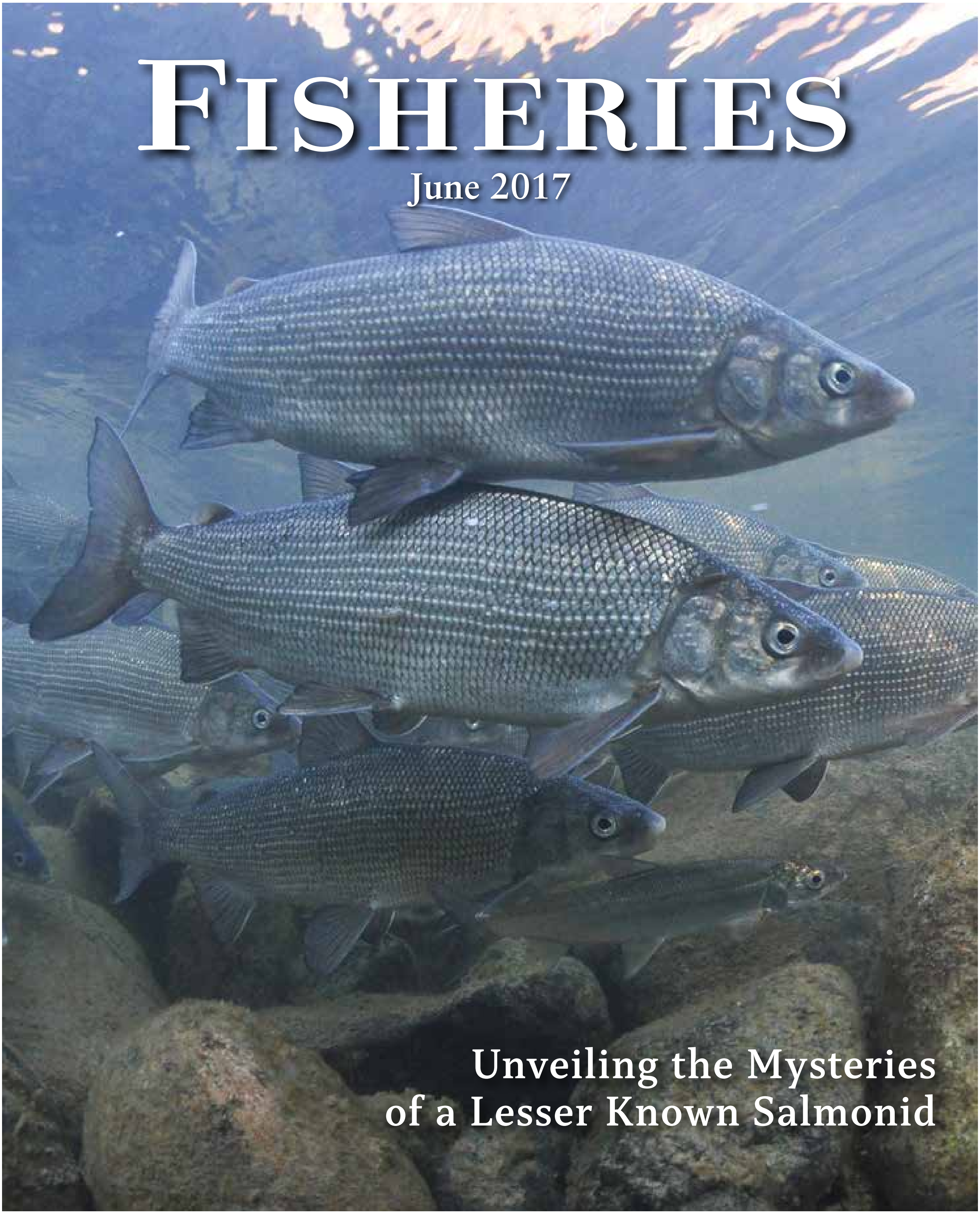
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of a Lesser Known Salmonid

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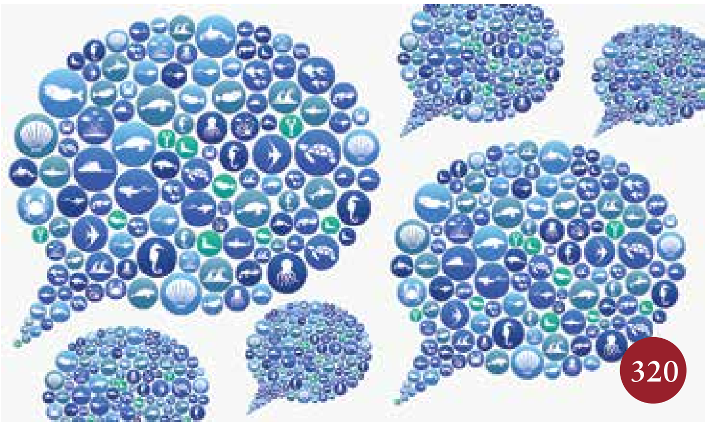

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COVER

Freshwater whitefishes (*Coregonus* spp.), including Lake Whitefish *C. clupeaformis* (cover photo) and Broad Whitefish *C. nasus* (article in this issue), are members of the Salmonidae subfamily Coregoninae, and are often common in high latitude ecosystems and are an important subsistence resource in Arctic Alaska. Photo credit: Paul Vecsei (https://www.flickr.com/photos/fishasart).

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COLUMN
PRESIDENT'S COMMENTARY

Is There a Solution?

Joe Margraf, AFS President. E-mail: jmargraf@alaska.edu

If you've been following my column, you know I grew up on the water and fishing. I had fish in tubs in our basement. I love fish and the outdoors. I started my career working for a state agency, but spent most of the first 10 years in private ecological consulting before going to the Cooperative Fish and Wildlife Research Unit Program, where I was mostly an academic. I believe in diversity in our profession and I don't believe that our biggest issue is finding people who are like me. Our salvation will not come from convincing "the younger generation" that life is all about being like me. It will come from convincing young people that what we do is important—to us personally and to society as a whole.

As I also related in an earlier column, fisheries is not rocket science—it's harder. To augment my thoughts, I borrowed a few definitions from the Internet (so be warned as to their veracity). The working definition of fisheries management from the Food and Agriculture Organization of the United Nations is, "the integrated process of information gathering, analysis, planning, consultation, decision making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities to ensure the continued productivity of the resources and the accomplishment of other fisheries objectives" (FAO 1997:7). Banga (2017) defines fisheries science as "the academic discipline of managing and understanding fisheries. It is a multidisciplinary science, which draws on the disciplines of limnology, oceanography, freshwater biology, marine biology, conservation, ecology, population dynamics, economics and management to attempt to provide an integrated picture of fisheries." Fishery biologists (managers and scientists) require advanced education that includes a bachelor's or master's degree or a Ph.D., depending on the position they seek. The job outlook for these positions is about as the same as all jobs. According to the U.S. Bureau of Labor Statistics (BLS; 2017) for 2016, the average annual salary is about US$64,000. Most college programs related to fishery or marine biology state that jobs are very competitive, especially for federal or state government positions.

The typical federal government engineer salary is $92,567 (BLS 2017). Engineer salaries at the federal government can range from $47,380-$160,040 (BLS 2017). This estimate is based upon federal government engineer salary reports provided by employees or estimated using statistical methods. If fisheries is harder than (or as hard as) rocket science, why do fisheries biologist make one-third less on average than engineers? For comparison, according to TruckDrivingJobs.com, truck driver salaries can be as little as $35,000 and as much as $250,000+, with a Walmart freight driver earning an average of $76,000 annually. According to BLS (2017), in 2016 there were 65 professions that were similar to fisheries biologist in expected earnings with a B.S. degree, including dietitians, foresters, geographers, middle and high school teachers, and nurse practitioners. Along with engineers, there were 63 professions that could expect to earn more than fisheries biologists with a B.S. degree, including education administrators, sales representatives, hydrologists, construction managers, and computer analysts (BLS 2017).

So why aren't fisheries biologists in this upper group? Is it because we like our jobs? I would suspect that other professionals like their jobs as much as we do. Is it because we can be outdoors and with nature? I don't know about you, but that hasn't been a major part of my job for years, and other professions can be outdoors with nature as well. From my February 2017 column, you know that I came to the conclusion that the issue is one of the perceived relevance of our profession. It takes a lot of academic training to become a fisheries biologist. If a potential student is bright enough to enter the fisheries biology, why not go into a profession that will clearly be of benefit to and understood by their community. There could be little that's worse than going home and having your family or community leaders ask why you wasted your talents and education on this. The truth is that fisheries science and management have at their heart providing healthy fish populations. Yet, this is not widely understood. To most people, if you're smart enough to succeed in fisheries biology, then why not go into the medical or legal professions, or for that matter, become a rocket scientist. Notice that I have not mentioned money, but as I pointed out earlier in the column, that may be an issue too. In general, the profession is accomplished by government or university employees that are typically paid less relative to private enterprise or least that is the perception. In many communities, working for the state or federal government is not looked upon favorably—pay is only part of the equation. So, how do we fix it? Clearly if I had a simple concrete answer, I would forcefully act on it. The answers are not simple, and they are not hard and fast. Increasing the relevance of the profession will not be accomplished without a huge amount of work on our part. It is something that all must do, and do over and over again.

If you're interested in helping to solve this problem, I appointed a committee chaired by Tom Lang of Texas Parks and Wildlife to start working on it. Contact me, and I'll forward your interest on to Lang, who I'm sure could use your help.

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COLUMN
GUEST COLUMN

Habitat Science Is an Essential Element of Ecosystem-Based Fisheries Management

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The 2016 releases of the National Marine Fisheries Service (NMFS) Ecosystem-Based Fisheries Management (EBFM) Policy (NMFS 2016a) and Road Map (NMFS 2016b) are shifting fisheries science and management from a traditional single-stock focus toward a more comprehensive approach, requiring a greater understanding of ecological factors that affect fisheries species. Of key importance to these efforts is identifying habitats that are most essential for sustaining living marine resources (LMRs) and understanding the relationships between habitat dynamics and LMR productivity. Since LMRs rely on a mosaic of environments that influence their ecologies throughout their life cycles, habitats are a relevant unit of analysis to help operationalize EBFM. However, relatively few habitats have been characterized in detail and studied in a systematic manner, leaving knowledge gaps that can limit scientific advice and management options.

The Marine Fisheries Habitat Assessment Improvement Plan (HAIP) was created to improve the availability of ecological information for federally managed species and habitats, and is now used to set NMFS' strategy for pursuing habitat science, developing more robust assessments for scientifically sound management of marine fisheries and their associated habitats, and guiding program priorities (NMFS 2010). In this document, habitat assessment is defined as, "the process and the products associated with consolidating, analyzing, and reporting the best available information on habitat characteristics relative to the population dynamics of fishery species and other living marine resources" (NMFS 2010). The HAIP set out two major goals: 1) improve the identification of essential fish habitat (EFH), and 2) reduce habitat-related uncertainty in stock assessments. Due to a lack of comprehensive data on distribution and abundance of habitat types; limited data on habitat-specific vital rates (e.g., natural mortality), catchability, and movement among habitats; and the complexities of assimilating habitat data into population models, many stock assessments do not explicitly consider habitat information, despite its potential to reduce uncertainty in abundance estimates and in modelling population dynamics.

Presently, much foundational habitat information on species-habitat relationships is still needed to enhance the efficacy of NMFS science in meeting its conservation and management mandates. Because NMFS is responsible for managing nearly 500 stocks, it is necessary to prioritize this work to ensure resources are devoted to the species and habitats for which habitat assessments can provide the greatest potential benefit in terms of improved fisheries management. HAIP-recommended regional habitat assessment prioritizations (NMFS 2011) are helping to focus scientific investigations to address this need. The EBFM Road Map includes the HAIP-based habitat assessment prioritization as a component of a broader ecosystem-level risk assessment to identify taxa and habitats that are most vulnerable to human and natural pressures, with the intent of systematically investigating relationships among priority stocks and habitats.

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Rivers and Fish, Not Rivers Versus Fish

Thomas E. Bigford, Policy Director. E-mail: tbigford@fisheries.org

I've noticed an uptick related to issues involving our nation's rivers, extending beyond drought, deeper than climate, and relevant to issues such as dams, diversions, and related human interventions. AFS anticipated keen interest when preparing our fisheries recommendations for the next President, "Future of the Nation's Fisheries and Aquatic Resources" (2016), but the discussion is escalating. That's a good thing.

No one else has reviewed nearly 50,000 large dams, identified 21 variables, analyzed every stream fragment in the lower 48 states, and considered thousands of fish assemblage records. This is solid science, not fake news.

Several recent publications fueled my interest. In late 2016, the National Fish Habitat Partnership (NFHP; www.fishhabitat.org) released its 5-year assessment of fish habitats across the nation (Crawford et al. 2016; Roberts 2016). Those data then served as the basis for a national (lower 48) evaluation of dam effects on rivers and fish assemblages by Cooper et al. (2017). That latter paper focused on dams, but the ramifications include many issues related to in stream flow and water levels. Then the U.S. Forest Service's (USFS) Pacific Northwest Research Station released a summary of lessons learned from 40 years of dam removal.

Cooper et al. (2017) provide a clear conclusion: most streams have been severely fragmented, the resulting damage exists at local and landscape scales, and redirected flow volumes sometimes exceed undammed flows. The extent of these manifestations is that most rivers and associated watersheds no longer represent natural systems. Most waters are increasingly unlikely to be suitable for native species, despite our strategic intentions. Cooper et al.'s (2017) conclusions were based on a thorough review, not some casual observation. In fact, their findings merit headlines in major media outlets, not a story in a technical journal. The authors' state, "[d]am-induced stream fragmentation and flow alteration are critical natural resource issues" (p. 879).

As noted above, the work by Cooper et al. (2017) is based on work by NFHP, of which AFS is an active member. Based on my personal engagement in NFHP since its creation in 2006, I trust their conclusions. I also recognize their significance. No one else has reviewed nearly 50,000 large dams, identified 21 variables, analyzed every stream fragment in the lower 48 states, and considered thousands of fish assemblage records. This is solid science, not fake news.

Our challenge is how to respond. Since these large dams, associated reservoirs, and millions of smaller blockages and impoundments already exist, our options are mostly retroactive. With changing environmental conditions, the best scientific knowledge, and shifting intentions, it's time for a new approach, a

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Responsible Recreational Fisheries: A Chinese Perspective

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Recreational fisheries have been largely developed only in recent decades in China. However, this development is not occurring in an entirely responsible manner. Responsible recreational fisheries in China require fully considering socioeconomic and environmental impacts and minimizing negative impacts of fisheries and fishery products. Responsible recreational fisheries also need to consider climate change, responsible tourism, and developing a modern fishery. In this paper, we define the concept of responsible recreational fisheries, present its current status and challenges, and then provide strategies and recommendations. We conclude that both recreational anglers and fishery enterprises should practice self-discipline, be aware of local community needs, follow fisheries laws and regulations, and respect local cultures. It is urgent for fisheries governmental agencies in China to generate policies and regulations to ensure the development of its recreational fisheries in a responsible manner.

INTRODUCTION

Fisheries (including aquaculture) are important considerations for Chinese citizens, culturally and economically. For instance, in ancient China, the ability to catch fish was one of the criteria to be a tribal leader (Yu 2009). Over a series of dynasties, fishing in China gradually developed three types: individual angling for recreation, commercial catch for food and economic benefits, and raising fish in artificial systems (i.e., aquaculture) for food and economic benefits (Yu 2009). In modern China, only the latter two types of fisheries have been widely developed, mostly resulting from challenges of food security and protein sources for the world's largest population (MOA 2015; Lian et al. 2016). On the other hand, the western world (e.g., Europe and North America) has highly developed recreational fisheries, whereas aquaculture is less developed than in China.

