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AMERICAN FISHERIES SOCIETY
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2013 ANNUAL REPORT

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ANNUAL REPORT INSIDE

valuable [aspects of the organization]. Right now the NMFS [National Marine Fisheries Service] is in the middle of reauthorizing the Magnuson Stevens Act. It's hard to get everyone involved in fisheries at one single time. A group like AFS can provide that forum for professionals in fisheries to discuss and come together and establish goals of what they could change and refurbish within the act. ”

Steve Meyers
NMFS, Domestic Fisheries Division

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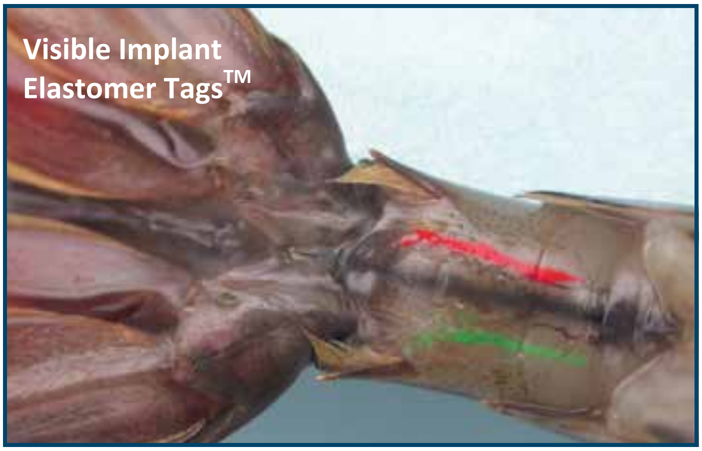
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Northwest Marine Technology, Inc.

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Shaw Island, Washington, USA

Corporate Office
360.468.3375 office@nmt.us

Biological Services
360.596.9400 biology@nmt.us

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Cover: European Mudminnow (*Umbra krameri*). Photo credit: J. Wanzenböck.

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(301) 897-8616 • fax (301) 897-8096 • main@fisheries.org

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COLUMN

President's Commentary

Livestock Grazing in the West: Sacred Cows at the Public Trough Revisited

Bob Hughes, AFS President

AFS President Bob Hughes can be contacted at: hughes.bob@amnisopes.com

Globally, agriculture has co-opted much of Earth's terrestrial primary production, but livestock grazing is a close second in converting native flora and fauna to anthropogenic products (Vitousek et al. 1986). Private-land agriculture remains the major pressure on North American waters on an areal basis; however, livestock grazing on public lands is the most widespread conservation concern in much of western North America. Many of the damaging effects of grazing can be reduced by markedly decreasing the number of animals grazed, greatly limiting their access to riparian zones, and fallowing large areas for multiple years (Knudson 1999). Although there are certainly many conservation-minded ranchers, it makes little sense to me to subsidize livestock grazing on public lands for three major reasons.

1. Economics

The U.S. Government Accountability Office (2005) documented the FY2004 expenditures and receipts of 10 federal agencies for livestock grazing on federal lands, with the Bureau of Land Management (BLM) and U.S. Forest Service (USFS) managing 98% of those lands. Those 10 agencies spent a total of at least $144 million on land and water management for livestock grazing, but generated only $21 million in grazing fees in 2004. Assuming that is a reasonable annual estimate, this is a yearly $123 million federal subsidy to livestock ranchers, mostly in the western United States. Rather than the BLM and USFS fee of $1.43 per animal unit month (cow/calf pair, 1 horse, 5 sheep), the agencies would need to charge $7.64 and $12.26, respectively, to match their expenditures (U.S. Government Accountability Office 2005).

These costs do not include the indirect costs of soil erosion, reservoir sedimentation, degraded water quality, alien invasive plant introductions, and species endangerment. Some may argue that these subsidizes stimulate western economies and employment, but Power (2002) reported that federal forage contributed an average of only 0.04% and 0.07%, respectively, to the income and jobs of the 11 western states. When the nation is cutting other social and environmental programs, why should taxpayers subsidize a small class of often wealthy citizens, at least three of whom (Cliven Bundy, Kit Laney, Frank Robbins) refused to pay even those fees and penalties for decades? Why should we be sacrificing public land, forage, water, and wildlife and fish species to benefit three sacred species—thereby leading to the extirpation of native species? Why should we subsidize livestock grazing in national parks, wilderness areas, and wildlife refuges with markedly contrary management goals (Fleischner 1994; Kerr and Salvo 2002)?

2. Ecological damage

Livestock grazing damages more public land than fire, logging, and roads combined in the western United States, but much less is spent to mitigate grazing effects than to mitigate those other pressures (Beschta et al. 2013). Roughly 70% of the land area in the conterminous 11 western states is grazed by livestock (Fleischner 1994). In seven states (Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming), the majority of land area, and thus the waters that drain those lands, is managed by the federal government for livestock grazing. Riparian areas cover less than 2% of the West. However, livestock tend to aggregate in riparian zones, which are essential habitats for many terrestrial wildlife taxa and produce crucial aquatic habitat for fish through their effects on channel morphology, food webs, water quality, and fish cover (Gregory et al. 1991; Baxter et al. 2005; Beschta et al. 2013).

