (USFWS 2012). So, in general, Americans have little to no direct interaction with fish. In spite of this, our role as fisheries professionals is to clearly articulate to the public and policy makers that fish are important and have value – locally, regionally, nationally, and internationally. Such demonstration of public value ensures that fish and fisheries are afforded appropriate consideration in decision making – from the dinner table to the United Nations general assembly floor. Fish are important; no, they are more than important. They are essential to the survival of mankind. Fish, after all, directly or indirectly contribute to subsistence, livelihoods, health, and prosperity for much of the world.

As fisheries professionals, we are all passionate about fish. This personal and professional passion emanates for many different reasons, as shown by the diversity of the American Fisheries Society sections and membership. However, our drive is often hard to explain to someone who doesn't share the same interest and wonder for fish, their habitats, and fisheries.

We [*the authors*] propose "The Four Fs of Fish": Food, Finances, Fun, and Function as a means to effectively communicate the public value of fish and fisheries. Surely, there are other values, but these four can start the discussion and hone our passion into something tangible to the public and policy makers.

FOOD

Perhaps the most direct argument to make in support of the importance of fish and their habitats is food. Capture fisheries are the last large-scale wild food resource in the world and aquaculture is a quickly growing sector. Both provide essential protein and nutrients to many across the globe. Fish directly provide more than 1.5 billion people with almost 20% of their animal protein and another 3.0 billion with at least 15% (FAO 2010). This equates to more than 40% of the world's human population.

Fish are also an important indirect source of protein for many others who generally do not realize it. Approximately 12.4% of global fishery production is reduced to fish meal and fish oil (FAO 2009), which is subsequently formulated into specialized feed for livestock and aquaculture operations. So, choosing between chicken and fish as meal options may, in fact, be choosing fish or reprocessed fish. We can do a better job of emphasizing the role of fish in other protein sources. For example, instead of asking "how's the chicken?" to someone enjoying a piece of fried chicken, ask "how's the fish?" By helping people understand the supply chain that leads to their meals, we will help them appreciate the importance of fish as a food source that provides healthy, nutritious meals for many at local and global scales.

FINANCES

People recognize the importance of economic impact or, as the old adage goes, money talks and employment walks. First-sale value of global capture fisheries production and aquaculture is approximately US$93.9 billion and US$98.4 billion, respectively, and US$192.3 billion, collectively (FAO 2010). Numbers that large can seem intangible, but the first-sale of value of fisheries basically equates to one-seventh of the U.S. Gross Domestic Product.

More than strict monetary value, fisheries are significant sources of employment, income, and livelihood. Globally, 44.9 million people are directly engaged in capture fisheries or in aquaculture (FAO 2010). So, fisheries employ over 20 times more people than Walmart, the world's largest private employer. Taking families and dependents into account, fisheries are an important source of income and livelihood for 8% of the world's population, around 540 million people (FAO 2010). And, these are just minimum estimates. These Food and Agriculture Organization of the United Nations (FAO) statistics are very likely a gross underestimate of their full value because obtaining accurate capture and employment statistics on small-scale fisheries, the bulk of the world's fisheries, is difficult as they are highly dispersed and underreported (Cochrane et al. 2011).

FUN

Fish, lest we forget, also provide fun. Recreational fishers, snorkelers, SCUBA divers, and hobby aquarists seek enjoyment and relaxation through interacting with fish and their habitats. Though we cannot over-emphasize the value of these experiences to the individuals who find fish fun, the financial value of recreation can be understood even by those choosing not to engage in these types of activities. In 2011, for example, American anglers spent $41.8 billion in support of fishing activities (e.g., trips, equipment, licenses; USFWS 2012). Even those who have never picked up a fishing rod or visited an aquarium can appreciate the employment and economic stimulus generated by recreational fishing and fish watching.