As China has been catching up with the developed countries economically, so has its recreational fisheries (Ping 2011; Dong and Liu 2015a). Especially since the 1990s, recreational fisheries in China have been developing rapidly. In the past 20 years, many recreational fishery sites, aquaculture farms, and marine recreational fisheries (e.g., Dong and Liu 2015b; Li et al 2016) were developed, and ornamental fishes and public aquaria have become popular too. Most recreational fisheries in China are privately owned fishing ponds (Figure 1) in which fish are either purchased from a hatchery and then stocked into the pond or from a food fish production facility directly, and/or grown from that fishing pond (Yu 2009; Zhang 2014). Anglers then pay a fee to fish in that pond; usually they pay a higher price for the same fish species or size than that from the market. These ponds are generally managed at lower feeding rates and stocking densities than in a typical aquaculture pond (Yu 2009). For instance, in recreational ponds raising fish species that need less dissolved oxygen (e.g., Common Carp *Cyprinus carpio*, Crucian Carp *Carassius carassius*), the total stocking weight could be 12,000 kg/ha or less. For ponds mainly stocking fish species needing more dissolved oxygen (e.g., Grass Carp *Ctenopharyngodon idella*, Wuchang *Megalobrama amblycephala*), the total stocking weight could be 8,250 kg/ha or less (Yu 2009). Compared with typical aquaculture ponds, these recreational fishing ponds will usually generate less waste or pollutants (e.g., nutrients, sediment, and chemicals) into the environment (Yu 2009; Zhang 2014).

In addition, natural water bodies, such as lakes, rivers, and streams, are available for recreational fishing in China (Yu 2009). In some urban areas, some historically aquaculture lakes (Figure 2) were converted to recreational fishing water bodies (Li and Han 2015). Anglers pay a relatively low fee (e.g., 20 Chinese yuan or about US$3) for fishing in the lake for one day. Fishing in natural rivers and streams (Figure 3) is the third choice for inland anglers, even though there are few rivers and streams with angler access, and many of these natural rivers and streams have limited fishery resources (Yu 2009). Marine recreational fisheries in China are mainly concentrated in coastal shores, coastal islands, harbors, and estuaries (Zhou et al. 2015; Li et al. 2016; Chen 2016; Guo and Yang 2016). Moreover, there are many in-

Top: Figure 1. A typical fish pond serving for both aquaculture and recreational fishing purposes in Central China. Photo credit: Yushun Chen. Bottom: FIgure 2. Anglers fishing along the shore of a typical urban lake in central China. Photo credit: Yushun Chen.

land and marine fishery festivals, such as crab festivals, fishing festivals, fishermen festivals, fish food festivals, and fish decoration festivals (Yu 2009; Liu 2015).

However, more and more problems have appeared, such as small-scale production, dispersed distribution networks, uncoordinated infrastructure, poorly developed operations, poor service quality, inadequate strategic and tactical planning, disorderly construction, unreasonable development, and the lack of laws, regulations, and management measures (Dong and Liu 2015a; Fu 2016). The major reason for these problems is that the concept of responsible recreational fisheries is not fully accepted by anglers, operators, and government managers. Below we present the concept of responsible recreational fisheries, then present its current status and challenges in China, and finally provide recommendations and strategies for improvement.

RESPONSIBLE RECREATIONAL FISHERIES: THE CONCEPT

The concept of responsible recreational fisheries was adopted and developed from the United Nations Food and Agriculture Organization responsible fisheries goals, which call for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with the environment (FAO 1995). Here our definition of responsible recreational fisheries includes the persons who experience recreational fisheries, the enterprises that provide recreational fisheries, and the government agencies that manage and study recreational fisheries. Responsible recreational fisheries should minimize the cost to the economy, culture, and ecological environment, while maximizing the emotional and socio-economic benefits of the experience. By optimizing allocation and rational use of the fishery, environment, and human resources, a responsible recreational fishery yields relaxation, tourism, and employment, thereby increasing economic and social benefits (Ping 2004; Cai 2005; Li 2005). Tourism combines the recreational fishery with market requirements for both marine and inland fisheries.

Responsible recreational fisheries maximize the efficient use of facilities, space, production area, fishery gears, fishery products, fishery activities, living organisms, natural environment, and village cultural resources (Yang 2007). They thereby increase village incomes and promote village fishery development (Jiang 1992). Recreational fisheries also improve local economies by providing aquatic life, aquatic products, fishery services, and fishery crafts (Yang 2007). Finally, responsible recreational fisheries incorporate research on development trends, operation types, existing problems, future threats, fish populations and their habitats, and recreational fishery management (Yu 2009).

RESPONSIBLE RECREATIONAL FISHERIES: CURRENT STATUS AND CHALLENGES

Despite the increasing importance of recreational fisheries in China, it was not formally recognized or classified as a specific fishery sector until recently (Yang et al. 2011). Also, the economic contribution of recreational fisheries to the total fishery value is still relatively small (MOA 2015). For instance, the total economic contribution of China's recreational fishery was about 43 billion Chinese yuan (or about US$6 billion) in 2014, which was close to the contribution of the total freshwater commercial catch (MOA 2015). But this amount was only 8%, 15%, and 22% of the marine commercial catch, mariculture, and freshwater aquaculture, respectively (MOA 2015).

Responsible recreational fisheries in China are challenged by the need to develop a responsible tourist industry and sustainable recreational fisheries in the context of global climate change, a lower carbon economy (Yang 2007; Yang et al. 2011), and inefficient management (Dong and Liu 2015a). Small, shallow, recreational fish ponds (the most common type of recreational fishery system in China) will be challenged most by the increased air and water temperatures resulting from global climate change (Yu 2009; Winfield et al. 2016). These ponds will face sharp water temperature increases for extended periods, which will affect survival and growth of stocked recreational fishes (Chen et al. 2016). In addition to increases of air and water temperature, precipitation regimes will also challenge recreational fisheries in China, especially the experience of increased drought frequencies in recent years. The decreased precipitation will dry out many small tributaries and canals where many recreational anglers fish (Chen et al. 2016). As these tributaries and channels dry out, anglers must move to lower reaches with more water, or to ponds where they must pay for access.

In regard to the carbon footprint, there are variations in energy consumption of the Chinese recreational fisheries. For instance, a pond stocked with both fishable fish (i.e., usually large-sized fish) and larval fish will generally consume less energy than a pond only stocked with fishable fish (Yu 2009). The former will use the natural resources in the pond ecosystem better whereas the latter will largely depend on other aquaculture-based fish ponds to provide fish (Yu 2009). Also, pond-based recreational fishing will consume more energy than natural lake/river based recreational fishing. The former can provide more fish for anglers but there are energy costs of producing those fish for anglers (Yu 2009).

Regarding recreational fisheries management, current Chinese governmental fishery agencies at both national and provincial levels show insufficient interest in developing and managing recreational fisheries, which has slowed their responsible development in China. In particular, local ecological and social conditions need to be understood better to allocate fish resources, increase the heterogeneity of recreational fisheries products and services, and sustain recreational fisheries—all of which would benefit from more scientific research and improved government planning and management (Dong and Liu 2015a).

It is necessary and feasible to strengthen research on responsible recreational fisheries (Dong and Liu 2015a). Poor aquaculture practices have produced deformed, unhealthy, and short-lived fish. For instance, water quality is not managed well in some hatcheries or the source water is polluted (Fu 2016) resulting in poor quality hatchery fish (Yu 2009; Chen et al. 2014a, b). Stocking such fish in recreational fishing ponds will produce too few good quality fish for anglers and the angling experience will not be enjoyable. Both aquaculturists and recreational fishing ponds must not pollute the water by discharging byproducts, garbage, or drugs into it (Fu 2016).

Recreational fishery enterprises depend on the products and services provided by recreational fisheries facilities; however, recreational fisheries facilities are frequently misused and damaged by providing unsustainable levels of products and services (Fu 2016). In addition, some recreational fisheries boats and ports load excessive numbers of passengers and some fishing ponds have too many anglers (Fu 2016). Such conditions reduce the value of the experience to the anglers. Similarly, anglers seek better experiences at lower prices, but suppliers want to provide those products at higher prices. In China, unlike western market economies, both sides need to bargain to achieve mutually acceptable prices. The business model of Chinese recreational fisheries is voluntary, decentralized, extensive, and mainly individual or private (Yang 2007). Therefore, it is difficult to conduct scientific management, marketing, and brand building, and products are

Figure 3. Anglers fishing along the shore of a typical river in central China. Photo credit: Yushun Chen.

often poor quality. Such fisheries emphasize economic benefit, but ignore rural culture, energy conservation, environmental protection, low carbon development, and resource conservation (Liu 2015).

The recreational fisheries industry is concerned that new rules and their execution will increase requirements and restrictions on fishing operations (Yang 2007; Dong and Liu 2015a). The aquaculture industry is also concerned that new rules will restrict using aquatic genetic resources and non-native species. Both recreational and aquaculture fishery industries are concerned that fishery management rules will lead to long-term management targets and management actions, including rigorous fisheries statistical data collection methods and standards, over-fishing preventative measures, and higher fisheries management standards and regulations (Yang 2007; Dong and Liu 2015a).

RESPONSIBLE RECREATIONAL FISHERIES: DESIRED CONDITIONS AND STRATEGIES

Responsible recreational fisheries should involve several components: angler self-discipline and respect for local cultures and nature; business operators with a sense of economic, social, and ecological responsibility; and government research, planning, management, and communications. The urban recreational fishery in Shanghai is an excellent example of linking a recreational fishery with local culture (Li and Han 2015). The fishing culture in Shanghai has been well-established based on (1) its name abbreviation of "Hu" (i.e., a type of fishing gear used in the ancient Shanghai area) and (2) the city was originally developed from a small fishing village where local residents have strong ties with fishing (Li and Han 2015). Responsible tourism, including recreational fisheries, refers to minimization of cultural and ecological impacts and research on the negative effects of tourism (Hetzer1965; Krippendorf 2010). For example, in the process of developing the recreational fisheries in Anhui province, the government combined tourism development with ecological protection, nature appreciation, improving fishing efficiency, and sustainable development (Li 2015). The fishery in Zhejiang province incorporates leisure and ecological fish culture (soil-less vegetable cultivation, waste recycling, and water purification; Zhou et al. 2015; Guo and Yang 2016). This system beautifies the natural landscape, improves the fishery, protects the environment, and promotes public science outreach (Zhou et al. 2015; Guo and Yang 2016). The rural nature of a recreational fishery increases its attraction to tourists (Lane 1994; Zou 2004), especially for an increasingly urban population (Zou 2004; Hughes et al. 2014). The rural nature of recreational fisheries is enriched by natural ecological resources, rural lifestyles, rural fishery histories, and uniquely local recreational fishery products and services (Yang 2007). Here we present the following recommendations and strategies:

(1) Recreational anglers in China should embrace self-discipline and community awareness, respect for local cultures, conduct equal treatment to local residents, share pleasant experiences, and be aware of conservation ecology, fish welfare, and low carbon/energy fishing, maintenance and breeding.

Self-discipline requires dedication by recreational anglers to maintain local cultures, to be ecologically sensitive, and to abide by local rules and regulations (Yu 2009). For instance, a large number of visitors concentrated together in the recreational fisheries area can produce collective irrational behavior, which requires a sense of community awareness to constrain those behaviors (Dong and Liu 2015a). That is, an executable constraint system is needed, including laws, regulations, and practical social rewards and punishments (Liu 2015). A combination of self-discipline and community awareness is needed for recreational anglers to maximize their experience with responsibility.

Respect and equality means both tourists/anglers and local residents respect the local social and ecological environment.

Low carbon/energy fishing involves recycling, more efficient resource use, low carbon transportation and fishing modes, and reduced electricity consumption and carbon combustion.

Also, anglers should maintain and manage aquatic resources in a sustainable manner. This means that they should strictly follow fishery regulations, including purchasing fishing licenses, using only designated fishing gears, only fishing at designated times and areas, and only catching designated species and sizes.

(2) Responsible recreational fisheries enterprises should generate local economic benefits, improve local services and infrastructure, employ local residents, promote local culture, and attract associated economic resources (Dong and Liu 2015a). Responsible enterprises should also provide the recreational anglers with safe and high quality products and services at reasonable prices (Yu 2009). While creating jobs for local employees, responsible enterprises should improve local incomes, living standards, and working environments (Fu 2016). In addition, recreational fisheries should make positive contributions to sustainable development and social harmony and stability (Yu 2009). Recreational anglers and local residents should mutually benefit from fishing experiences and contribute to social and economic development and environment protection, thereby increasing total social welfare. Recreational anglers can help and support local economic and cultural development, and environmental improvements, thereby improving local residents' living conditions.

CONCLUSIONS

Responsible recreational fisheries provide aquatic products and rural employment, improve income distribution, protect aquatic life in a sustainable manner, conserve fossil fuels and energy, and promote cooperative research and management. Recreational anglers and fishery enterprises should practice self-discipline, follow fisheries laws and regulations, and respect local cultures.

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AFS

COLUMN
BETTER KNOW A HATCHERY

Conservation Fisheries, Inc.

AFS Fish Culture Section

WHAT IS THE NAME OF YOUR FACILITY, HOW DID IT GET THAT NAME, AND HOW LONG HAS IT BEEN IN OPERATION?

We are Conservation Fisheries, Inc. (CFI). We wanted a name that was descriptive of our mission and goals (and "Rare Fish R Us" seemed a bit fluffy). "The Fish Conservancy" finished a close second. We were incorporated as a 501(c)(3) nonprofit with this name in 1992 but had been performing the same work since 1986 in graduate school (University of Tennessee Knoxville under David A. Etnier). We have been at our current location since 2002.

WHAT FISH DO YOU RAISE, APPROXIMATELY HOW MANY DO YOU RAISE, AND WHAT ARE THEY USED FOR?

We specialize in propagating mostly imperiled nongame freshwater fish of the southeastern United States, many of which are state or federally listed. We have successfully reared to adulthood nearly 70 species to date, including many darter, madtom, and cyprinid species. In addition to these diminutive fishes, we have produced Sicklefin Redhorse (*Moxostoma* sp.), a relatively large sucker. Numbers produced vary widely among species, dependent upon many factors but primarily defined by life history and reproductive biology. For example, Smoky *Noturus baileyi* and Yellowfin madtoms *N. flavipinnis*, after more than 30 years of propagation, will not spawn reliably in captivity, so we collect nests from the wild to rear in the hatchery. Because these species produce only about 30 and 150 eggs per nest, respectively, and because federal permits limit the number of nests that may be collected in order to protect source populations, we may produce no more than 100–200 young per species per year (despite average survivorship of 60%–70%). Even such low numbers are still far greater than what could practicably be collected from the wild to translocate for reintroduction efforts and have proven sufficient for successful restorations. At the other end of the spectrum, we may produce several thousand young Spotfin Chub *Erimonax monachus* per year from aquarium spawnings or Sicklefin Redhorses from field-stripped gametes. Production of such species is largely limited by funding available for grow-out space, and we collaborate with other private, state, and federal hatcheries to produce more than would otherwise be possible. None of the fish we spawn in the hatchery are batch spawners; all are fractional spawners that release one to a few eggs per deposition over a period of weeks or months, creating considerable difficulty and often demanding labor-intensive techniques for successful captive propagation.