Those livestock aggregations remove riparian vegetation, trample stream banks, initiate incision or widening depending on channel slope and substrate, reduce groundwater and stream flow, elevate water temperature, increase turbidity and sedimentation, and lead to eutrophication (Platts 1991; Beschta et al. 2013). Such habitat changes have led to range reductions and imperilment of salmonids throughout the West (Jelks et al. 2008), but livestock removal experiments have produced marked increases in salmonid production, biomass, and individual size (Fleischner 1994). For example, small (<500 m long) grazing exclosures showed significant positive effects on age-0 Rainbow Trout (*Oncorhynchus mykiss*), but because of the extensive and intensive damage of western riparian zones by livestock grazing, those exclosures are ineffective at the population or watershed scales (Bayley and Li 2008). Watershed-scale impacts from grazing include devegetation, soil compaction, and water removal for irrigated pastures and hayfields—all of which mean reduced streamflows, degraded channel morphology, reduced and degraded fish habitat, and salmonid extirpations (Ferguson and Ferguson 1983; Platts 1991; Fleischner 1994; Wuerthner and Matteson 2002; Beschta et al. 2013).

3. Aridity and climate change

Nearly all public land livestock grazing occurs on arid and semi-arid lands where approximately 100 times the acreage is

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COLUMN
Policy

Forage Species and Issues

Thomas E. Bigford, AFS Policy Director

AFS Policy Director Thomas E. Bigford can be contacted at: tbigford@fisheries.org

"Forage" was once a simple term synonymous with food. The word conjured visions of little fish being consumed by larger predators. We've known about food chains since forever but the concept now is more complex than basic ecology. The term and its implications have been evolving for the last couple decades, prompted by our increasing pursuit of driving factors in ecosystem dynamics and effective management. This column seeks to add clarity while also garnering attention for what is certainly an important variable in ecosystem models, overall environmental awareness, and fishery management. Though forage is a broad term, I will focus on forage fish, leaving other delectable morsels for a later discussion.

This issue gained attention when some forage stocks were depleted by directed fisheries. For example, schools of Menhaden, a valued industrial fish along the Atlantic and Gulf coasts, were captured in huge quantities by industrial fisheries that prompted secondary impacts on highly prized Bluefish and Striped Bass populations. Attention heightened when some charismatic birds and mammals suffered from fewer River Herring, Smelt, Alewives, Alaskan Pollock, or other food species. The lack of sufficient preferred food, a.k.a. forage, emerged as a new factor in resource management. Forage morphed from an ecological term in our college textbooks into an issue with major implications, including many with economic overtones. Forage stocks had shifted from the background to the foreground, where they remain today.

Some definitions will help. At least visually, forage species are dominated by the tiny fish that school by the millions and nourish aggressive predators such as muskies, salmon, and sharks. Ecologically, forage fish of all sorts are invaluable and pose multiple challenges to our research and management endeavors. All of the scientific and management challenges we associate with highly valued predators apply equally to forage species. We need to conserve their habitat, understand their population dynamics, monitor their health, and relate all of that in an ecosystem context that intersects with other levels in aquatic food webs. As we're learning, healthy forage populations often translates into more, larger fish to allocate to harvest sectors, including but not exclusively humans.

With a common understanding of my definition, we can delve into the issues and seek common ground, or at least improved acceptance. Responsible fishery management, or ecosystem management, implores us to consider multiple levels of the food chain. We can't manage Great Lakes Whitefish separately from its forage. Ditto for every other species we study or manage. Successful fishery management must be based on research that establishes forage biomass thresholds, models harvest options, and considers management decisions as diverse as spatial area designations or set asides to meet the needs of their natural predators. Outside fishery management but still very much related to forage, we'll need clarity as we develop recommendations to protect or restore habitats of forage species, which is an essential basis for healthy populations of most species.

These are complicated ecological issues. The literature alludes to predator–prey dynamics with phrases such as "who drives whom," "finding the accelerator and brake" in harvest quota management, and "riding the forage fish accelerator" in ecosystem approaches. The colorful writing recognizes forage as key variables, as elusive targets that demand our attention as they zoom through aquatic systems.

The attention focused on forage fish is timely. As we approach fishery management from an ecosystem perspective, we are constantly reminded that fish populations can be affected by any of multiple factors. When managing fish stocks with commercial or recreational value, harvest controls alone do not always remedy fish population problems. Sometimes poor population health relates to a lack of forage or indirectly from some environmental factor that affects forage. As one emerging example, we're learning that some fish population challenges may be related to aquatic systems shifting in the face of climate change and then manifested through decreased forage fish availability.