Fish are important components of most human systems. While some cultural values, like recreation and tourism, can be translated into economic impact, other religious, spiritual, or artistic values are more difficult to assess economically. Nonetheless, fish are symbolized in every major world religion and the natural beauty of aquatic ecosystems is commonly evoked in art.

FUNCTION

Without question, fishes are the most diverse, numerous group of vertebrates on the planet. The estimated 27,977 species of fishes make up more than half of the approximate 54,711 recognized living vertebrate species (Nelson 2006) and occupy almost all major aquatic habitats (Helfman et al. 2009). In this role, fishes are a particularly important taxa for biodiversity conservation and resilience of ecosystems to change (Naeem 2012). As such, they often serve as symbols of the health and integrity of their habitats. They are, for all practical purposes, the aquatic version of "canaries in a coal mine." Fish are critical links in aquatic systems – indicators of ecosystem health and a litmus test of what the potential impacts could be for humans.

For people who fish, eat fish, or recreate in aquatic environments, the value of fish and fisheries is an easy sell. They use and appreciate the resource and want to ensure that fish will be around for them and future generations to use. But, demonstrating the value of fish to those who have no direct contact with them can be daunting, especially when negotiating tradeoffs for water security, agriculture, power generation, and other sectoral interests. As a whole, we, as professionals can be better communicators. We need to be cognizant that others may not share our passion for fish and we must provide them with a clear rationale of why fish and their habitats should be important to them: Food, Finances, Fun, and Function. Our future and that of fishes depend on us to do just that – make fish meaningful and important to all!

Fast Stats

Food

- 3.0 billion people (>40% of global population) depend directly on fish as an important source of protein.

Finances

- 540 million people (8% of global population) depend upon fishery industries for livelihood and income.

Fun

- Anglers in the United States spend over $40 billion in support of fishing activities annually.

Function

- Fishes comprise more than half of all vertebrate species and occupy all major aquatic habitats.

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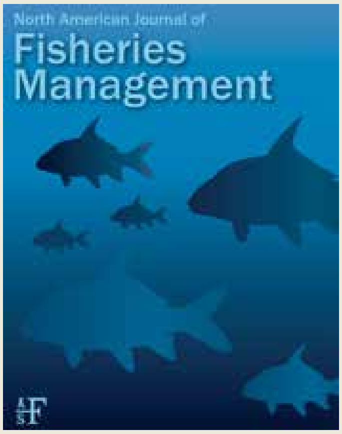
JOURNAL HIGHLIGHTS

North American Journal of Fisheries Management, Volume 32, Number 6, December 2012



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[Management Brief] Latitudinal Influence on Age Estimates Derived from Scales and Otoliths for Bluegills. *Lucas K. Kowalewski, Alexis P. Maple, Mark A. Pegg, and Kevin L. Pope. 32: 1175–1179.*

Privately Owned Small Impoundments in Central Alabama: A Survey and Evaluation of Management Techniques for Largemouth Bass and Bluegill. *Norman V. Haley III, Russell A. Wright, Dennis R. DeVries, and Micheal S. Allen. 32: 1180–1190.*

Frequency of Strong Year-Classes: Implications on Fishery Dynamics for Three Life History Strategies of Fishes. *Daniel J. Daugherty and Nathan G. Smith. 32: 1191–1200.*

[Management Brief] Sex at Length of Summer Flounder Landed in the New Jersey Recreational Party Boat Fishery. *Jason M. Morson, Eleanor A. Bochenek, Eric N. Powell, and Jennifer E. Gius. 32: 1201–1210.*

A Comparative and Experimental Evaluation of Performance of Stocked Diploid and Triploid Brook Trout. *Phaedra Budy, Gary P. Thiede, Andrew Dean, Devin Olsen, and Gilbert Rowley. 32: 1211–1224.*

Inferring Adult Status and Trends from Juvenile Density Data for Atlantic Salmon. *Heather D. Bowlby and A. Jamie F. Gibson. 32: 1225–1236.*