Although our initial and primary goal has been to produce fish for restoration/reintroduction efforts, and we have several successful projects on our résumé, there are sadly few such opportunities due to habitat destruction and ongoing degradation throughout the Southeast. However, captive propagation has also proved invaluable for other aspects of conservation, such as elucidating critical reproductive and ecological requirements for imperiled species which can guide management and protection efforts (i.e., specialized spawning substrates and larval habitat/food requirements). We have also produced and provided fish for numerous research projects, ranging from interspecific behavioral interaction observations to exposure to various toxins and pollutants (to assess the need for imperiled species-specific protective water quality standards). On several occasions we have utilized a common species as a surrogate for propagation protocol development when a closely related species (presumed to share the same early life history and reproduction traits) was too rare or not permitted to be collected. Finally, we have produced substantial numbers of several species of more common fish to be utilized

A Barrens Topminnow *Fundulus julisia* male from the interviewee's (P.L.R.) pre-CFI thesis research.

as hosts for the parasitic larval glochidia of imperiled mussels at mussel conservation hatcheries. Propagated fish survive the stresses of infestation and transform far more juvenile mussels than wild-caught fish.

HOW BIG IS YOUR HATCHERY?

Our hatchery is a 5,000-ft^2 warehouse on 1 acre of land in a mixed-use suburban area in Knoxville, Tennessee. We have about 700 containers of various sorts, ranging in size from 2-gallon plastic "boxes" to 400-gallon circular vats, although most of our tanks are 20- to 50-gallon glass "long-footprint" aquaria (total capacity ~25,000 gallons). All tanks and systems are closed recirculating. Many of the smallest and largest tanks are isolated, but about half of our capacity consists of 300- to 500-gallon multitank systems with as many as 27 tanks on a three-shelf 4 ft × 10 ft steel pallet rack. We have some vats outdoors, but Knoxville temperatures preclude midsummer outdoor aboveground culture of most of our species.

WHAT IS THE BIGGEST CHALLENGE FACING YOUR HATCHERY TODAY? WHAT CHALLENGES DO YOU FORESEE IN THE FUTURE?

Funding is the biggest challenge. Although we are a nonprofit, most of our funding consists of annually awarded grants and contracts by various state and federal conservation agencies with no guarantee of renewal, despite the fact that almost no nongame fish restoration effort can possibly be completed in less than a decade. After 30 years of steady budget growth, we are facing a first-time downturn due to the effects of sequestration on all of our funding agencies, particularly the U.S. Fish and Wildlife Service. Although we are the only hatchery of our kind and are located in the heart of the greatest fish diversity and imperilment in the United States, the relatively little funding we receive for propagating and monitoring dozens of species relative to other single species conservation efforts for "charismatic megafauna" and commercially important fish like salmon is a constant frustration.

Fish culture is important because it can reduce overharvest of limited wild stocks, restore extirpated populations, and prevent extinction until habitats are restored.

INNOVATION IS A PART OF HOW ANY OPERATION DEALS WITH EMERGING CHALLENGES. HOW DOES INNOVATION HAPPEN AT YOUR FACILITY, AND HOW DOES IT BENEFIT YOUR OPERATION AND OTHERS?

Innovation is a never-ending constant in our unorthodox hatchery! Very few of our techniques and tools have been derived from existing models in game fish or commercial aquaculture due to the small scale of the operation and the biology of the species produced. Although we have utilized methods and equipment from the aquarium trade and hobbyist breeders as a starting

A male Ashy Darter *Etheostoma cinereum* displays dorsal fins in a CFI aquarium (note ceramic tile artificial substrate).

point in some instances, many of the species we have propagated have required the creation of unique tools and protocols that we have developed from close observation of the fishes' behavior in aquaria and in their native habitats, combined with knowledge of the biology of taxonomically related species. Finding out what the fish require for a spawning substrate, for example, while satisfying our need to efficiently harvest and incubate the eggs has led to the use of unorthodox or in-house-constructed media that may not be very natural but that are effective in the hatchery. Improvements and refinements to improve production and survivorship are a constant process and more a matter of constant trial-and-error, creative problem solving or discovery of previously unknown technology (i.e., astronomic timers to provide natural, seasonal day length changes) than controlled research.

We have been contracted to produce hatchery manuals detailing protocols necessary to propagate a species, after which we "hand off" production to another facility (i.e., Yellowcheek Darter *Etheostoma moorei*/Greers Ferry National Fish Hatchery).

ANY RECENT SUCCESSES, NEWS, TRIVIA, OR FACTS YOU CAN SHARE?

Recent propagation successes might be difficult to appreciate outside of a rather narrow circle of scientists and researchers who would realize their significance. For instance, we successfully propagated Blackside Dace *Chrosomus cumberlandensis* for the first time in captivity this year in the absence of a larger nest-building minnow on whose nest they typically deposit their eggs in the wild. This has major implications for both future captive propagation efforts as well as management of wild populations. On a more popular note, we are extremely proud to have been a featured part of the April 2010 issue of *National Geographic*!

ARE YOU AND/OR THE STAFF AT YOUR FACILITY ACTIVE IN AFS? IF SO HOW HAS THIS BEEN BENEFICIAL TO YOU?

I, Pat Rakes (interviewee), am a member of AFS and the Fish Culture Section but have not had time to be very active. Other staff are members of the Tennessee Chapter. Most of us have attended and presented papers and posters at Tennessee Chapter, Southern Division (particularly in the past with Southeastern Fishes Council), and AFS Annual Meetings, sharing with and learning from other AFS members. Costs of attendance have definitely limited our participation at the larger and distant meetings.

IN ONE SENTENCE, WHY IS FISH CULTURE IMPORTANT?

Fish culture is important because it can reduce overharvest of limited wild stocks, restore extirpated populations, and prevent extinction until habitats are restored.

HOW CAN PEOPLE REACH YOU?

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ACKNOWLEDGMENT

We thank Pat Rakes at Conservation Fisheries Inc. for answering our questions and providing photographs. You may see more photos from CFI on the Fish Culture Section Facebook page and on CFI's Facebook page. We also encourage you to check out their website above. AFS

Two male Redline Darters *Etheostoma rufilineatum* display to each other in the stream.

Top: Blackside Dace *Chrosomus cumberlandensis* in brief nuptial colors while spawning at CFI to produce young for water quality tests. Bottom: Endangered Yellowcheek Darter *Etheostoma moorei*.

COLUMN

OUT IN THE FIELD

Biofiltration: An Attractive Extractive Solution

Panel Releases Initial Findings for Use of Oysters to Reduce Nutrient Load in Chesapeake Bay

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Not only are oysters a tasty treat packed with iron and omega 3, but researchers are hoping that this powerful filtering dynamo will also help clean up one of the most important U.S. waterways. Recent studies are focusing on developing recommendations for addressing some of the problems caused by eutrophication, or nutrient overload, in Chesapeake Bay. The deteriorating water quality levels in and near the bay have long been on the government's radar and a concern for fishermen and shellfish growers in that area.

At the end of 2016, a special panel of scientists, including the National Oceanic and Atmospheric Administration's (NOAA) Northeast Fisheries Science Center and the University of Maryland and coordinated by the Oyster Recovery Partnership, came up with oyster best management practices (BMPs) to develop ways in which oysters may be used to reduce nutrients, in particular nitrogen and phosphorous, in order to meet the U.S. Environmental Protection Agency's water quality standards and the total maximum daily load (TMDL) numbers that have been set for this area. To help combat eutrophication, the Chesapeake Bay Program partnership has just finished the first stage of approving best management practices for the uptake of nitrogen and phosphorus into harvested oyster tissue.

THE PROBLEM

Excessive nitrogen and phosphorus are making their way into the waterways and have dramatically increased the nutrient load in Chesapeake Bay over the past two centuries due to human habitation and agriculture near the watershed. In small doses, nitrogen and phosphorus stimulate the growth of algae and aquatic plants that are the basis for a healthy ecosystem. In large amounts, those same nutrients can cause an overstimulation of plant growth, which leads to harmful algal blooms and low oxygen conditions.

The economic loss due to eutrophication does not end with shellfish. Researchers at the Virginia Institute of Marine Science have found concrete evidence that the low oxygen conditions, called "dead zones," have direct impact on the distribution and abundance of demersal fish like White Perch *Morone americana*, Atlantic Croaker *Micropogonias undulatus*, Striped Bass *M. saxatilis*, and Summer Flounder *Paralichthys dentatus* living and feeding near the bottom of the bay. The study was authored by Andre Buchheister and colleagues, who note, "This is the first study to document that chronically low levels of dissolved oxygen in Chesapeake Bay can reduce the number and catch rates of fish species on a large scale" (Buchheister et al. 2013).

Everyone loves a good oyster, but what scientists are hoping is that "good" refers not just to taste but also to the biofiltration capacity of this much loved shellfish.

The water quality degradation has not gone unnoticed. Despite extensive restoration efforts during the prior 25 years, in 2010 the U.S. Environmental Protection Agency was prompted into action by insufficient progress and established the Chesapeake Bay TMDL, a measure of accountability to ensure that major changes are made to reduce pollution and restore clean water to the region's most important watershed.

BIOFILTRATION FOR EXTRACTION

Everyone loves a good oyster, but what scientists are hoping is that "good" refers not just to taste but also to the biofiltration capacity of this much loved shellfish. Oysters gather food by filtering particulates and algae out of the water and, when harvested, the nutrients absorbed in their tissues—including nitrogen—are removed from the environment. How effective they are at this process can be measured using different approaches. The panel evaluated observed oyster data from various studies and determined that the amount of nutrients stored in oyster tissue for different-sized oysters ranged from 110 to 1,477 lb of nitrogen and 22 to 154 lb of phosphorus per 1 million oysters. These estimates were approved and can be counted toward reaching the TMDL requirements for Chesapeake Bay and given as credits for counties that agree to use approved BMPs and work with the shellfish industry to help clean up their nearshore environment.

Another model already used in 14 locations across 9 countries and 4 continents is the farm aquaculture resource management model, which estimates the impact of shellfish nutrient removal through growth, harvest, and shellfish production. The model has estimated an overall annual amount of nitrogen removed by shellfish from those locations to be between 105 and 1,356 lb/acre. The numbers look promising, and the approach is unique:

Top: Growers tend to oyster cages at the Honga River Oyster Company, Wingate, Maryland. Photo credit: Suzanne Bricker, NOAA. Bottom: Eastern oyster *Crassostrea virginica* from True Chesapeake Oyster Co. aquaculture site on St. Jerome Creek in Southern Maryland. Photo credit: Oyster Recovery Partnership.

Suzanne Bricker of NOAA tells us, “The novel part of this project is engaging with new industry partners and joining with the aquaculture community for help in this large-scale clean-up” (S. Bricker, NOAA, personal communication).

RESULTS ARE CYCLIC

In a perfect scenario, the proposed biofiltration project would create its own sustainable loop: increased aquaculture leads to improved water quality and vice versa. From this loop could emerge a new sustainable source of seafood. Jeff Cornwell at the University of Maryland sees another plus, stating that “oyster on-bottom reef systems are good for the diversity of animal communities” (J. Cornwell, University of Maryland Center for Environmental Science, personal communication). He cites one study near a 7-year-old oyster bed revealing a whopping 20,000 different species per square meter. The promising results from previous farm aquaculture resource management models and the new numbers from the Chesapeake Bay oyster BMP panel have already created a conversation between growers and regulators interested in using shellfish filtration to address eutrophication issues on a worldwide level. With so many positives (good for consumers, good for economy, good for the environment, and good for wild oysters), it seems likely that the panel recommendations will have far-reaching implications. Panel discussions will continue into late 2017, when BMPs addressing the evaluation of oyster shells and another on burial of their biodeposits into sediments can be given a denitrification value for further credits to oyster growers. Julie Rose, also at NOAA, says, “The approach of biofiltration isn’t new, but the visionary aspect of Chesapeake Bay’s BMPs are addressing nitrogen in waters with a much broader application than ever before and providing a framework of policy that other states can use” (J. Rose, NOAA NEFSC Milford Laboratory, personal communication).

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COLUMN
COOL FISH

In Search of Arctic Bonefish

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Fisheries technician Mike Lunde prepares to check a floating gill net on the middle Colville River. Photo credit: Jason C. Leppi.

In the cold waters of Alaska's Arctic swims a mysterious fish with large, silvery scales and a strong tapered body.

With its mouth turned down slightly, the fish is adapted to feeding on its prey from above. Moving between marine and freshwater habitats, it covers great distances while using shallow lakes and flooded marshes to gorge on a diverse array of prey. Sometimes all that can be seen at the surface is a series of fins like those of a school of tropical bonefishes *Albula* spp. working saltwater flats in search of food.

A close-up inspection reveals that this is not a type of bonefish commonly found feeding on tropical and subtropical coastal flats. It is not the famous sport fish that inspires fishers to make pilgrimages from around the globe. There is no one here working the network of shallow lakes with expensive fly-fishing gear in hopes of landing the silvery fish under Alaska's midnight sun. Unknown to most people, this fish belongs to the Salmonidae subfamily Coregoninae (which contains whitefishes and ciscoes) and has quietly inhabited Arctic and sub-Arctic ecosystems for thousands of years..

Broad Whitefish *Coregonus nasus*, the whitefish species under study here, is widely distributed in Arctic and boreal basins of North America and Eurasia. These fish are known to travel great distances between habitat types (e.g., summer foraging, spawning, and overwintering areas) within a single year, sometimes traveling hundreds of kilometers.

Aquatic ecosystems in the Arctic change dramatically from summer—when most water bodies are open and connected—to the winter, when ice reduces habitat connections and limits movement for nearly 9 months each year. To cope with extreme seasonal changes in habitat and resources, many fish species have evolved migration strategies and life history patterns to maximize individual fitness.

Large summer dispersal patterns are common for Broad Whitefish and allow fish to exploit abundant food resources during the brief but productive warm period. During summer, fish are thought to migrate to a variety of productive habitat types such as streams, shallow lakes, and coastal marine areas, to feed on abundant clams, snails, crustaceans, and shrimp.

Anadromy is a common strategy for high-latitude fish species, and Broad Whitefish engage in it to varying degrees. Migrations between freshwater and marine ecosystems are thought to be a successful strategy to capitalize on dispersed food resources and important habitat. In late summer, Broad Whitefish generally leave productive foraging areas and migrate to freshwater spawning locations conducive for egg development. While populations have been studied extensively in some areas, the proportion of time spent in freshwater, brackish, and marine habitats remains largely unknown for many populations across Alaska's Arctic.

Broad Whitefish spawn in early winter after fish migrate to freshwater habitats. To increase offspring survival, spawning typically occurs in gravel-rich habitat that does not freeze during the long, cold Arctic winter. Timing of spawning likely varies by region, habitat, and individual, and typically involves individuals greater than 5 years of age and occurs over several days as rivers begin to freeze. The fish congregate as water temperatures begin to drop, signaling the start of the spawning ritual. Females are thought to initiate the spawning process, and as they broadcast their eggs, one or more males simultaneous broadcast their milt into the water column.

A female can release between 10,000 to 70,000 eggs about 2

A Colville River Broad Whitefish *Coregonus nasus* is held briefly before a radio transmitter is surgically implanted. Photo credit: Jason C. Leppi.

Aerial photo of the middle Colville River, looking downstream and toward the Colville River Special Area within the National Petroleum Reserve-Alaska. The middle section of the Colville River is composed mainly of a single deep channel bounded by high bluffs on the west with only small creeks entering as tributaries. Photo credit: Jason C. Leppi.

mm in diameter, which sink rapidly due to their negatively buoyant properties. Once the eggs reach the streambed, they become lodged within gravel crevices, preventing the eggs from being swept downstream.