As I reminisced about the past few decades of fishery management, I recall glimpses of forage management at all levels. The Pacific Fishery Management Council (2014) developed a fishery management plan for forage fish in the 1970s that was shelved but formed some of the basis for an effort that eventually matured in 2013 into an ecosystem plan for the West, with a focus on unmanaged forage. The Atlantic States Marine Fisheries Commission's (2014) long interest in Menhaden evolved into a decision to reduce commercial harvest in favor of conserving smaller sizes to support stocks of prized predators. Now it is rare for a regional fishery research or management body not to have a forage fish under its jurisdiction or not to have a plan for addressing forage issues.

Limited data remain a challenge throughout the forage arena, but we are filling gaps in both knowledge and

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Ecology and Conservation of Mudminnow Species Worldwide

Lauren M. Kuehne

School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195

Julian D. Olden

School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195, and Australian Rivers Institute, Griffith University, QLD, 4111, Australia. E-mail: olden@uw.edu

ABSTRACT: *We review and summarize the ecology and conservation status of the group of fishes commonly known as "mudminnows" (formerly known as the family Umbridae but recently reclassified as Esocidae), consisting of only five species distributed on three continents. These small-bodied fish—residing in freshwater habitats and exhibiting limited mobility—often occur in isolated populations across landscapes and are subject to conservation threats common to highly endemic species in close contact with anthropogenic impacts, such as pollution, habitat alteration, and nonnative species introductions. Herein we summarize current knowledge of the distributions, phylogenetic relationships, ecology, and conservation status of each species of mudminnow, including nonnative occurrence and distribution. We also outline the primary conservation threats to particular species and make recommendations for future research to promote much needed knowledge and conservation attention.*

Ecología y conservación a nivel mundial de los lucios

RESUMEN: *en este trabajo, se revisa y resume la ecología y estado de conservación del grupo de peces comúnmente conocido como "lucios" (anteriormente conocidos como la familia Umbridae, pero recientemente reclasificados en la Esocidae) los cuales se constituyen de sólo cinco especies distribuidas en tres continentes. Estos peces de cuerpo pequeño —que viven en hábitats de agua dulce y presentan movilidad limitada— suelen presentar poblaciones aisladas a lo largo de distintos paisajes y son sujetos a las típicas amenazas que enfrentan las especies endémicas que se encuentran en contacto directo con los impactos antropogénicos como la contaminación, alteración de hábitat e introducción de especies no nativas. Aquí se resume el conocimiento actual acerca de la distribución, relaciones filogenéticas, ecología y estado de conservación de cada especie de lucio, incluyendo aquellas que son de ocurrencia y distribución no nativa. También se identifican las principales amenazas a nivel género o especie y se hacen recomendaciones para investigaciones futuras encaminadas a promover tanto el conocimiento como la atención de conservación hacia este grupo.*

INTRODUCTION

Worldwide, biodiversity of freshwater fish species is increasingly threatened by anthropogenic pressures such as land use, pollution, water management, and species invasions (Dudgeon et al. 2006). In the 20th century, North American freshwater fishes had the highest extinction rate worldwide among vertebrates (Burkhead 2012), and predicted future rates of extinction are up to five times higher than for terrestrial organisms (Ricciardi and Rasmussen 1999). This includes many small-bodied species that are at global risk for extinction (Olden et al. 2007). With many competing interests in freshwater resources to balance, research on status, potential declines, and conservation threats inevitably focus on species of economic or particular ecological importance (e.g., large-bodied fish, game fish, or "keystone" species; Stone 2007). This can leave very large research gaps, however, in assessing the existing research knowledge and conservation status of nongame freshwater species that may serve important ecological roles or represent important components of biodiversity but are simply understudied and underappreciated (Monroe et al. 2009).

We believe this is the case (and seek to address a knowledge gap) with the group of fishes commonly known as "mudminnows," composed of only five species worldwide that inhabit low elevation regions in Europe, the eastern and northwestern coasts of North America, and Alaska/Siberia ("Beringia"; Figure 1). Mudminnows are small-bodied (<20 cm) fish typically found in wetlands, stream and river margins, bogs, lakes, and marshes. Historically, the five species were classified and referred to as a monophyletic family Umbridae, but phylogenetic evidence accumulated over several decades has led to recent reclassification with their closest relatives, the Esocidae (pike and pickerel; Box 1). Mudminnows are thought to have diverged into their three recognized genera (*Umbra*, *Novumbra*, and *Dallia*) prior to the Oligocene (Cavender 1969; Gaudant 2012). Their historical biogeography is known by only a small number of fossil records, but current populations are generally considered to be relicts of larger historical distributions (Cavender 1969; Gaudant 2012; Campbell and López 2014).