Assessing Avian Predation on Juvenile Salmonids using Passive Integrated Transponder Tag Recoveries and Mark–Recapture Methods. *Danielle Frechette, Ann-Marie K. Osterback, Sean A. Hayes, Morgan H. Bond, Jonathan W. Moore, Scott A. Shaffer, and James T. Harvey. 32: 1237–1250.*

Strategies to Control a Common Carp Population by Pulsed Commercial Harvest. *Michael E. Colvin, Clay L. Pierce, Timothy W. Stewart, and Scott E. Grummer. 32: 1251–1264.*

Expanding Aerial–Roving Surveys to Include Counts of Shore-Based Recreational Fishers from Remotely Operated Cameras: Benefits, Limitations, and Cost Effectiveness. *C. B. Smallwood, K. H. Pollock, B. S. Wise, N. G. Hall, and D. J. Gaughan. 32: 1265–1276.*

Continued from page 3

registration fees to compensate the instructor and pay for the technology required to deliver the course effectively and add some funds to the AFS coffers.

No doubt, what I have prescribed for the Special Committee on Educational Requirements and the Continuing Education Committee is a lot of work for a set of volunteers and will likely take several years to accomplish. The tasks should probably become a matter of routine for the AFS, undertaken every 5–10 years to ensure that students and career professionals being trained in fisheries-related disciplines have the right educational foundation for meeting the challenges that lie ahead.

STUDENT FUNDING AVAILABLE

American Institute of Fishery Research Biologists (AIFRB)

Clark Hubbs Research Assistance Award

A benefit of AIFRB membership for students and associate members:

The Hubbs Research Assistance Award was established in 1986 to support travel expenses associated with professional development for AIFRB graduate students and other Associate members of the Institute in good standing. The award covers travel expenses associated with presenting results of an original research paper or research project of merit at scientific meetings or to conduct research at distant study sites. Each award is a maximum of $500; an individual may receive two awards in a lifetime. The number of awards varies each year depending on the annual budget approved by the Board. **Since 1986, a total of 154 awards have been given, including four in 2012, three of which funded student travel to present at this year's AFS meeting.**

NOMINATIONS are due JUNE 15 of each year
To apply for an award: send a research abstract, letter of support from the student's sponsor, and a two-page curriculum vitae, to:

Dr. Jerald S. Ault
University of Miami
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
Miami, FL 33149
or via email to jault@rsmas.miami.edu

for more information, visit www.aifrb.org

CALENDAR
Fisheries Events

To submit upcoming events for inclusion on the AFS web site 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

DATE	EVENT	LOCATION	WEBSITE
February 5–7, 2013	32nd International Kokanee Workshop	Fort Collins, CO	Jesse Lepak at Jesse.Lepak@state.co.us
February 7–8, 2013	Winter Fisheries Training for Acoustic Tag & Hydroacoustic Assessments	Seattle, WA	www.HTIsonar.com/at_short_course.htm
February 14–15, 2013	Using Hydroacoustics for Fisheries Assessment		www.HTIsonar.com/at_short_course.htm
February 21–25, 2013	Fish Culture Section Mid-Year Business Meeting	Nashville, TN	www.was.org/WasMeetings/meetings/Default.aspx?code=AQ2013
February 21–25, 2013	Aquaculture 2013	Nashville, TN	www.was.org/WasMeetings/meetings/Default.aspx?code=AQ2013
March 13–16, 2013	31st Annual Salmonid Restoration Conference	Fortuna, CA	http://www.calsalmon.org/salmonid-restoration-conference/31st-annual-salmonid-restoration-conference
March 26–29, 2013	Responses of Arctic Marine Ecosystems to Climate Change Symposium	Anchorage, AK	seagrant.uaf.edu/conferences/2013/wakefield-arctic-ecosystems/index.php
April 8–12, 2013	7th International Fisheries Observer and Monitoring Conference (7th IFOMC)	Viña del Mar, Chile	www.ifomc.com/
April 15–18, 2013	Western Division of the AFS Annual Meeting	Boise, ID	www.idahoafs.org/meeting.php
April 25–26, 2013	NPAFC 3rd International Workshop on Migration and Survival Mechanisms of Juvenile Salmon and Steelhead in Ocean Ecosystems	Honolulu, HI	http://www.npafc.org/new/index.html
June 24–28, 2013	9th Indo-Pacific Fish Conference	Okinawa, Japan	http://www.fish-isj.jp/9ipfc
July 14–20, 2013	2nd International Conference on Fish Telemetry	Grahamstown, South Africa	Contact: Dr. Paul Cowley at tagfish@gmail.com
August 3–7, 2014	International Congress on the Biology of Fish	Edinburgh, United Kingdom	http://icbf2014.sls.hw.ac.uk