FIELDWORK

It is September, and we are on the third trip of our second field season working on the mighty Colville River. The Colville is the largest Arctic river in Alaska, about 560 km long, with its headwaters in the partially glaciated Brooks Range and a large delta on the edge of the Arctic Ocean near the village of Nuiqsut. As we stretch out another 45-m gill net, a cool breeze blows across the Arctic Coastal Plain. Leaves of the alpine shrubs have faded to yellow, snow covers the high peaks of the Brooks Range. This will be our last chance this season to catch Broad Whitefish.

As fisheries researchers for the Alaska Cooperative Fish and Wildlife Research Unit, we began a collaborative project a year ago with The Wilderness Society, U.S. Bureau of Land Management, U.S. Fish Wildlife Service, and U.S. Geological Survey to investigate the ecology of Broad Whitefish. One goal for this field season is to understand how the species uses the watershed's habitat by season. This can be a challenging task, but working on an under-studied species in a remote Arctic location greatly complicates the collection of fish and the ability to track them. From our previous field season, we collected baseline information that showed that pre-spawning fish were migrating through the middle Colville during August, but our attempt to intercept fish during that month was abruptly halted by a large storm that dumped 8 cm of rain across the 52,000-km^2 watershed (an area five times as large as Yellowstone National Park). The Arctic receives precipitation amounts similar to those of a desert, but large, late-summer rainstorms commonly cause the Colville to flood. The river is crystal clear now, but less than a month ago it was raging at 10 times its normal flow and remained high and filled with suspended sediment debris for several weeks.

Our nets have been set again at several strategic locations throughout the river to intercept Broad Whitefish migrating upstream. For 4 days, we have failed to catch a fish. Our objectives are to catch pre-spawning fish and surgically implant radio transmitters into them so we can track their movements to spawning and overwintering habitat. We watch the nets intently, but hours slowly pass with nothing happening. This requires extreme patience but is crucial for our project if we hope to release each fish back into the river unharmed. Broad Whitefish are known to respond poorly to minor injuries so we want to minimize the time that each fish is entangled.

Suddenly the white foam floats at the top of a gill net begin to bobble up and down on the water's surface. We race to our Zodiac boat, fire up the 40-hp jet motor, and head toward the net. Reaching into the frigid water with elbow-length neoprene gloves, we slowly pull in the net while scanning the depths for entangled fish. The breeze blows harder now, creating whitecaps on the river as snow begins to fall. At last, a white underbelly emerges as the mesh ascends toward the surface. It is a large Broad

Whitefish. The sounds of shouts and high fives carry across the floodplain. We scoop up the fish and place it in a small tote filled with oxygenated water. We fire up the jet motor and transport the fish to a holding pen near the shore, where it will wait to undergo anesthesia and surgery. Catching the fish has proved difficult, but it is only the first step. We have to be extremely careful handling each fish as we surgically implant the radio transmitter.

Half an hour after we removed the fish from our net, the surgery was successful and we have implanted our first transmitter. The wind is cranking outside the ice-fishing tent that we use as our portable surgical room. We carefully hold the fish upright in the holding pen for 5 minutes until it can maintain its position. After another 10 minutes, we watch our first tagged fish swim upstream toward a river eddy, seemingly unaffected by the transmitter.

It took nearly 5 days of watching our nets to catch and tag our first fish. Our catch rate picked up a little after that and we managed to bring our total up to 14 for the season. While this was much lower than our goal of 50, every fish we caught was well earned. Wildlife is abundant in the Arctic, but not everywhere and not all the time. Resources are dispersed across the landscape, and animals must make large seasonal migrations to find food resources. Just like caribou, Arctic fishes move hundreds of kilometers seasonally across a variety of aquatic habitats, and there can be countless fish in an area one week and none the next. To understand more about these seasonal movements, our tagged fish will transmit radio signals every 3 seconds for more than 2 years. During this period, we will track fish using aerial and ground-based methods during the fall and winter to understand their story.

Subsistence fisheries are a vital resource to most Arctic communities. About one-third of all adults participate in some type of fishery, and the mass of fish harvest by coastal communities is roughly equal to the annual harvest of bowhead whales *Balaena mysticetus* (ca. 90,000 kg). Of the numerous fish species caught, Broad Whitefish is among the most important subsistence species because of its size and abundance during migrations. Fish reach maturity around 40 cm long, but individuals have been caught that are 65 cm long, which is similar in size to Sockeye Salmon *Oncorhynchus nerka*.

Nuiqsut, a native Inupiat village, is located near the Colville River delta, and village residents target Broad Whitefish using gill nets from June through September during the upstream migration. Nuiqsut fishers have been annually harvesting fish from the Colville River for more than 50 years, and their harvest of Broad Whitefish ranges from 6,300 to 15,800 kg. Despite the historical importance of this fishery, the basic ecology of the Broad Whitefish remains poorly understood.

The lack of basic information on habitat use, especially during the spawning period, puts this important subsistence fish species potentially at risk. Expanding hydrocarbon development in the Colville Delta and lower watershed has the potential to overlap with critical habitat, so identifying spawning and overwintering habitat is more important than ever.

Broad Whitefishes with surgically implanted radio transmitters recover in a holding pen before being released into the Colville River. Photo credit: Jason C. Leppi.

AN EARLY END TO THE SEASON

Twelve days later, as we board our charter flight heading back to Fairbanks, the temperature is well below freezing and heavy snow is forecast to hit soon. The first winter storm of the season is bringing our field season to an abrupt end. The landing strip at Umiat, a former Air Force base, is unmaintained, so if we do not take advantage of this window of "good" weather, we could easily be stuck here for days or even weeks. With no permanent residents and a record low temperature of –66°C, Umiat serves as a center for summer research, a fuel stop for aircraft, and a camp for oil and gas exploration.

Our small Piper Navajo accelerates down the landing strip and rises above the Colville River. Looking down from the air, the perspective has changed. Braided and side channels seem separate on the ground, but now from above, it is obvious that they are annually connected by seasonal floods. Oxbow lakes, remnant channels, and floodplain features are suddenly revealed without the interference of riparian vegetation. We continue to fly upriver toward the Brooks Range. The Colville is wide, with numerous channels and gravel bars as far as the eye can see. Most of the river appears to be good spawning habitat, and we begin to wonder if our tagged fish will be nearby or 100 km

Aerial view of the middle Colville River, looking upstream toward the Brooks Range. In this section, the river channel has a lower gradient than the upper section, and is wider (ca. 100–300 m) and contains numerous side channels and large sand and gravel bars. Photo credit: Jason C. Leppi.

upstream when we return.

Soon, the plane leaves the river and heads southeast over the foothills of the Brooks Range, toward Anaktuvuk Pass and then Fairbanks. Besides the small native community of Anaktuvuk Pass, there are no year-round residents living within the upper watershed, and even today, most of the area remains wild and free from human disturbance. The view from inside the small plane is unreal. We fly over creeks and tributaries, and the high mountains of the magnificent Brooks Range begin to rise in the distance. To the west, you can see the upper section of the Colville that flows almost directly east for 200 km from the De Long Mountains before making a sharp turn north at Killik Bend. To the east, we can begin to see the meandering Anaktuvuk River that flows down from the pass and between a network of small lakes. Snow has already blanketed the mountains, and it will not be long until the entire North Slope is frozen and covered in snow.

A Broad Whitefish with a surgically implanted radio transmitter is released into the Colville River. Photo credit: Jason C. Leppi.

As our plane starts to gain altitude, rising above the foothills, we begin to imagine our tagged fish along with hundreds of other Arctic bonefish swimming below in the middle Colville river. Slowly climbing into the clouds above the Brooks Range, we imagine our tagged fish, packed tightly, swirling in the mighty Colville, waiting for river temperatures to drop to begin their mating ritual.

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FEATURE

Using Voice Recognition Software to Collect Fisheries Biodata: A Proof of Concept

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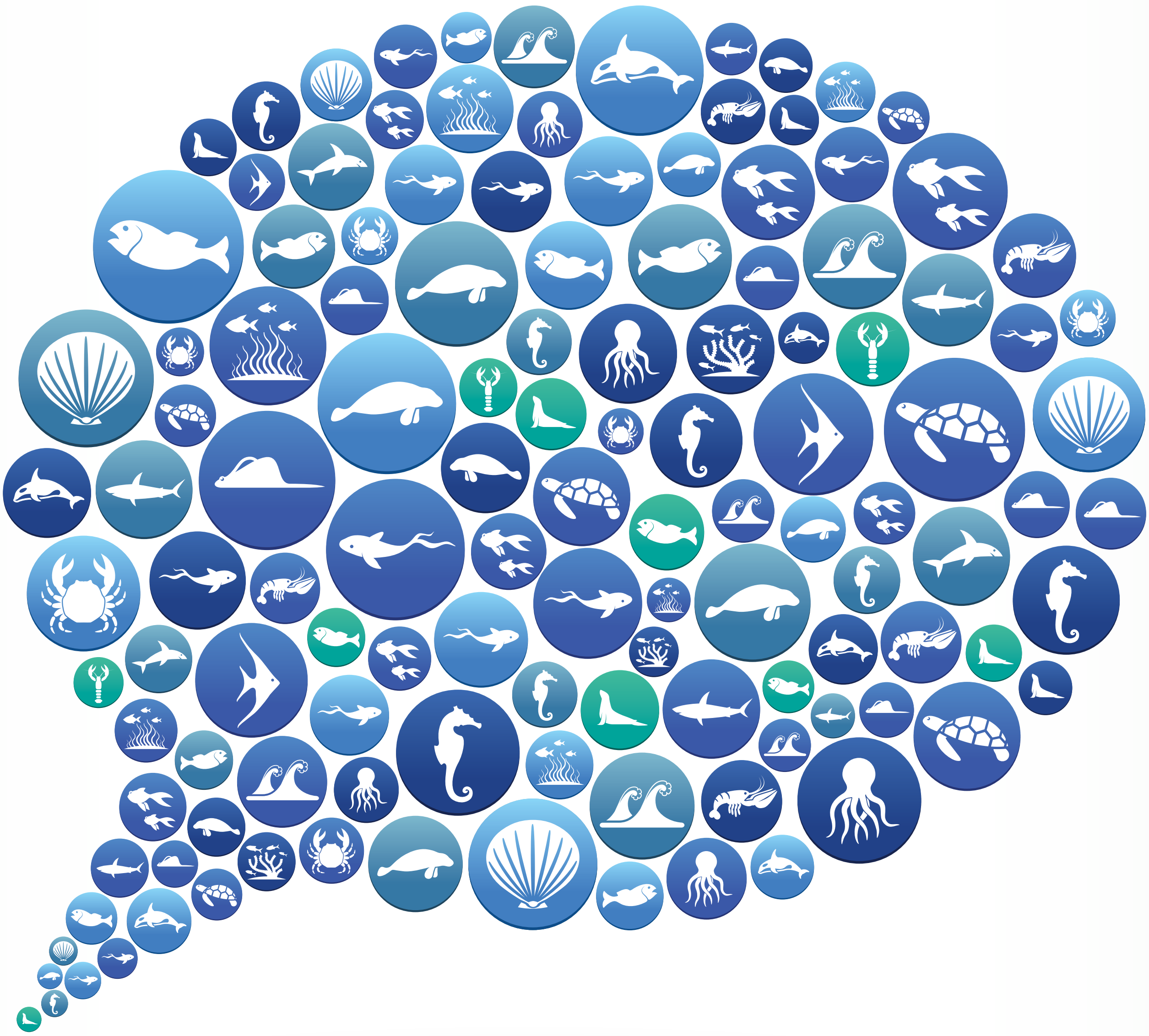

Biological data collection and processing involves numerous steps, is time consuming, and is error prone. We developed the Voice Data Recording System (VDRS) that eliminates multiple steps in the traditional process by integrating voice recognition software with a normalized, relational database to capture data onto a laptop computer. We compared traditional and VDRS methods and report efficiency and error rates based on Lake Superior Lake Trout *Salvelinus namaycush* survey data collected during 2000–2016. Efficiency was measured by data collection rate and processing duration. Data collection rates were not different between methods. Processing duration for the traditional method averaged 200 staff hours per year, whereas the VDRS has no data processing. Error rates measured for the traditional data method averaged 5% and the VDRS had 0% error. We found that the VDRS is more efficient and less error prone than the traditional method of data collection and provides substantial cost and time savings.

INTRODUCTION

Data are the foundation of fisheries science and management. The efficient and accurate collection of fish biological data is vital to proper interpretations of patterns in fisheries biology, ecology, and population dynamics. The quality of the data collected is diminished by sampling error; thus, quality control measures are necessary to minimize errors. Errors occur in both the data collection and data entry processes (Johnson et al. 2009). Traditional biological data (biodata) collection and processing involves six steps within two phases and begins with sample observation and ends with validated digital data (Figure 1). In the first phase (data collection), one person observes the fish sample (observer), conducts the measurement, and relays the information. Then, a data recorder writes the information on a data sheet. In the second phase (data processing), data sheets are transcribed into a computer database via keyboard. Digitized data are then compared to field data sheets to screen for errors (proofing). There are several approaches to proofing data, including (1) simple visual comparison of data sheets with digitized data on computer screen or on printed copy of electronic data by one person (visual checking), (2) reading of printed copy of electronic data aloud to another person who compares it with the original data sheet (read-aloud), and (3) keypunching the data into the database twice and comparing the first and second entries (double-entry; Johnson et al. 2009; Barchard and Pace 2011). When errors are detected, corrections are made to the digital data and then the data are considered validated (proofed). Each step in the traditional data collection and processing is a source of error. The first error source is when the observer conducts an incorrect measurement or misreads the value from a measurement device (observational error). This is the most difficult to detect and is sometimes detected as an outlier in subsequent data processing or analysis. The second error is a difference in what the observer measures from what is actually relayed to the data recorder (measurement error). The third error source is a disparity in what the observer relays to the data recorder and what is actually recorded on the data sheet (interpretation error). This is likely influenced by noise levels and the amount of distractions impacting the data recorder (e.g., labeling sample bags). The fourth source of error occurs when data sheets are entered into the database, which can be due to misinterpretation of what was written on the data sheet or pressing the wrong key (transcription error). The fifth source of error occurs in the proofing process, where errors are undetected by staff (interpretation error). In the traditional method, at least two people are required for data collection (phase I) and generally at least two people process data (phase II).

Advanced methods of biological data recording using computerized devices (e.g., laptop computer, personal digital assistant, smartphone, or tablet) can reduce a few steps in the process (Gutowsky et al. 2013; Kopaska 2014a, 2014b) but are still prone to transcription errors that need to be proofed (Johnson et al. 2009). The three general types of error in the data collection and recording process can be reduced by having reliable measurement devices, limiting distractions, and proofing the data. Measurement errors are most difficult to reduce and are usually detected only if they are outliers in the data set. Transcription and interpretation errors are challenging because they involve human communication and audio and visual perception, but they can be reduced by eliminating the number of steps in data collection and processing. In addition to error reduction, minimizing the steps in the process increases efficiency.

In 2009, we reduced the steps in our biological data collection and entry process by developing the Voice Data Recording System (VDRS), which integrates voice recognition software with a relational database to record and validate data at early steps in the biological data collection process, where the observer voices the measurement directly to the database, proofs what was entered, and corrects errors in real time (Figure 1). The basis for developing the VDRS was to increase efficiency and reduce errors by eliminating transcription by a data recorder (phase I, Figure 1) and eliminating the data processing phase (phase II) of the traditional data collection approach by capturing the data digitally from measurements spoken by the observer (Figure 1). Two versions of the VDRS have been developed: ship-mounted and mobile (Figure 2). The VDRS has been used since 2009 to collect Lake Trout *Salvelinus namaycush* biological data in surveys in Lake Superior aboard the Michigan Department of Natural Resources (MIDNR) 17-m RV *Lake Char*. Between 3,500 and 5,300 fish are sampled annually in these surveys. Since 2015, the mobile VDRS has been used in our commercial fisheries monitoring program to collect biodata from state-licensed Lake Whitefish *Coregonus clupeaformis* fisheries in Lake Superior and northern Lake Michigan. In this article, we present the VDRS and compare it with traditional biodata collection by reporting efficiency and error rates for each method.