The five species of mudminnows present not only an interesting case study into the challenges that face many highly endemic freshwater species in a changing world but a fascinating snapshot into components of biodiversity and adaptation. Over the years, mudminnow species have often excited (local) research interest due to curious physiological and life history adaptations that allow them to make use of underutilized habitats. Stories by indigenous peoples in Alaska attributed Alaska Blackfish with the ability to revive after being frozen (Brown et al. 2010); although this particular legend has been proved false, mudminnows are very cold tolerant (Peckham and Dineen 1957; Meldrim 1968). Their ability to withstand harsh winters is

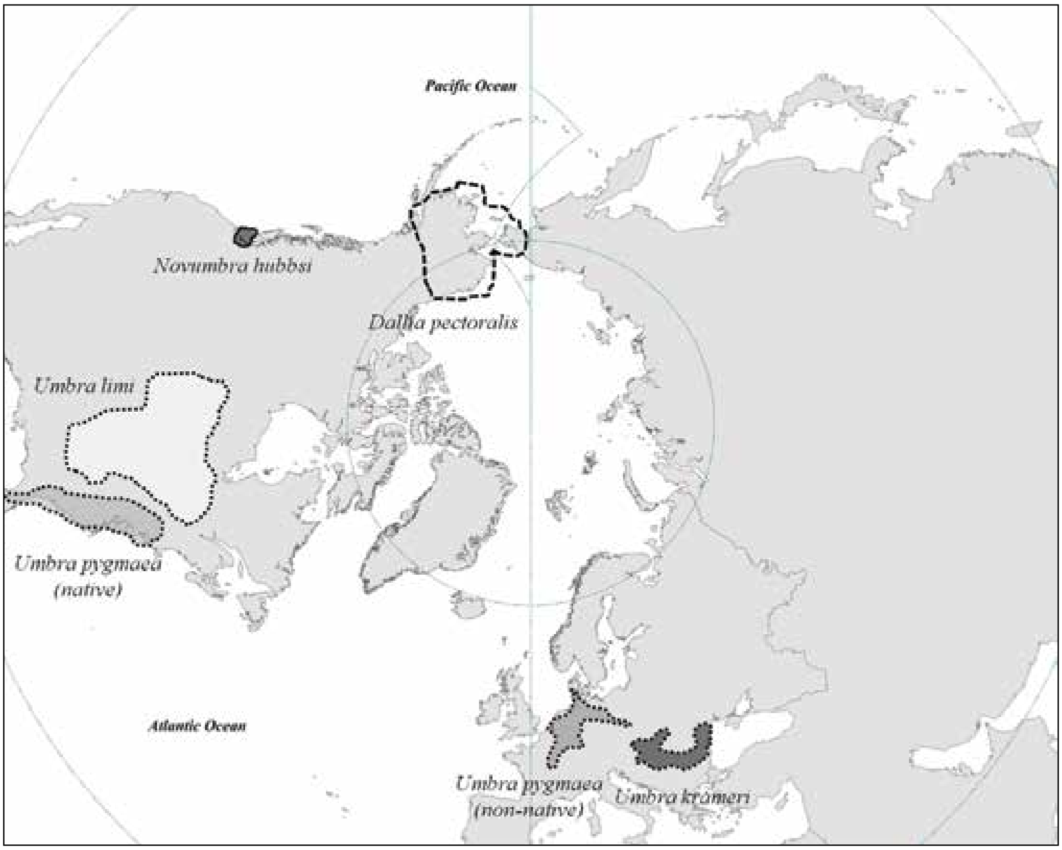

Figure 1. Generalized distributions of mudminnow species worldwide, including the nonnative distribution of Eastern Mudminnow in Europe. Species distributions are shown as follows: Central Mudminnow (*Umbra limi*); Eastern Mudminnow (*Umbra pygmaea*); European Mudminnow (*Umbra krameri*); Alaska Blackfish (*Dallia pectoralis*); Olympic Mudminnow (*Novumbra hubbsi*). Distributional data sources are Becker (1983; *U. limi*), Verreycken et al. (2010; *U. pygmaea*, native and nonnative ranges), Wanzenböck (2004; *U. krameri*), Campbell (2011; *D. pectoralis*), and Harris (1974; *N. hubbsi*).

BOX 1. Mudminnow phylogeny: from Umbridae to Esocidae

The two high school students (Edward Frazer and William Prince) taking part in a summer science camp in central Oregon in 1964 likely had no idea that the fossil specimens (later named *Novumbra oregonensis*) they discovered would spark a 50-year phylogenetic debate on inter- and intrarelationships of mudminnow species. Interest in evolutionary relationships of mudminnows to each other and within the order Esocifomes has proved as intense as it has been problematic, however, with our literature review resulting in no less than 12 (out of a total 69) peer-reviewed articles, with evidence ranging from morphological to molecular.

Soon after the Oligocene fossil remnants of *Novumbra* were found—determined as the oldest North American fossil of any Umbridae species—they were described by Cavender (1969) in a paper that also discussed the “problem” of relationships within the suborder Esocoidei. Though Cavender concluded that the fossil evidence was too slim to put forth a true phylogenetic hypothesis, he placed *Novumbra* and *Dallia* closest together and intermediate to *Esox* and *Umbra* spp. A more definite attempt to construct the relationships of mudminnows was published by Nelson (1972) based on examination of the cephalic sensory system. Nelson placed *Dallia* closer to *Umbra* and suggested that *Novumbra* constitute its own subfamily as a sister group of *Esox*.