ANNOUNCEMENTS
January 2013 Jobs

Employers: to list a job opening on the AFS online job center submit a position description, job title, agency/company, city, state, responsibilities, qualifications, salary, closing date, and contact information (maximum 150 words) to jobs@fisheries.org. Online job announcements will be billed at $350 for 150 word increments. Please send billing information. Listings are free (150 words or less) for organizations with associate, official, and sustaining memberships, and for individual members, who are faculty members, hiring graduate assistants. if space is available, jobs may also be printed in *Fisheries* magazine, free of additional charge.

Modeler/Biometrician
Cramer Fish Sciences; Auburn, CA
Permanent

Salary: $5,265–$6,046 monthly, plus bonuses; excellent benefits

Closing: Until filled

Responsibilities: CFS seeks an individual with very strong quantitative and programming skills. Expertise in developing and analyzing individual/agent based models using NetLogo or other modeling platforms is highly desirable. Knowledge and experience with other statistical analyses, programming languages, and with ecology and resource management is a plus. Must be able to collaborate with biologists to develop simulation models and quantitative assessments for ecological data.

Qualifications: Ph.D. or M.S. with one or more years of experience with simulation modeling and statistics. Strong technical writing and advanced computer skills.Experience leading small to moderate sized projects. Highly-motivated, self-starter who can work independently and as part of a team. Speak and write English fluently.

Contact: E-mail cover letter and resume to below email Full job announcement at: www.fishsciences.net

Email: hr@fishsciences.net

Vice President of Conservation & Science
Monterey Bay Aquarium, CA
PhD

Salary: Competitive

Closing: Until filled

Responsibilities: The Vice President is responsible for overall leadership of the aquarium's Conservation and Science Division and is a member of the senior leadership team of the aquarium. The current activity areas in this division include Seafood Watch, ocean conservation policy and conservation research. For a full position description & details on how to apply please go to explorecompany.com.

Qualifications: Strong scientific background is required, particularly in the areas of ecology, marine biology, or conservation science. Ph.D. in Ecology, Biology, Natural Resources, Environmental Science or a closely related field desirable.

Email: resumes@explorecompany.com

Link: http://www.montereybayaquarium.org

Journal Editor
AFS, Bethesda, MD
Professional

Salary: Editors receive an honorarium, and support to attend the AFS Annual Meeting.

Closing: Until filled

Responsibilities: : AFS Seeks Journal Editor

The American Fisheries Society (AFS) seeks a scientist with a broad perspective on fisheries to serve as editor of North American Journal of Fisheries Management (NAJFM). Editor must be committed to fast-paced deadlines, and would be appointed for a five-year renewable term which begins January 2013.

Duties include:

1. Deciding on the suitability of contributed papers, and advising authors on what would be required to make contributions publishable, using advice of associate editors and reviewers. Reviewing papers for scientific accuracy as well as for clarity, readability, and interest to the broad fisheries community;

2. Soliciting manuscripts to ensure broad coverage;

3. Setting editorial standards for NAJFM in keeping with the objectives of the publication in accordance with AFS policies, and guidance provided by the Publications Overview Committee and the NAJFM editorial board;

4. Making recommendations to enhance the vitality and prestige of the Journal.

Qualifications: This position requires marine and estuarine fisheries expertise.