METHODS

Data used in this study were collected from MIDNR Lake Trout gill-net surveys conducted during 2000–2008 (traditional method) and 2010–2015 (VDRS method). The basic hardware requirements for the ship-mounted VDRS include a laptop computer, wireless headset microphone, large computer monitor, and digital voice recorder (Figure 2). The mobile VDRS hardware includes a tablet PC (or laptop), wireless headset microphone, and digital voice recorder. Optional input or output devices can be integrated into the VDRS, such as a label printer, barcode or other code scanner, and tag reader (e.g., passive integrated transponder or other radio-frequency identification tags). In both versions of the VDRS, the voice recorder is used as an independent backup by recording each data collection. The voice recognition software used in the VDRS is Dragon Naturally Speaking Professional (Nuance Communications, Burlington, Massachusetts), which allows commands to be programmed such that the software is not used to translate speech but translates commands and numbers

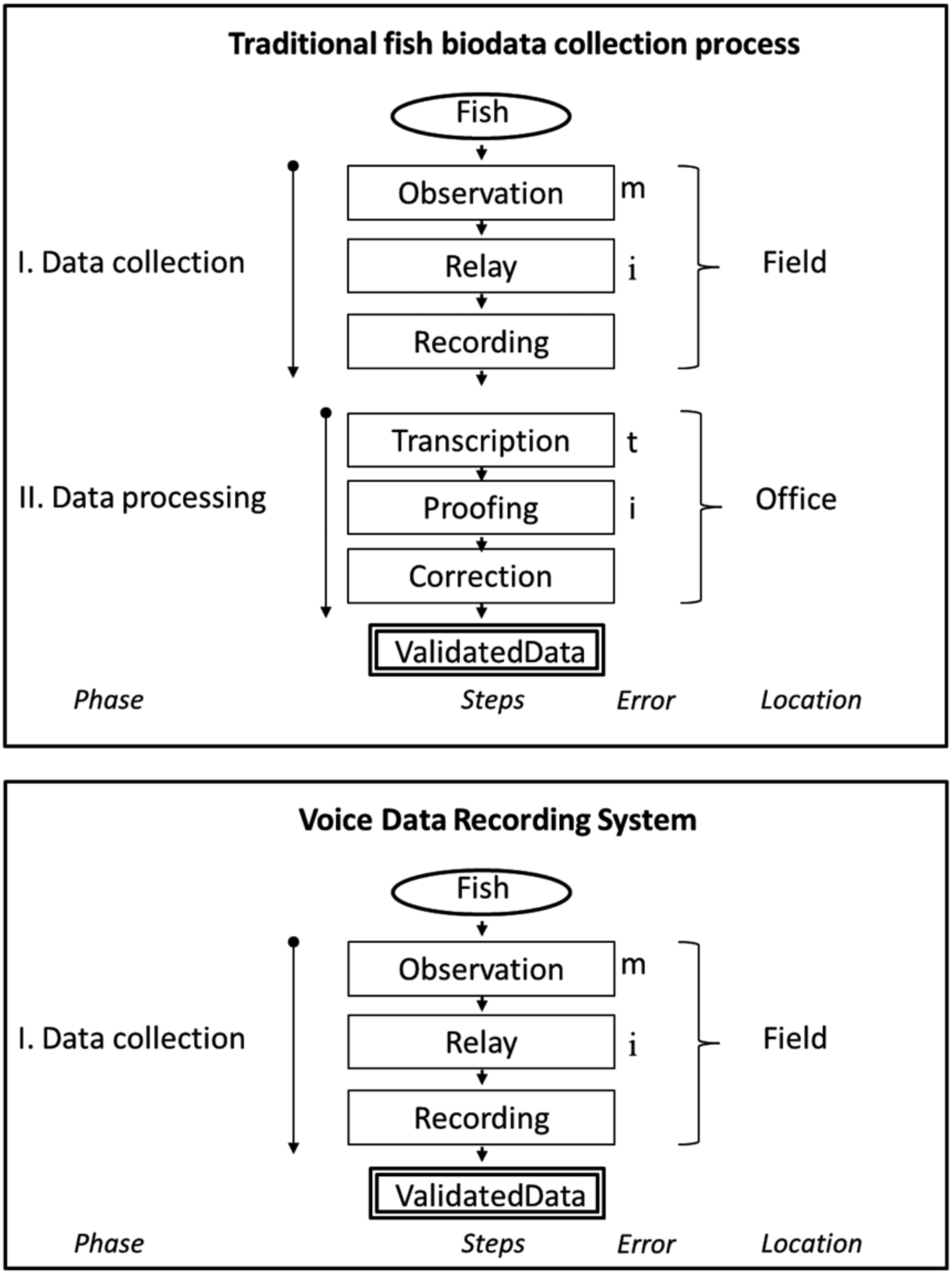

Figure 1. Traditional fish biodata collection process (top) and voice data recording system (bottom). Error types are measurement (m), interpretation (i), and transcription (t).

as data directly into the database. Dragon software is typically used to translate speech to text and utilizes a large vocabulary set and can be prone to high levels of errors if what is spoken is not correctly translated. In contrast, the vocabulary set used in the VDRS for fish biodata collections is limited to less than 200 words; therefore, the potential for the software to misinterpret what was spoken is very limited. Furthermore, the flexibility of the voice recognition software allows commands to be succinct and be customized to differing user preferences while maintaining data integrity. Data entry errors were limited by using a normalized (Codd 1970), relational database (Microsoft Access), which implements data validation rules to limit entries to valid values. We developed practical field data codes for categorical data to be intuitive and contrasting in pronunciation so that misinterpretation was minimized. For example, “boy” is used for “male” and “girl” for “female” in the field because male and female can often

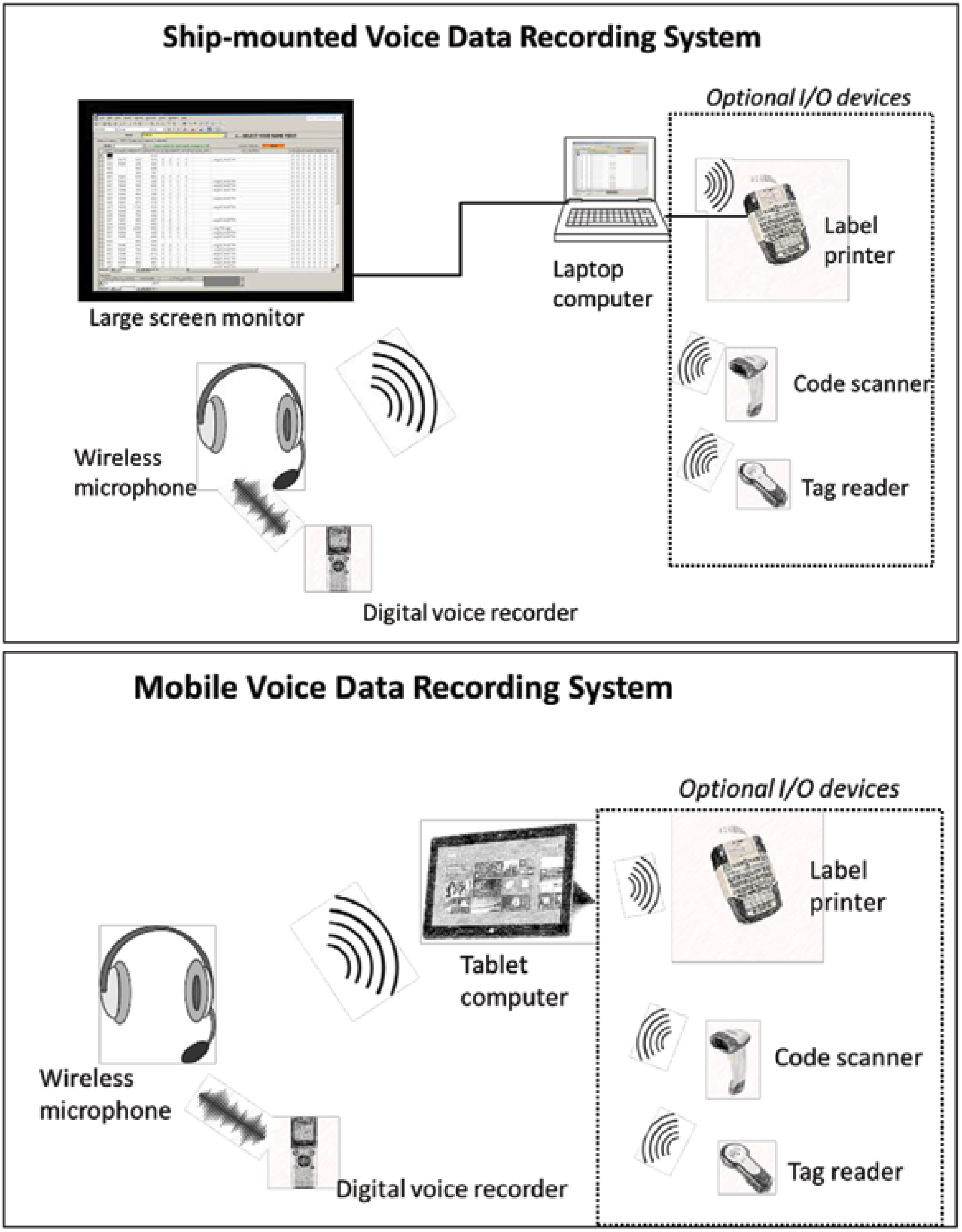

Figure 2. Hardware components of the ship-mounted and mobile Voice Data Recording Systems. Some optional input/output (I/O) devices shown inside dashed box.

be misheard. Handwriting errors were further eliminated by the integration of an industrial label maker (Rhino 6500, Dymo Corporation, Atlanta, Georgia) to allow automated labeling of sample bags from voice commands. Sampling site physical parameters such as coordinates, bottom depth, and sea surface temperatures were captured automatically by the vessel's Global Positioning System when waypoints were established and then downloaded and imported to the database.

The biodata collected in the surveys were the same for both methods (time periods), and each individual fish data record included the following measurements and attributes (data fields): species, length, weight, sex, maturity status, visceral fat index, type and number of Sea Lamprey *Petromyzon marinus* wounds, fin clip status, gill-net mesh size, and any notations on the fish. Furthermore, for most fish sampled, a serialized envelope number was recorded for age structures, and a binary check field on the data sheet was marked indicating whether tissue samples were collected from the fish, such as the stomach for diet analysis in the laboratory. Sample bags were labeled by handwriting in the traditional method and labels were automatically generated from a label printer in the VDRS. The sampling unit (collection) was the total number of fish collected per net-lift. Details on the design and specifications of the Lake Trout gill-net surveys are described in Sitar (2017). Prior to the development of the VDRS, the amount of time for data processing using the traditional method was measured by staff members for the 2008 annual spring Lake Trout gill-net survey (phase II, Figure 1). There were 88 collections with 2,473 fish data records, and the amount of time to keypunch, proof, and correct all data were documented by staff. The read-aloud proofing method (Kawado et al. 2003) was used at our station prior to the development of the VDRS.

Efficiency

Two measures of efficiency for fish biodata collection (phase I) and processing (phase II) were estimated: data collection rate and data processing duration. Collection rate was defined as the number of seconds to sample a fish for biodata (described above). For the traditional method, collection rate was sample duration divided by the total number of fish sampled per collection. Sample duration was the total time required to observe, relay, and write data on a paper data sheet for a collection of fish. Collection rate for the traditional method was measured from three collections from the 2016 Lake Trout survey. Collection rate for the VDRS method was measured from surveys conducted during 2010–2015. In the VDRS database, time and date are automatically recorded for each fish when the data record is created. Collection rate for the VDRS was estimated by sequentially subtracting the record creation time for each fish and estimating the overall mean value per collection. Collection rates for VDRS and the traditional method were statistically compared using the Wilcoxon signed rank test (Siegel and Castellan 1988) with significance established at $\alpha = 0.05$.

Data processing duration (person-hours; phase II) was the total amount of time to transcribe, proof, and correct data (Figure 1) and was based on estimates from the 2008 spring survey data processing. Total transcription time was estimated for each year by multiplying the total number of fish collected (C) by the average transcription rate per fish (r). Average transcription rate was 28.45 s per fish as measured from the 2008 spring survey data. Total proofing time (person-hours) was calculated as $C * r * 2$. The rate at which each data record was proofed was assumed to be equal to double the transcription rate because the amount of time to read the data record was considered to be approximately equal to keypunching and was doubled because read-aloud proofing required two people. Total error correction time was calculated as the number of records with errors multiplied by 10 s per fish (time required to make corrections in the database). For the VDRS method, there was no data processing phase because data were entered directly into the database and errors were screened at that time. Therefore, efficiency of the VDRS would also be the time savings of the data duration measured for the traditional method.

Error Rate

For the traditional method, error rates were calculated from 2000 to 2008 Lake Trout survey data. The data management protocol during that time period was to keypunch data from paper data sheets into the relational database and then to proof data using the read-aloud method with two staff members by comparing raw datasheets with computer printout of entered data (phase II, Figure 1). Any discrepancies were notated and then corrected in the database. The database contained a data validation field that recorded whether a correction was made. Error rates for the traditional method were calculated by summing the number of corrected records and dividing by the total number of records for each year and expressed as a percentage. The error rate only indicates the number of fish records with errors but does not include multiple errors within a fish record (e.g., errors in both length and weight data). The relational database used between 2000 and 2008 when data were collected with the traditional method was the same one used in the VDRS and had the same suite of data validation rules.

Accuracy of the VDRS was measured by comparing the data transcribed from digital voice backup files (treated as correct data) with VDRS-entered data and summing the number of corrected records. Digital voice–recorded files for 10 net-lifts (collections) sampled in the 2016 spring Lake Trout survey (using VDRS) were transcribed into a relational database by keypunching the data twice (double-entry proofing method; Cummings and Masten 1994). Transcription errors were detected by subtracting the data values of the first entry from the second entry and counting the number of records with nonzero residuals. The double-entry data were corrected (treated as the correct data) and then compared with the VDRS data to estimate the percentage of records with errors.

RESULTS

Efficiency

Mean data collection rate for the traditional method was 36 s/fish (SD = 1 s/fish; Table 1). The mean collection rate for the VDRS method was 38 s/fish (SD = 25 s/fish; Table 2). Collection rate was not statistically different between the VDRS and traditional methods (Wilcoxon signed rank test, $W = 6$, $P = 0.51$). It is important to note that the SD for the traditional method was conservative and calculated from mean processing rates that were based on the ratio of processing duration to number of fish sampled and was limited to much lower sample size ($n = 3$) of collections than the VDRS. In contrast, the SD for the VDRS was based on the mean of individual processing rates. Total data processing time (phase II) for the traditional method averaged 200 person-hours per year (range: 154.4–236.2) based on annual average of 8,386 fish data records (range: 6,869–10,574; Table 3). Data proofing time was two-thirds of the processing time.

Error Rates

For the traditional method, the average error rate was 5.1% (SD = 3.4%) and ranged from 1.3% to 12.7% based on 75,474 fish data records that were collected during 2000–2008 (Table 3). There were 3,902 error records detected and ranged from 87 to 1,110 error records per year.