Nelson’s hypothesis was largely corroborated by Wilson and Veilleux’s (1982) osteological study of mudminnows, but genetic work that appears in this same time period began upending prior osteological and morphological evidence. Based on karyotypic and DNA values for all *Esox* and Umbridae spp., Beamish et al. (1971:1) bluntly stated that the grouping of mudminnows into the single family Umbridae was “ill-advised.” Crossman and Ráb (1996, 2001)—on the basis of chromosome banding work on *Dallia* and *Novumbra*—suggested strong divisions between these two genera and *Umbra* spp. Most recently, López et al. (2004) and Campbell et al. (2013) examined mitochondrial DNA and nuclear genomes of Esociforms and multiple outgroups and (1) concluded that Nelson’s widely accepted hypothesis of relationships was not supported and (2) strongly rejected the monophyly of the family Umbridae. The intrarelationships proposed by López et al. (2004) place *Novumbra* and *Dallia* in a clade with *Esox*, to the exclusion of *Umbra* spp.

Though ongoing paleontological and molecular work on mudminnows is likely to result in new insights on the evolutionary history of this group of Esociformes, the family name of Umbridae seems conclusively outdated. Thus, while the historical family name appears in most references for mudminnow species, the American Fisheries Society and many other researchers now recommend classification of mudminnow species in the family Esocidae (López et al. 2004; Campbell et al. 2013) or that Umbridae be used only in reference to the three known *Umbra* spp. (Gaudant 2012).

not only a function of coldwater resistance, but four of the five species have been documented as utilizing forms of supplemental aerial respiration, allowing survival in oxygen-depleted conditions that can occur during winter and summer in shallow bog, marsh, and pond habitats. Winter feeding and growth—atypical in most fishes—has also been documented in at least three species (Martin-Bergmann and Gee 1985; Panek and Weis 2013). Finally, several studies have revealed considerable behavioral flexibility of mudminnows, particularly in regard to foraging, courtship, and spawning (Hagen et al. 1972; Paszkowski 1984). Across the five species, evidence suggests that although mudminnows are restricted in their dispersal ability and may be particularly vulnerable to many human-derived pressures, they nonetheless exhibit many characteristics of a flexible, adaptable species that can take advantage of habitats considered unsuitable for other fish species (Rahel and Magnuson 1983; Martin-Bergmann and Gee 1985; Dederen et al. 1986).

In light of the largely scattered literature on mudminnows, we argue that it is timely to synthesize current knowledge and advocate for a more systematic approach to future research and management. The conservation status of mudminnows is presently difficult to assess and generalize—where mudminnows are found, they can be highly abundant or even dominant (Becker 1983); however, their occurrence is notoriously rare, patchy, and highly localized for some species (Harris 1974; Povž 1995; Wanzenböck and Spindler 1995). The extent to which distributions and population connectivity are limited by specialization in shallow, densely vegetated areas is currently not clear. Lastly, although mudminnows are hardy and relatively easy to study in captivity, the research that exists is typically local in scale and includes few cross-species comparisons. For these reasons, many smaller studies spanning several decades are ripe for analysis to summarize characteristics of biology, ecology, distribution, and conservation status across the group.

Here we summarize the available knowledge of the five mudminnow species, including local distributions and known population status. Notable aspects of biology and ecology are presented for each species, but we particularly focus on habitat constraints or life history requirements that may influence conservation status. We reviewed primary and secondary literature to summarize general ecological patterns across species, as well as to identify research gaps that may exist. Our protocols for search and selection generally followed those outlined by Pullin and Stewart (2006) for systematic review. We used Thomson ISI's Web of Science, Science Direct, JSTOR, and Google Scholar search engine to generate a database of publications through 2012 (Note: Some primary studies on European Mudminnow [*Umbra krameri*] were not available in English and may have reduced the amount of information reported herein for that species.) We screened references produced from our search and included 58 papers with a principal focus on one or more species of mudminnow and specifically relating to ecology, biology, or conservation. Although not a primary goal of this article, this review also includes a summary of additional articles that reflect changing knowledge of the phylogenetic relationships between mudminnow species (see Box 1). We conclude by reviewing the environmental issues that may pose particular conservation threats to mudminnows and outline recommendations for future research based on identified knowledge gaps and the most likely sources of threat to populations or species.

MUDMINNOW SPECIES

Central Mudminnow (*Umbra limi*)

Relative to the other species, the Central Mudminnow (*Umbra limi*) is comprehensively studied (Table 1), with at least two in-depth ecological studies documenting seasonal habitat use, diet, age structure, and spawning activities (Peckham and Dineen 1957; Martin-Bergmann and Gee 1985). To this are added numerous studies on individual aspects of biology, distribution, and behavior. The Central Mudminnow is also the most broadly distributed species, with a range extending from west of the Appalachian mountains northward to the Great Lakes region and extending into southern Ontario (Figure 1; Becker 1983). Extensions to this historical range have been documented with apparent introductions in Maine (Schilling et al. 2006) and New York (Schofield and Driscoll 1987), most likely resulting from baitfish releases. Their use as baitfish is widespread because they are common and often highly abundant, tolerant of harsh conditions, and attractive to other fish (predator) species (Becker 1983).