Contact: To be considered, send a current curriculum vitae along with a letter of interest explaining why you want to be the Journal editor to below email alerner@fisheries.org. To nominate a highly qualified colleague, send a letter of recommendation to the same e-mail address.

Email: alerner@fisheries.org

Regional Program Manager
WA State Dept of Fish & Wildlife
Permanent

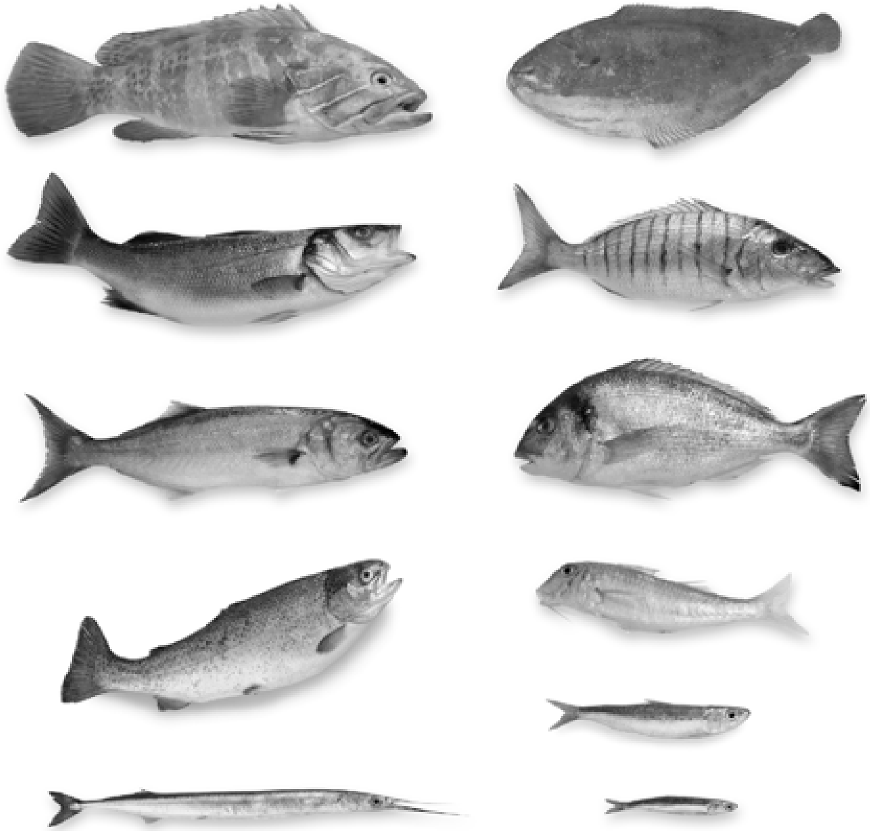
Salary: $5712.00–$7140.00

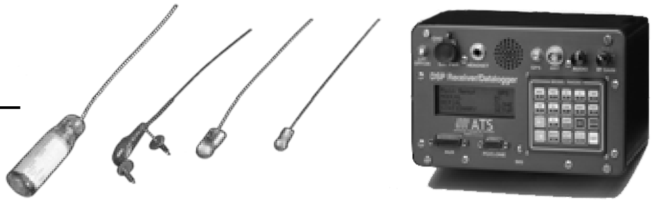
Closing: Until filled

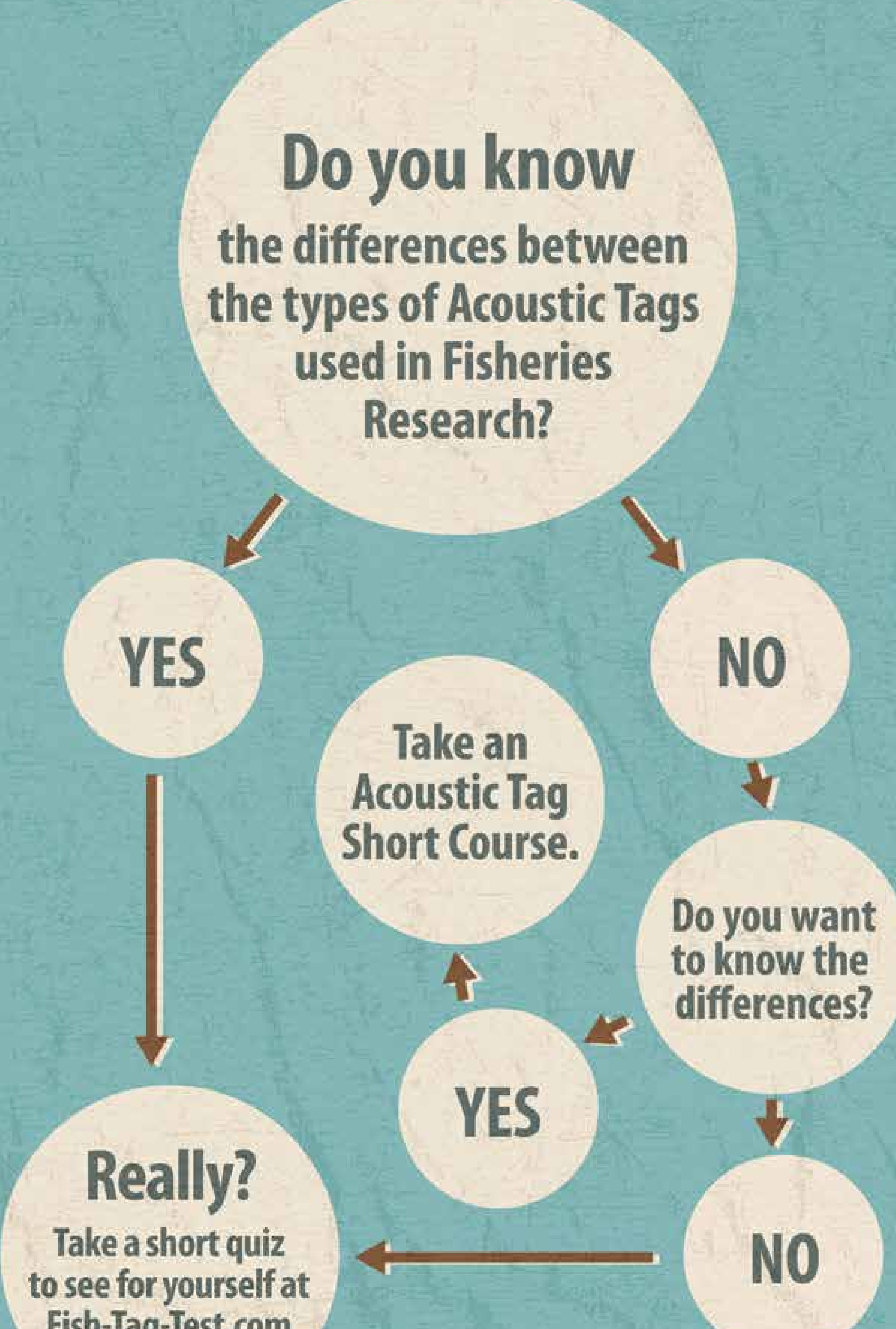
Responsibilities: The official duty station is Vancouver, WA. This position reports to the Deputy Assistant Director for the Fish Program. This position leads, controls, and directs regional operations for the Fish Management and Hatcheries activities and project including: staff, budgets and programs in Region 5.

Contact: To Apply: For more information see the WDFW Employment Page for a complete listing at. This will explain job duties, minimum qualifications, competencies and desirable qualifications. If you have questions about this recruitment, you may contact Margaret Gordon, Recruitment Specialist at 360 902-2209.

Link: http://wdfw.wa.gov/employment/index.htm







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