Based on comparison of the VDRS data with the corrected double-entry data, no errors (0%) were detected for any records. The average number of fish per sampling collection was 33 and ranged from 25 to 58. The error rate for the double-entry transcription process (keypunching) was 4.2% (14 records with errors).

DISCUSSION

We demonstrate that voice recognition software can be used to improve fish biodata collection by significantly reducing staff time and minimizing errors. How fast the data are recorded per fish (data collection rate) was not significantly different between the traditional and VDRS methods. The error rate for the VDRS was 0%, whereas the traditional method averaged 5% but was as high as 13%. Johnson et al. (2009) found lower levels of error (0.4%–1.3%) than in our study (1%–13%) for the traditional method of data processing and reported a significant difference

Table 1. Collection rates (s/fish) for the traditional data collection method based on survey data from Michigan Department of Natural Resources Lake Trout gill-net surveys conducted in Lake Superior during 2016.

Sample collection	*n*	Total time	Collection rate
1	11	6:53	38
2	52	31:25	36
3	24	14:53	37
		Mean	37
		SD	1
		Median	37

Table 2. Mean and median data collection rates (s/fish) for the Voice Data Recording System based on survey data from Michigan Department of Natural Resources Lake Trout gill-net surveys conducted in Lake Superior during 2010–2015.

Year	*n*	Mean	SD	Median
2010	4,064	35	25	27
2011	4,397	38	26	30
2012	5,312	39	26	32
2013	4,380	42	25	35
2014	3,618	39	23	32
2015	4,241	36	25	28
	Overall	38	25	31

Table 3. Data processing duration and error rates for traditional method of fish biological data collection. Each data record was a fish with standard biological measurements from Michigan Department of Natural Resources Lake Trout gill-net surveys conducted in Lake Superior during 2000–2008.

Number of records				Staff hours estimates for data			
Year	Total	With errors	% error	Entry	Proofing	Corrections	Total
2000	9,909	461	5	78.3	156.6	1.3	236.2
2001	9,314	602	7	73.6	147.2	1.7	222.5
2002	8,731	1,110	13	69.0	138.0	3.1	210.1
2003	8,412	479	6	66.5	133.0	1.3	200.8
2004	10,574	302	3	83.6	167.1	0.8	251.5
2005	7,130	449	6	56.3	112.7	1.2	170.3
2006	6,482	251	4	51.2	102.5	0.7	154.4
2007	8,053	161	2	63.6	127.3	0.4	191.4
2008	6,869	87	1	54.3	108.6	0.2	163.1
Mean	8,386	434	5	66.3	132.5	1.2	200.0
SD	1,401	303	3	11.1	22.1	0.8	33.5

in abundance estimates between corrected and uncorrected data sets but considered the difference acceptable because it was less than the mean confidence level. Although most errors tend to be benign, we have found some errors in our data set that had significant impacts on estimates of key biological quantities (e.g., shifting age compositions) that had biased stock assessment results. A key advantage of the VDRS over the traditional method was the substantial time savings from the elimination of data processing, which for our program was estimated to be about 200 person-hours per year. Furthermore, the traditional method of data collection requires at least two people to measure fish and record data, and generally two people process the data (phase II). With the VDRS, only one person is required to measure fish and record data, though a second person is usually in place to monitor data and collect tissue samples.

The VDRS takes advantage of current technology and integrates the quality control measures of a relational database, proper programming of commands in voice recognition software, and an efficient sample processing protocol. With the VDRS, the traditional role of the data recorder has changed to become a data monitor. The traditional method of biodata collection and processing is time consuming and subject to transcription and interpretation errors that can reduce data quality. Using the VDRS is more efficient because it eliminates four subsequent steps in the traditional fish biodata collection process, including data recording, entry, proofing, and error correction. In the VDRS, all of these steps are performed in real time by a data observer who measures and then visually validates the data on the computer screen as it is being transcribed into the database. Additionally, the data are being secondarily proofed and corrected at the same time by the data monitor (formerly the data recorder). Our results were based on comparing traditional data recording by handwriting on paper data sheets with the VDRS. We did not evaluate field data recording directly via keyboard or touchscreen to a database in the field. However, based on our experience, we think that these methods would be less efficient and more error-prone than VDRS because keyboard or touch screen entry is slower than voice entry of data and would result in transcription errors that would need to be proofed.

Extreme noise and wet environments can be challenges to data collection. However, the VDRS has performed well in noisy, bumpy, and damp conditions on Lake Superior. For example, the ship-mounted VDRS system on the RV *Lake Char* has been able to record biodata in sea conditions up to 2 m, with twin diesel engines with turbos operating at cruising speeds, with an on-ship generator running, with wash-down hose spraying, with a gill-net lifter operating, with music playing in the background, and with people talking in the background. Adding sound dampening panels to the ship bulkheads has helped to reduce background noise interference. The mobile VDRS has been able to operate in commercial fish processing facilities with descaling and fillet machines operating, people shouting, and wash-down hose spraying.

At extreme noise conditions, the VDRS will have issues because of noise interference, though the traditional method of data collection would also experience difficulties in these circumstances. The greatest challenge to use of the VDRS has been the training of staff in use of this new technology and changes in data collection methods. The voice recognition software requires rudimentary self-guided training and speech pattern calibration for each user. When staff did not properly follow the training procedure, spoke inconsistently, or deviated from the fish sampling protocol, the VDRS had difficulty converting spoken data to electronic records.

It is important to recognize that even with advanced technology, equipment failures and errors will inevitably occur. Therefore, contingencies are important to have in place to minimize data loss and errors. A concern regarding paperless data recording, such as the VDRS, is data loss when the computer fails. Generally, when computers fail, data are still able to be retrieved from the hard disk. Therefore, it is important that data be entered in a database as opposed to a spreadsheet because data are saved immediately by default in a database and spreadsheets require the user to manually save the file. If there is concern regarding hard disk failure, an independent backup, such as an audio or video recording of the data collection, is prudent. Lost data can be transcribed from these media. Like statistical tests, databases are tools that can be improperly used but still function. A database needs to be normalized (Codd 1970) and properly configured with validation rules and relationships to efficiently minimize errors. It is unreasonable to expect error-free data, but many tools are available, such as the VDRS, to minimize these errors in the data collection process. For example, errors from a dyslexic data recorder (traditional data collection method) would be difficult to detect but are prevented in the VDRS. However, neither the VDRS nor the traditional method of data collection would likely detect dyslexic errors from the data observer.

Before investing in new technologies for data collection, the cost–benefit should be considered. It is important to recognize that computer hardware and software technologies may be expensive, have a limited lifespan, or become obsolete. Furthermore, if new technologies are complex, the skill level and staff time required to build the system may be cost prohibitive. We developed the VDRS as a simple concept of the integration of three components: voice recognition technology (software and microphone), a relational database, and a portable computer, all of which have long lifespans, making the system resistant to obsolescence. Furthermore, the components of VDRS are off-the-shelf products that are relatively inexpensive and only require basic levels of programming that any user with moderate computer knowledge can perform. Thus, the infrastructure required can be minimal but may be developed on a larger scale.

The VDRS has been successfully used in Lake Superior aboard a research vessel since 2009 and in various commercial fish processing facilities to collect fish biodata. Our research vessel has become paperless for fish survey data collection. The VDRS has application to other types of fisheries field surveys and can also been used in more controlled environments such as laboratories, offices, or hatcheries. Any steps removed in the data collection process increase efficiency by reducing error and increases time savings. The VDRS is a simple concept of coupling voice recognition software and electronics to digitally capture data at the earliest stage in the data collection process. This is the first generation of the system and it will improve further as technology advances and innovative users enhance it.

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FEATURE

Can Amphibians Help Conserve Native Fishes?

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Bull frog at the John Heinz National Wildlife Refuge in Philadelphia, Pennsylvania. Photo credit: Bill Buchanan/USFWS.

Native fish populations have continued to decline worldwide despite advances in management practices. As such, new approaches are needed to complement the old. In many flowing and standing waters, larval amphibians are the dominant vertebrate taxa. This can be important to fisheries due to amphibians' ability to influence macroinvertebrate communities, alter benthic habitat, and supply nutrients in aquatic systems. These changes can, in turn, affect the ecology and fitness of other aquatic organisms such as fishes. Due to their large effects in some systems, it is suggested that fisheries managers carefully consider actions that may affect amphibian populations and actively conserve them in some cases. Preservation of riparian areas and amphibian-associated microhabitats may even be used as a tool to positively impact freshwater fisheries by conserving amphibians that help maintain aquatic systems. Therefore, knowledge of local amphibian life histories and behaviors may be important in conserving associated freshwater fisheries.

INTRODUCTION

Population management of fishes has historically employed a diverse array of techniques, including habitat management, hatchery-reared fish stocking, species conservation, and harvest regulation (Cowx and Gerdeaux 2004). Despite the many successes of these techniques, the overall abundance and distribution of native North American fishes steadily declined throughout the 20th century (Williams et al. 1989), and climate change is predicted to further impact freshwater fishes in the 21st century (Heino et al. 2009). As such, a complementary suite of techniques and approaches is needed if management is to prevent further losses. One such complementary approach is the preservation of organisms that maintain ecosystem processes and geomorphic functions (Mills et al. 1993). Indeed, freshwater organisms that are particularly dominant or have a high biomass can exert a significant influence on sympatric species (Vanni 2002). In many ponds, wetlands, and stream headwaters, larval amphibians of the orders Anura (frogs and toads) and Urodela (salamanders) are the dominant vertebrate taxa (Davic and Welsh 2004; Ranvestel et al. 2004; Gibbons et al. 2006). Fisheries management plans that incorporate amphibians will likely be beneficial to much of the aquatic community.

Due to their high biomass in some systems, amphibians can have measurable effects on lotic and lentic habitats (Seale 1980; Rantala et al. 2015) and food webs in aquatic systems (Burton and Likens 1975; Pough 1980; Unrine et al. 2007). These effects can be divided into three general categories: (1) trophic interactions, (2) direct habitat alteration, and (3) nutrient redistribution (Figure 1). Here, I describe the three primary roles of amphibians in freshwater ecosystems and provide direction for future conservation of native fish and amphibian populations, a common management objective. Additionally, I give some suggestions for incorporating amphibians into fisheries management plans following the precedent of Knapp et al. (2001).

TROPHIC INTERACTIONS

Trophic interactions in aquatic ecology are a well-established phenomenon in which changes in the abundance of one species may alter the structure of the entire food web (Vanni 2002). In freshwater habitats, larval salamanders and anurans typically occupy different trophic levels, because salamanders tend to be obligate carnivores (Davic and Welsh 2004), whereas tadpoles are generally herbivores (Altig et al. 2007). A number of studies have found that salamanders decrease the densities of their aquatic

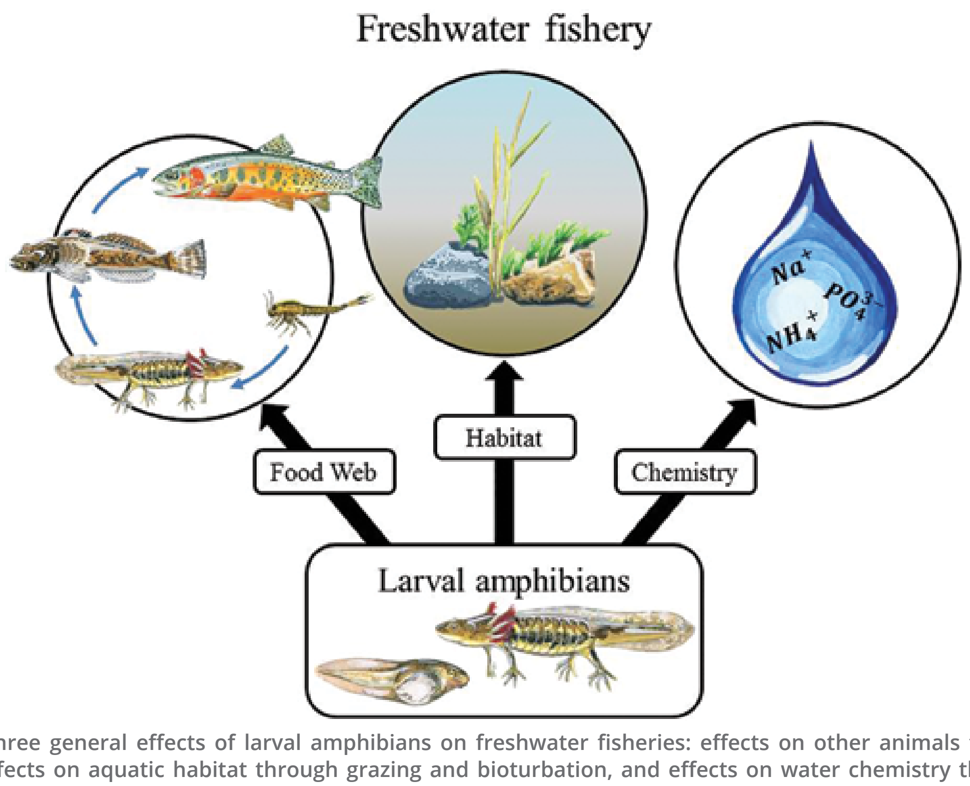

Figure 1. The three general effects of larval amphibians on freshwater fisheries: effects on other animals through trophic interactions, effects on aquatic habitat through grazing and bioturbation, and effects on water chemistry through nutrient redistribution. Figure by T. David Ritter.

invertebrate prey through direct predation and nonconsumptive effects (Huang and Sih 1991). Members of the genera *Ambystoma, Amphiuma, Cryptobranchus, Desmognathus, Dicamptodon, Notophthalmus, Siren,* and *Taricha* have all been implicated in altering densities of freshwater invertebrates (Petranka 2010). In some cases, predation by larval salamanders may be so extensive that responses may cascade through multiple trophic levels and regulate algal production and detritus–litter food webs (Davic and Welsh 2004). Indeed, the large effect of some salamanders on invertebrate populations has led some authors to label them as "keystone species" (Paine 1969; Davic and Welsh 2004). Impacts on invertebrate populations are likely to affect insectivorous fishes that are sympatric with salamanders.

In contrast to larval salamanders, anuran tadpoles are largely herbivorous (see Altig et al. 2007) and therefore can change invertebrate communities by influencing the biomass or productivity of primary producers; for example, tadpole losses in a Panamanian stream led to decreases in macroinvertebrate biomass and diversity, most likely through the consumption of biofilm and changes in benthic algal communities (Rantala et al. 2015). An additional study in four Panamanian streams found no difference in macroinvertebrate biomass before and after the loss of its anuran populations, but it did report shifts in the functional feeding groups of the invertebrate community from shredder to scraper dominance (Colon-Gaud et al. 2008). However, tadpoles of some taxa, such as the American bullfrog *Rana catesbeiana*, can even directly prey upon fish eggs and juveniles, which can have critical management implications where such fish are endangered (Mueller et al. 2006).

Larval amphibians also constitute a food resource for other animals, both aquatic and terrestrial (Rundio and Olson 2003; Petranka 2010). A study in a New Hampshire forest found that metamorphosed salamanders were a more nutritious food source than birds, mice, and shrews and comprised a greater biomass than that of all breeding birds and was at least equal to that of all small mammals (Burton and Likens 1975). Additionally, deposited eggs and carcasses of larval anurans and salamanders can be a terrestrial-derived, seasonal food source for aquatic organisms (Seale 1980; Capps et al. 2015). Where fish are introduced into previously fishless lakes and ponds, amphibian populations often decline, and subsequent removal of these fish can lead to population recovery (Knapp et al. 2007). In addition, where fish and larval salamanders co-occur, salamanders can incur nonconsumptive effects such as size reduction and reduced likelihood of metamorphosis (Kenison et al. 2016). As such, management actions that prioritize presence of nonnative fishes or overabundance of native fishes over larval amphibian conservation may inadvertently impact an important part of a fisheries food web (Knapp et al. 2001). In short, larval amphibians of both orders can influence macroinvertebrate communities. Accordingly, fisheries professionals should consider how local amphibian populations influence the invertebrate food resources of a fishery and where amphibians act as a food resource themselves.