A characteristic of the Central Mudminnow that has attracted significant attention is the use of the swim bladder for supplemental respiration (Gee 1981), as well as the use of bubbles (composed of air and other gas mixtures) trapped under ice (Magnuson et al. 1983). This adaptation, along with consistent evidence of being generalist, opportunistic foragers in terms of both a versatile diet (Table 2) and flexible foraging strategies (Paszkowski 1984), is thought to broaden their ecological niche and allow *U. limi* to take advantage of and persist in specialized habitats that are subject to large fluctuations in dissolved oxygen. For example, use of supplemental oxygen has been shown to enhance foraging by mudminnows

Table 1. Summary of the number of existing research studies that report on aspects of mudminnow ecology by species and subtopic.

Species	Topic						
	Distribution	Phylogeny	Biology	Ecology	Life history	Behavior	Conservation
Umbra limi	2	7	2	4	2	4	1
Umbra pygmaea	1	7	1	4	1	—	—
Umbra krameri	8	5	2	4	1	1	5
Dallia pectoralis	—	8	1	4	1	—	—
Novumbra hubbsi	4	7	1	2	1	1	—

in (lethally) hypoxic waters (Rahel and Nutzman 1994) and is also believed to help avoid some effects of winterkill in small ponds and lakes (Martin-Bergmann and Gee 1985). This may allow compensation to some extent for both competition and predation from other fish species, notably Yellow Perch (*Perca flavescens*; Tonn and Paszkowski 1986).

Information on spawning habits and behaviors seems to be incomplete. The reported temperature range (2.8°C) for spawning (Becker 1983) is quite narrow compared to other species (Table 2), and there is little data on the length of time over which spawning occurs. Migrations to areas suitable for spawning (often lateral movements to flooded stream margins) are well documented (Peckham and Dineen 1957; Martin-Bergmann and Gee 1985) however, and guarding of nests by females is suggested by one source (Becker 1983).

Eastern Mudminnow (*Umbra pygmaea*)

Separated from their closest relatives *U. limi* by the Appalachian range, the Eastern Mudminnow (*Umbra pygmaea*) inhabits lowland waters with little to no streamflow between southern New York and northern Florida (Jenkins and Burkhead 1994). Although much less well-studied than Central Mudminnow (Table 1), strong similarities to their westward relatives are apparent. Eastern Mudminnows across the range exhibit very broad diets consisting of up to 13–17 distinct prey classes in a single season, with significant feeding occurring during the winter (Panek and Weis 2013). Like Central Mudminnow, their diet will even include fish, but where Central Mudminnows are thought to primarily feed on other fish species during winter months (Martin-Bergmann and Gee 1985), Eastern Mudminnows have been documented using cannibalism to augment their diet in summer (the period with the most empty stomachs; Panek and Weis 2013). Although cannibalism is not uncommon in fishes, this points to diverse diets (Table 2) as well as flexible and context-dependent foraging strategies for this group of species.

Eastern Mudminnows appear to exhibit flexible—and perhaps more complex—spawning habits, although this may simply be due to a lack of investigation into these patterns for Central Mudminnows. Migration to shallow spawning sites, such as backwater areas in streams, is documented (Breder and Rosen 1966; Jenkins and Burkhead 1994). Courtship by males and nest building are known to occur; nests are variable, including cavities in algae, under loose rocks, in depressions in sand, or scattered (Breder and Rosen 1966). Females have been observed guarding and occasionally fanning the nest; males may also be engaged in guarding, but this has not been observed conclusively (Breder and Rosen 1966).

Eastern Mudminnows have gained some notoriety since their introduction and spread to six European countries over the course of the 20th century as a result of intermittent popularity in the aquaculture and aquarium trades (Jenkins and Burkhead 1994; Verreycken et al. 2010). Conservation efforts for vulnerable species (i.e., European Mudminnow) can be undermined when closely related species (i.e., Eastern Mudminnow) are invasive in the same region; therefore, it is important to distinguish the human and/or ecological basis for invasion. In The Netherlands, notice of Eastern Mudminnows surviving in areas unsuitable for any native fish sparked investigations into the hypothesis of extreme acid tolerance. It was found that *U. pygmaea* tolerated exceptionally low (3.0) pH with no mortality, with optimal growth at pH 4.5, a level detrimental if not lethal for most fish species (Wendelaar Bonga et al. 1990); in field studies they were found to frequently inhabit areas of low pH that excluded other species (Dederen et al. 1986). Consistent with the hypothesis of acid tolerance underlying invasion dynamics, an assessment of Eastern Mudminnows in Europe found that the bulk of the nonnative distribution was in two countries—Belgium and The Netherlands–where acidification of shallow waters has significantly impacted fish communities (Verreycken et al. 2010). Combined with the fact that dispersal in other countries seems largely human mediated and their

Table 2. Mean ± SD of key habitat, environmental, and life history characteristics reported in published studies that focused on one or more species of mudminnow. N/A indicates that no reported values were found for this species, and a missing SD value indicates that only a single study was available. "DO" refers to "Dissolved Oxygen," (♀) designates female and (♂) designates males of species. Maximum lengths were summarized from studies reporting total (T) lengths only. Food groups are the number of micro- and macrofaunal items reported in mudminnow diets at the order (or higher) level of taxonomic classification.

			Habitat and environment			Reproduction				Other
Genus, Species	Maximum lengthT (mm)	Maximum age (years)	Minimum DO (ppm)	Minimum pH	Food groups (#)	Age at maturity	Fecundity (max)	Spawning temperature (°C range)	Reproductive behaviors	Air-breathing
Umbra limi	117.6 ± 14.5	5.8 ± 2.4	1.6 ± 0.9	6.0 ± 0.7	12.3 ± 0.5	1.8 ± 0.4	1,496 ± 10	12.9–15.6	Migration	Yes
Umbra pygmaea	124.0 ± 12.5	5.5 ± 0.7	2.0 ± 1.9	4.0 ± 0.9	13.0 ± 4.2	1.7 ± 0.3	1,978 ± 703	9.0–15.0	Migration Courtship Nest-building (♀) Guarding (♀) Fanning (♀)	Yes
Umbra krameri	107.6 ± 4.8	4.6 ± 0.8	1.0 ± 0.6	7.0 ± 0.4	16	1.3 ± 0.5	1,983 ± 1,201	11.8–16.4	Nest-building (♀) Guarding (♀) Fanning (♀)	Yes
Dallia pectoralis	154.0 ± 36.7	6.6 ±2.3	2.3	6.8	10.5 ± 0.7	2.3 ± 1.1	316	9.2–16.8	N/A	Yes
Novumbra hubbsi	89.1 ± 1.3	N/A	2.5 ± 1.5	3.8 ± 1.1	10	N/A	N/A	10.0–17.9	Courtship Guarding (♂)	N/A

presence is limited to small numbers of sites, Verreycken et al. (2010) reported Eastern Mudminnow as low-medium risk for invasiveness.

A high degree of acid tolerance has also been found to exist in *U. limi* (Rahel and Magnuson 1983). Our own review of pH values reported in field studies (Table 2) indicates that this extreme tolerance may not be similarly shared across all mudminnow species, but further study is indicated for a robust comparison across species.

European Mudminnow (*Umbra krameri*)

Although the current name was not adopted until 1792, *U. krameri* has been reported as inhabiting lowland habitats of the Danube River basin since 1726, when it was first described by Marsili (Wanzenböck 1995). Of the five species of mudminnow, the fossil records for the European Mudminnow are the most complete, offering the greatest insight into paleontological history. A primitive form of umbrids (*Palaeoesox*) have existed since the Paleocene (approximately 62 Ma), with forms of the more recent genus *Umbra* recorded since the late Oligocene (approximately 25 Ma)–it has been determined that the two genera coexisted in Europe until the Middle Miocene, or a period of 10–20 Ma (Gaudant 2012).

The present-day distribution of European Mudminnow is focused in the Danube River, with some populations in the neighboring Prut and Dniester basins. Of the 10 nations found along the Danube River (i.e., Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Romania, Bulgaria, Moldova, and the Ukraine), European Mudminnows occur in all except Germany. In addition, of several nations for which part of their territory belongs to the Danube catchment, European Mudminnows have been found in two of those, namely, Slovenia and Bosnia and Herzegovina (Wanzenböck 1995; Velkov et al. 2004; Sekulić et al. 2013). Out of concern for population declines that seemed to be occurring across the range, in 1995 an international workshop was held to assess the current population and research status. In the workshop proceedings, all countries presented evidence of population declines since the early 1900s, varying from moderate in Hungary and the Ukraine (Keresztessy 1995; Movchan 1995) to near extinction in Austria (Wanzenböck and Spindler 1995) or reported that the available data was insufficient to determine changes in historical abundance and distribution (Bănărescu et al. 1995; Leiner 1995). Insufficient data made it challenging to pinpoint causes of decline in individual countries, but the research as a whole overwhelmingly pointed to the negative impacts of water regulation, with habitat loss through draining of wetlands and bogs, as well as loss of floodplain and oxbow habitats (Guti 1995; Keresztessy 1995; Povž 1995). Pollution and high nutrient loads were indicated as a secondary threat (Bíró and Paulovits 1995; Wanzenböck and Spindler 1995; Sekulić et al. 1998), though unlike with water regulation, the causal mechanisms were not as well understood. Based on these known conservation threats and an estimated population decline of 30% over the past several decades, *U. krameri* has been assessed as Vulnerable (VU A2c) by the International Union for Conservation of Nature (IUCN) since 1996 (Freyhof 2011). It is also on national red lists or has some protected status in 9 of the 11 countries where it occurs (Wanzenböck 1995; Freyhof 2011). European Mudminnows do appear to respond favorably to habitat restoration (in the form of dredging oxbows and natural reestablishment of wetlands) where it has been tried (Povž 1995; Trombitsky et al. 2001), indicating the potential for focused conservation programs to revive populations.