DIRECT HABITAT ALTERATION

Habitat management is one of the most widely appreciated and accepted tenets of fisheries conservation. The term "habitat" generally includes both physical and biological variables, such as water depth and quality, substrate type, amount of cover, and macrophyte abundance (Fisher et al. 2012). Tadpoles can alter their surrounding biotic and abiotic habitats, in streams and still waters, through two mechanisms: (1) grazing and (2) the mechanical disturbance of benthic sediment from swimming (Flecker et al. 1999). These two mechanisms, though different, are inseparable. Several studies have found large decreases in benthic sediment and suspended particulate concentration with increasing tadpole abundance (Seale 1980; Flecker et al. 1999; Ranvestel et al. 2004). In addition to affecting primary producers, decreases in sediment can affect invertebrates and small fishes that are reliant on certain benthic conditions (Wood and Armitage 1997; Angradi 1999). Sediment can smother both primary and secondary producers (Power 1990); therefore, sediment removal may be one of the most important impacts of tadpoles in freshwater. Succinctly, tadpole foraging can change the benthic habitat of primary producers, invertebrates, and small fishes in both lotic and lentic habitats. In turn, this may affect fish species of management concern.

NUTRIENT REDISTRIBUTION

Nutrients such as nitrogen and phosphorus are extremely important to the growth and survival of all aquatic organisms (Sterner and Elser 2002). Freshwater animals can increase the concentration of nutrients through release of urea and solid waste. Larger animals, such as fish, can have similar or even greater total excretion rates than small, abundant animals, such as zooplankton (Vanni 2002). In habitats with and without fish, many amphibians also can substantially affect ecosystems due to nutrient redistribution (Connelly et al. 2011).

In some systems, both anuran and urodelan larvae can supply significant amounts of nutrients in streams, which often are important to primary producers and eventually other animals via nutrient flow through food webs (Vanni 2002; Connelly et al. 2011). However, nutrient inputs that contribute substantially on a localized scale may contribute more modestly over larger scales, and because amphibians leave freshwater following metamorphosis, aquatic nutrient subsidies are seasonal and depend on their specific life stage (Keitzer and Goforth 2013). Additionally, where temperature-related declines of fish cause a subsequent loss of nutrients supplied to a stream, the effect may be partially buffered where large populations of larval salamanders (Munshaw et al. 2013) and tadpoles are found. However, more research is needed to fully understand the effects of amphibian nutrient redistribution on freshwater systems.

MANAGEMENT IMPLICATIONS

As freshwater animal populations experience large global declines (World Wildlife Fund 2016), fisheries management must embrace new approaches and techniques to conserve native species. Larval frogs, toads, and salamanders can be important in maintaining the structure and function of freshwater ecosystems through trophic interactions, direct habitat alteration, and nutrient redistribution (Figure 1). Because of the abundance and subsequent effects of these vertebrates on the structure and function of some aquatic ecosystems, managers should incorporate amphibians into native fish conservation plans. Despite many management plans incorporating fish effects on amphibian populations, to the author's knowledge, few if any management plans have incorporated the reverse. Approaches for doing this can be broken into organismal and land management-based approaches.

Organismal approaches are often what fisheries managers are responsible for directly. Such approaches for incorporating amphibians include removal of invasive fishes where native amphibians are abundant, ceasing hatchery stocking of naturally fishless lakes (Knapp et al. 2001), and recording the types and numbers of amphibians observed during fieldwork. Recording amphibian sightings takes minimal effort and can be helpful to those attempting to compile information on anuran and urodelan populations and may aid in conservation efforts. Invasive amphibians, such as the American toad *Bufo americanus*, should also be carefully monitored and controlled if necessary. Additionally, population modeling efforts should determine whether incorporation of amphibian abundances can increase model accuracy.

In contrast to the manipulation of organisms, fisheries managers may not be directly responsible for management of riparian and aquatic habitats but may fill more of an advisory role. Therefore, land management approaches for conserving amphibians and fish must be tailored to specific land managers' needs. In areas of high amphibian abundance, these approaches should include limiting human impacts in headwater, pond, and wetland habitats; maintaining a riparian buffer zone (Petranka and Smith 2005); reducing pesticide application near waterways (Davidson and Knapp 2007); and maintaining or improving important amphibian microhabitats in both aquatic areas and the surrounding riparian areas during restoration activities. Some microhabitats that are especially important to amphibians include dense tree stands, rotting logs, leaf litter, backwaters, and wetlands (Semlitsch and Bodie 2003). In some cases, it may be useful to consider published thermal niches and habitat preferences for amphibian species of interest (Welsh 2011).

Overall, conservation of native amphibian populations and control of invasive populations may be an effective tool for managing freshwater fisheries. These actions will be most effective where larval amphibian populations are large. It should be noted that some actions may possibly have unforeseen consequences for fish populations of interest due to the inherent complexity of aquatic systems. As such, the aforementioned approaches should be applied in an adaptive management framework. Where amphibians and fishes coexist, the stream corridor can be thought of as a mosaic of amphibian and fish habitats. Maintenance of this mosaic is likely important for all organisms within, and it is possible that ignoring amphibian species may lead to unintended degradation of aquatic ecosystems.

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FEATURE

Aquatic Biodiversity in the U.S. State Wildlife Action Plans

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A male (upper) and female (lower) Arctic Grayling collected from Red Rock Creek, Montana. Photo credit: Jim Mogen/USFWS.

We surveyed state wildlife action plan (SWAP) coordinators in all 50 U.S. states; the commonwealths of Puerto Rico and the Northern Mariana Islands; the territories of the U.S. Virgin Islands, Guam, and America Samoa; and the District of Columbia to document the inclusion of aquatic animal species in the revised SWAPS, completed by state fish and wildlife agencies in 2015–2017. Based on the responses received, we anticipate increased coverage of several major aquatic groups, including fishes, dragonflies and damselflies, mollusks, crayfishes, and corals, in the revised plan documents. A majority of SWAPs will include key aquatic groups such as native freshwater fishes, freshwater snails, freshwater mussels, dragonflies and damselflies, crayfishes, stoneflies, and mayflies. By incorporating these species into the revised plans, state fish and wildlife agencies and their partners will have opportunities to apply dedicated funding from programs such as the State and Tribal Wildlife Grants Program to the conservation of these species and their habitats.

INTRODUCTION

The completion of the 56 state wildlife action plans (SWAPs) in 2005 marked a significant milestone in the conservation of native fishes and wildlife species in the United States. For the first time, each U.S. state, commonwealth, territory, and the District of Columbia had a single document that brought together information about species of conservation interest and their habitats, threats to aquatic and terrestrial biodiversity, current and planned conservation activities, monitoring approaches for species and ecosystems, and opportunities for public input and engagement (Riexinger and Williamson 2009; Stoms et al. 2010; Meretsky et al. 2012).

During 2015–2017, the 56 U.S. states, commonwealths, territories, and the District of Columbia revised these plans, with input from a broad spectrum of conservation organizations, academic biologists, government experts, and interested members of the general public (AFWA 2012). To date, most states have already completed their revisions, although many states are still awaiting the final review and endorsement of their draft plans by regional review teams and the U.S. Fish and Wildlife Service (USFWS).

The original 2005 SWAPs included 12,800 species that were considered species of greatest conservation need (SGCN) by individual state and territorial fish and wildlife management agencies (Benson 2016). Taken together, these plans included 1,523 fish species, 302 amphibian species, 277 Odonata species, 1,438 mollusk species, 886 crustacean species (including 244 crayfish species), and 143 coral species (Bried and Mazzacano 2010; Benson 2016). A complete list of all 12,800 species is currently available at a dedicated website maintained by the U.S. Geological Survey (USGS; Benson 2016).

One critique of the original set of SWAPs was the lack of coverage of certain aquatic invertebrate groups: Bried and Mazzacano (2010) reviewed coverage of Odonata species (dragonflies and damselflies) in the original set of SWAPS and found that more than half the states had not assigned dragonflies, damselflies, or species from both groups as SGCN in their plans. Building on this analysis, the states in the Northeast Association of Fish and Wildlife Agencies (AFWA) launched a major project, completed in 2014, to improve knowledge of the conservation status of these important aquatic invertebrates throughout the Northeast (White et al. 2014).

As part of broader efforts to improve and enhance the next round of SWAPs, our team at AFWA conducted a series of web-based surveys of SWAP coordinators in the 56 U.S. states, commonwealths, territories, and the District of Columbia between 2013 and 2016. Using the online survey platform SurveyMonkey, we asked the SWAP coordinators a series of questions about the status of their SWAP's revision. Given the strong interest in these plans on the part of our federal, academic, and nongovernmental organization partners, we also asked the SWAP coordinators several questions about particular groups of organisms that were likely to be included in their revised SWAP. In January 2016, as most of the SWAP revisions were undergoing review or nearing completion, we specifically asked the 56 SWAP coordinators whether they would be including representatives of certain aquatic groups (listed in Appendix A) in their revised plans. For three states where we did not receive responses to the survey, we consulted online drafts of their revised SWAP documents directly.

Based on data in Table 1 and Appendix A, it is clear that aquatic taxa will be featured prominently in many of the newly revised SWAPs. Nearly all 56 SWAP coordinators reported that they will be including native freshwater fishes (51 plans) and freshwater mussels (49 plans) in their revised SWAPs. The number of states and territories that will be including dragonflies and damselflies is now 38, and more than half of the plans will be including other important insect groups such as mayflies (28 plans) and stoneflies (32 plans). Even such relatively low-profile groups such as planarians and sponges will be included by 11 and 6 states, respectively. After all of the revised plans are approved by USFWS, complete lists of species in each of these groups will be available at a dedicated web site maintained by the USGS (Benson 2016).

By including these species in their SWAPs, states and territories will have expanded opportunities to conserve aquatic species in the United States. Dedicated funding is available to support the conservation of these species through the USFWS State and Tribal Wildlife Grants Program (AFWA 2011, 2012). Funds from this program can be used by states and territories and their conservation partners to develop and implement conservation strategies for aquatic organisms listed in their SWAPs, including assessment, monitoring, and habitat management activities. And multistate collaborations to benefit aquatic species can be supported through the competitive grants portion of the State and Tribal Wildlife Grants Program or through regional grant programs such as the Northeast Association of Fish and Wildlife Agencies Regional Conservation Needs Grant Program (Northeast Fish and Wildlife Diversity Technical Committee 2015).

From a conservation perspective, simply including a species as a SGCN in a SWAP is not enough to ensure that there will actually be conservation actions taken to benefit that species. There must also be dedicated funding, staff, and partners who are all willing to implement the needed conservation activities for that species. In recent years, State and Tribal Wildlife Grants Program funding has been provided as an annual appropriation from the U.S. Congress at levels that provide basic support for the nongame or wildlife diversity programs in each state and territory but that do not begin to cover all of the conservation requirements for all of the species included in SWAPs. Recent legislative proposals, such as the Recovering America's Wildlife Act (2016) introduced in the 114th Congress, would dedicate significant new resources (potentially up to US$1.3 billion per year) to the conservation of SGCN and their habitats.

Even with relatively modest funding, states, territories, and their partners have been able to take significant actions since

Table 1. Coverage of select groups of aquatic vertebrate and invertebrate organisms in the 2005 and 2015–2017 (anticipated) state wildlife action plans.[a]

Aquatic group	Number of species, 2005	Number of plans, 2005	Number of plans (anticipated), 2015–2017
Fishes	1,523	55	56
Odonata	277	35	38
Crayfishes	244	28	32
Mollusks	1,428	55	56
Corals	143	5	7
Planarians	23	10	11
Sponges	19	6	6

[a] The number of species from each group included in the 2015–2017 plans will be available on a dedicated U. S. Geological Survey website (Benson 2016) when all of the revised plans are finally approved by the U.S. Fish and Wildlife Service.

2005 to conserve species identified in the first round of SWAPs. A 2011 report by AFWA provided examples of projects supported by State and Tribal Wildlife Grants Program funding which benefited species included in the SWAPs. In this report, 17 of the 50 states provided details on projects involving native aquatic species, including freshwater fish species (seven states), freshwater mussels (five states), freshwater snails (three states), and aquatic salamanders (two states). Prominent examples of projects supported with State and Tribal Wildlife Grants Program funding include the creation of the Alabama Aquatic Biodiversity Center, which has successfully raised 12 federally listed and candidate freshwater mollusk and fish species; the Fluvial Arctic Grayling Restoration Project in Montana, which worked with private landowners to conserve habitat for the upper Missouri River basin distinct population segment of Arctic Grayling *Thymallus arcticus*; and surveys for rare native fish species in Pennsylvania, which resulted in more accurate population estimates for 10 native fish species and the removal of these species from the state's endangered species list (AFWA 2011).

Given this record of conservation activities, the fact that additional aquatic taxa are being included in the revised SWAPs suggests that these plans could lead to additional conservation opportunities for aquatic organisms throughout the United States. However, the full realization of these opportunities will require broad and sustained collaboration between the state fish and wildlife agencies and the larger conservation community. We therefore encourage U.S. members of the American Fisheries Society with an interest in the conservation of imperiled aquatic species to reach out to the SWAP coordinator in their state or territory in order to contribute their knowledge and technical assistance toward the implementation of this new and ambitious round of SWAPs.

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APPENDIX A

The following text question was provided using the online survey platform SurveyMonkey to the 56 U.S. SWAP coordinators for response on January 29, 2016. Survey responses (in parentheses, with additions from review of draft SWAP documents from nonresponding states indicated as such) were received during February 2016 and tallied for presentation at the North American Wildlife and Natural Resources Conference in Pittsburgh, Pennsylvania, in March 2016.

Which of the following aquatic taxa did you include in your 2015 (or most recent) state wildlife action plan revision as species of greatest conservation need? Check all that apply: native freshwater fishes (49 positive responses plus 2 from plan documents), marine fishes (20 plus 2), freshwater snails (35), freshwater mussels (47 plus 2), marine mollusks (snails, clams, oysters, etc.,16 plus 2), crayfishes (31 plus 1), other crustaceans (24 plus 2), Odonata (dragonflies and damselflies; 35 plus 3), Ephemeroptera (mayflies; 28), Plecoptera (stoneflies; 30 plus 2), Trichoptera (caddisflies; 26 plus 1), planarians (9 plus 2), corals (6 plus 1), and sponges (5 plus 1). AFS


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BOOK REVIEW

The Fishes of Pennsylvania

Jay R. Stauffer, Jr., Robert W. Criswell, and Douglas P. Fischer. Cichlid Press, El Paso, Texas. 2016. 556 pages. US$49.50.

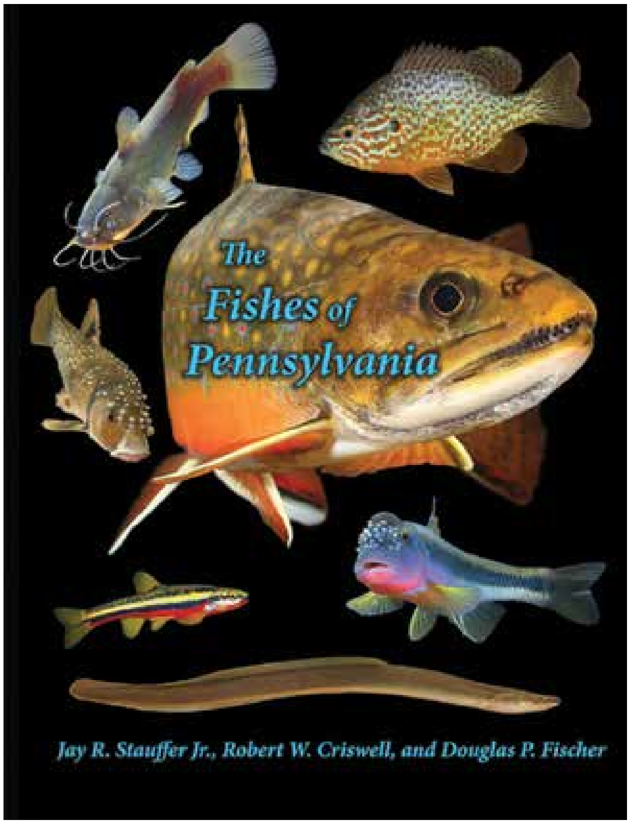
The last major treatment of the fishes of Pennsylvania was the 1983 publication *Fishes of Pennsylvania and the Northeastern United States* by Edwin L. Cooper. This current volume is a welcome advanced edition to the fishes of the Commonwealth of Pennsylvania. An advantage over the previous edition is its beautiful glossy photographs of habitat; full-color photographs of all of the fishes represented in habitat simulated situations; and 196 distribution maps, divided into pre-1940, 1940–1989, and 1990–2015 distributions over the six major drainage basins of the state.

All of this information is accurate, well presented, and clearly written, making this a very useful book for professionals and nonprofessionals alike.

There is also an abundance of black-and-white photographs and line illustrations pointing out key features used in the identification keys. In addition, each species is given a current conservation status and general remarks aimed at a mixed audience of professionals, conservationists, and anglers.

The structure of the book consists of the first 69 pages divided into six chapters providing important background information, which includes an introductory chapter giving a brief history of Pennsylvania ichthyology, a chapter outlining the major watersheds and drainage basins of the state, a brief discussion of conservation of fishes in Pennsylvania, and a synopsis of sportfishing in the state. This is followed by a chapter on basic fish anatomy, outlining the features used in the family and species keys, and a chapter giving a brief history of the study of fishes in Pennsylvania. This interesting and useful background information is then followed by the main section of the book, Chapter 7, a thorough description of the families, genera, and species historically reported from and/or currently found in the state.

This main section of the book begins with an excellent dichotomous key to all of the 28 families covered in the text, including the page where the family discussion begins. This is then followed with a dichotomous key to all of the species in each family, some 200 species in total, unless there is only a single species in the family represented in the state. These keys are excellently constructed and illustrated making for ease of use. I have tested all of the family keys and the majority of the species keys and found them user friendly and accurate. The format of the text is to provide a brief description of the family, followed by a description of the genus, and then the species within that genus. The characters of each species are fully described and match the points made in the keys. This is followed by a discussion of the distribution and habitat and then a section on the biology of the species, including life history, fecundity, and diet. The final paragraphs for each species consist of the current global and state conservation ranking, including notes of interest to the conservationist and angler, such as stocking history. All of this information is accurate, well presented, and clearly written, making this a very useful book for professionals and nonprofessionals alike.



There is also a useful glossary and index and an extensive literature cited section. My one criticism of the work is that not all of the citations in the text are found in the literature cited section, and this can be frustrating. This was a particular problem in Chapter 3, "The Conservation of Fishes in Pennsylvania," but was found at a minimum in all of Chapter 7, the main section of the book. This should be addressed in any future revisions of the book.

Reviewed by Joseph W. Rachlin, Professor
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NMFS has supported habitat assessments (NMFS OST 2017) that led to improved stock assessments and supported the goals of EBFM for several managed species since the 2010 release of HAIP. A well-publicized example is work led by John Manderson and colleagues at the Northeast Fisheries Science Center that examined temperature-dependent fluctuations in Butterfish *Peprilus triacanthus* habitat to account for shifts in their catch in fishery-independent surveys. Catch data were recalibrated to account for this habitat-related influence on distribution, with the results applied to refining the stock assessment that had previously underestimated their numbers. As a direct result of this study, the Butterfish quota was increased seven-fold, from 3.2 million lb in 2014 to 22.5 million lb in 2015, and the stock was no longer declared as overfished (Adams et al. 2015). Another example is work conducted by Shelton et al. (2014) that integrated spatial habitat and fisheries effort data to improve estimates for West Coast groundfish species. The results of this study have the potential to enhance groundfish stock assessments as well as to provide information relevant to the California Current Integrated Ecosystem Assessment (IEA) combine and separate; (NOAA 2017b). Other examples include studies that improved catchability estimates of Alaska snow crab populations (resulting in an increase in their overfishing limits by 64%), provided habitat-specific growth and productivity rates of juvenile penaeid shrimps in the Gulf of Mexico, as well as habitat assessments for a suite of species including Summer *Paralichthys dentatus* and Winter *Pseudopleuronectes americanus* flounder, sardine species, West Coast groundfishes, and Southeast reef fishes—all of which can advance ecosystem modeling and inform EBFM.

Applied understanding of the ecological role of habitat in marine ecosystems through habitat research and assessments can strengthen EBFM implementation. Studies should integrate physical habitat characterizations (including substrate and water column) with the quantification of ecological relationships between habitats and LMRs at the species and multi-species levels. They should also account for physical and biological connections among habitats, since the connections between habitats may be indirect (e.g., through food chains), and the habitat dependencies of fishes change over their life cycles. An important connection for NMFS is between inshore and offshore habitats, because many anthropogenic impacts (including hydropower effects, river diversions, and water quality impairments) extend inland within freshwaters where diadromous species and their prey occur. Additionally, these and many other human factors continue to impact downstream estuarine and coastal areas throughout watersheds, where many nursery habitats are located, while the harvests managed by NMFS primarily take place offshore in federal waters. Multi-scale approaches that address the integral role of habitat from the population to ecosystem level can lead to more holistic assessments of LMRs and facilitate improved design and analysis of fishery-independent surveys, reduced uncertainty in stock assessments, and enhanced EFH designations and ecosystem models. Under an EBFM context, a systematic approach to habitat research is warranted that considers multiple habitats in a given area to better delineate EFH across multiple life stages, species and trophic levels. Improved information on shared habitats among stocks also can be used to reduce bycatch, and a better understanding of habitat disturbance by fishing and other anthropogenic activities can be used to reduce or mitigate effects on local, stock, and ecosystem-level productivity.

Since the publication of the HAIP, NMFS has supported research to improve habitat science and habitat assessments by funding short-term, small-scale projects. Building on these efforts, NMFS is working to enhance support for habitat science through habitat-centric efforts, including NOAA's Habitat Blueprint (NOAA 2017a), and by increasing habitat information that is available to ecosystem science efforts such as NOAA's IEA program. Despite limited resources and budgetary challenges, advances in habitat science and in the promotion of habitat conservation continue to be made since the release of the HAIP, and are now being applied in a broader EBFM context. Continued focus on the habitat aspects of ecosystem processes and their associated species will lead to a more complete implementation of an ecosystem approach to management, and provide for the most scientifically sound conservation of our managed species, the ecosystems that support them, and the sustainability of our fisheries.

ACKNOWLEDGMENTS

We thank the Habitat Assessment Improvement Plan coauthors and working group members for their continued efforts to advance habitat science priorities for NOAA and for their input to this article. We additionally thank Jason Link, Rebecca Shuford, and Rebecca Peters for their reviews of earlier drafts.

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new policy. As we examine hydropower facility operations, fisheries and waterway managers should petition to re-open the Federal Energy Regulatory Commission licensing process, thereby allowing debate about fish prescriptions to allow sufficient water flow and volume to fill channels as needed. For other water control structures, we might have re-openers in other regulatory processes run by the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and other water management agencies.

This is hopeful, perhaps audacious, but reasonable. Why shouldn't we apply an ecosystem-based approach to these regulatory processes and evaluate basin-wide decisions by watersheds? Ownership and licensing schedules differ among dams in most watersheds and legal resources are limited but shouldn't we synchronize decisions to make better decisions? The situation differs in artificial habitats like reservoirs but ecosystem perspectives would help. It is possible.

A recent USFS (2017) newsletter provided a complementary perspective. When we remove dams (72 in 2016; 1,384 since 1912; see American Rivers 2017), our waterways can recover. Applying that logic to the findings of Cooper et al. (2017), my optimism increases. Resilient rivers and fish assemblages can be improved with our help . . . if we act before the situation worsens.

Note: the opinions expressed herein are those of the author alone. Comments are invited at tbigford@fisheries.org.

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CALENDAR

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

June 19–21, 2017

Fish Passage 17: International Conference on Engineering and Ecohydraulics for Fish Passage | Oregon State University, Corvallis, Oregon | https://fishpassage.umass.edu

June 20–22, 2017

58th Western Fish Disease Workshop | Clearwater Resort, Suquamish, Washington | http://www.afs-fhs.org/perch/resources/14770834352017wfdwsavedate.pdf

June 26–28, 2017

European Inland Fisheries and Aquaculture Advisory Commission Symposium: Adaptation of Inland Fisheries to Climate Change | Olsztyn, Poland | eifaac2017.infish.com.pl

July 3–7, 2017

50th Anniversary Symposium of the Fisheries Society of the British Isles | University of Exeter, UK | http://www.fsbi.org.uk/conference-2017/symposium-theme-3

July 11–14, 2017

ICAST 2017 Sportfishing Trade Show | Orlando, Florida | http://www.icastfishing.org

July 16–20, 2017

World Recreational Fishing Conference | Victoria, British Columbia, Canada | wrfc8.com

July 18–20, 2017

Joint summer meeting of the AFS NCD Centrarchid Technical Committee, Esocid Technical Committee, and Walleye Technical Committee | Isle, Minnesota | ncd.fisheries.org/walleye

August 20–24, 2017

147th Annual Meeting of the American Fisheries Society | Tampa, Florida | afsannualmeeting.fisheries.org

September 10–15, 2017

13th International Symposium on the Biology and Management of Coregonid Fishes | Bayfield, Wisconsin | http://www.coregonid2017.com

September 26–29, 2017

Wild Trout Symposium XII | West Yellowstone, Montana | http://wildtroutsymposium.org

October 2–4, 2017

8th International Conference on Fisheries & Aquaculture | Toronto, Canada | http://fisheries.conferenceseries.com

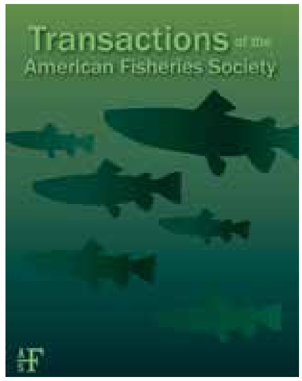
October 19–21, 2017

7th International Conference on Aquaculture & Fisheries | Rome, Italy | http://aquaculture-fisheries.conferenceseries.com

October 30–November 3, 2017

Workshop on Recruitment: Theory, Estimation, and Application in Fishery Stock Assessment Models | Rosenstiel School of Marine and Atmospheric Science, Miami, Florida | http://www.capamresearch.org/workshops

Journal Highlights



Transactions of the American Fisheries Society
Volume 146, Number 2, March 2017

[Note] Use of Molecular Techniques to Confirm Nonnative Fish Predation on Razorback Sucker Larvae in Lake Mohave, Arizona and Nevada. *Chase A. Ehlo, Melody J. Saltzgiver, Thomas E. Dowling, Paul C. Marsh, and Brian R. Kesner*. 146:201–205.

Spatial Variability of Chinook Salmon Spawning Distribution and Habitat Preferences. *Jeremy M. Cram, Christian E. Torgersen, Ryan S. Klett, George R. Pess, Darran May, Todd N. Pearsons, and Andrew H. Dittman.* 146:206–221.

[Note] A Quantitative Chronology of Diurnal Feeding in Juvenile Pacific Salmon. *Stuart H. Munsch, Jeffery R. Cordell, and Jason D. Toft*. 146:222–229.

Effects of Passive Integrated Transponder Tags on Survival, Growth, and Swimming Performance of Age-0 Shovelnose Sturgeon. *David A. Schumann, David Deslauriers, Matthew D. Wagner, Katie N. Bertrand, and Brian D. S. Graeb*. 146:230–239.

Deletion and Copy Number Variation of Y-Chromosomal Regions in Coho Salmon, Chum Salmon, and Pink Salmon Populations. *A. F. Muttray, D. Sakhrani, J. L. Smith, I. Nakayama, W. S. Davidson, L. Park, and R. H. Devlin.* 146:240–251.

Walleye Introduction Eliminates Predation Refuge for Adfluvial Cutthroat Trout and Rainbow Trout. *Clark F. Johnson, Brett M. Johnson, Travis E. Neebling, and Jason C. Burckhardt*. 146:252–267.

Reproduction of Lake Trout Morphotypes at Isle Royale in Northern Lake Superior. *Frederick Goetz, Shawn Sitar, Andy Jasonowicz, and Michael Seider.* 146:268–282.

Timing and Location of Spawning Based on Larval Capture and Ultrasonic Telemetry of Atlantic Sturgeon in the Saint John River, New Brunswick. *Andrew D. Taylor and Matthew K. Litvak*. 146:283–290.

Trophic Interactions and Consumption Rates of Subyearling Chinook Salmon and Nonnative Juvenile American Shad in Columbia River Reservoirs. *Craig A. Haskell, David A. Beauchamp, and Stephen M. Bollens*. 146:291–298.

Electrical Guidance Efficiency of Downstream-Migrating Juvenile Sea Lampreys Decreases with Increasing Water Velocity. *Scott M. Miehls, Nicholas S. Johnson, and Alex Haro*. 146:299–307.

Critical Foraging Habitat of Atlantic Sturgeon Based on Feeding Habits, Prey Distribution, and Movement Patterns in the Saco River Estuary, Maine. *Ashleigh J. Novak, Amy E. Carlson, Carolyn R. Wheeler, Gail S. Wippelhauser, and James A. Sulikowski*. 146:308–317.

Population Characteristics of Adult Atlantic Sturgeon Captured by the Commercial Fishery in the Saint John River Estuary, New Brunswick. *Michael J. Dadswell, Cornel Ceapa, Aaron D. Spares, Nathan D. Stewart, R. Allen Curry, Rodney G. Bradford, and Michael J. W. Stokesbury*. 146:318–330.

Effects of Common Carp on Trophic Dynamics of Sport Fishes in Shallow South Dakota Water Bodies. *Alexander P. Letvin, Michael L. Brown, Katie N. Bertrand, and Michael J. Weber*. 146:331–340.

[Note] Feeding by Bluefish and Weakfish along Riprap-Hardened Shorelines: Comparisons with Adjacent Sandy Beach in Delaware Bay, USA. *Michael P. Torre and Timothy E. Targett*. 146:341–348.

Relationships between Chinook Salmon Swimming Performance and Water Quality in the San Joaquin River, California. *Brendan Lehman, David D. Huff, Sean A. Hayes, and Steven T. Lindley*. 146:349–358.

[Note] Microtrolling: An Economical Method to Nonlethally Sample and Tag Juvenile Pacific Salmon at Sea. *William D. P. Duguid and Francis Juanes*. 146:359–369.

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A Hairy Couple

"This pair of Hairy frogfishes *Antennarius striatus* was waiting for their next meal at night in the Lembeh strait in Indonesia. To be noted, we have witnessed frogfishes eating mates of similar size. The male (smaller in this picture) must hope madam is in the right mood."

Christian Gloor
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