European Mudminnows exhibit similar specialization in shallow and densely vegetated habitats as their North American relatives, but have one of the shorter reported life spans (Table 2). Despite numerous studies, there seems to be little agreement in fecundity estimates (Table 2); however, in a review of multiple spawning experiments for *U. krameri*, Kováč (1997) described absolute fecundity as “relatively low” and suggested that this attribute, along with complex mating behavior and a long period of parental care by females, increases the vulnerability of this species to human-induced habitat disturbance. This hypothesis was to some extent supported by a 3-year study of European Mudminnow in Hungary’s Kis-Balaton region before and after flooding to fill a reservoir. Although mudminnows were found in newly flooded areas, 2 years of sampling failed to find any yearling fish, suggesting reproductive failure due to loss of shallow spawning habitat (Keresztessy 1995). Unlike with Eastern Mudminnow (invasive in Europe but not currently overlapping in range), there have been no laboratory studies into extreme acid tolerance in *U. krameri*, but values reported in field studies do not seem to support similar extreme tolerances (Table 2). Wanzenböck and Spindler (1995:455), however, did conclude that suitable habitat for *U. krameri* showed “pronounced oxygen deficiencies,” supporting the idea that mudminnows can take advantage of some habitats underutilized by other fish species.

Alaska Blackfish (*Dallia pectoralis*)

The largest species of mudminnow (Table 2) with an extensive geographic range (Figure 1, Figure 2D) is the Alaska Blackfish (*Dallia pectoralis*), yet this species competes with Eastern and Olympic Mudminnow for the smallest number of studies conducted, particularly in terms of behavior and distribution (Table 1). Their relatively large area of documented occurrence ranges from the coastal Chukotka Peninsula in Siberia and in Alaskan coastal areas from the north Arctic all the way southward to Chignik. The distribution also reaches well inland into the Yukon River Basin. Two known fossil records exist, both of which are outside the current distribution, suggesting a historically larger range that was constrained by periods of glaciation during the Pleistocene. The older fossil from the Late Miocene was discovered on the Kenai Peninsula (Cavender 1969), 200 km east of today’s range, and a more recent fossil (Middle Pleistocene) in northeastern Siberia lies approximately 800 km west of the current distribution (Campbell 2011). The current distribution maps closely to the glacial refugia of the most recent Wisconsin period, including populations on islands between Alaska and Russia that formed part of the Beringian land bridge during that period (Campbell and López 2014). This

Figure 2. Mudminnow species of the world. (a) Central Mudminnow (*Umbra limi*); (b) Eastern Mudminnow (*Umbra pygmaea*); (c) European Mudminnow (*Umbra krameri*); (d) Alaska Blackfish (*Dallia pectoralis*); and (e) Olympic Mudminnow (*Novumbra hubbsi*). Photo credits: by U. Thomas (a), Biopix.dk (b), J. Wanzenböck (c), J. Brill (d), R. Tabor (e).

is not surprising, perhaps, given the limited dispersal ability and low tolerance for salinity found within the family.

A surprising proportion of the available research on Alaska Blackfish is related to phylogeny and taxonomy (Table 1). Since *D. pectoralis* was first described in 1880, up to three species of *Dallia* have been proposed. *D. delicatissima* from the northeastern Chukotka (part of Siberia) was recognized briefly in 1881 but shortly deemed a dwarf version of *D. pectoralis*, which was then considered the sole representative of the genus for nearly a century. In 1981, Chereshnev and Balushkin described a new Chukotka species based on morphology—*D. admirabilis*—and simultaneously revived *D. delicatissima*, with the hypothesis that morphological distinctions arose from survival in distinct glacial refugia. This suggested that north Arctic slope populations might be more closely related to the two Russian species than to *D. pectoralis*. Karyotypic comparison of Arctic slope and central Alaska populations was ambiguous, showing distinct chromosomal—but no morphological differences—between the two (Crossman and Ráb 1996). More recently, Campbell and López (2014) conducted an extensive biogeographical study across the full range of Alaska Blackfish using mitochondrial DNA and showed strong evidence for four phylogeographic groups that likely survived in separate glacial refugia. However, rather than supporting *D. admirabilis* as a separate species, the Russian population showed low divergence from Alaskan populations across the Beringian land bridge (*D. delicatissima* was not examined). There was greater evidence supporting potential reproductive isolation of the north Arctic slope populations, leaving the question of multiple *Dallia* species still unresolved.

The existence of divergent *Dallia* populations across the landscape may explain puzzling inconsistencies in life history and growth rate that have been found in studies (albeit small in number) of life history and ecology (Table 3). In a detailed study of spawning characteristics of a lake population near Bristol Bay, Aspinwall (1965) documented a maximum age of 8 years and maturity at 3 years of age. Spawning was determined to occur over a relatively short 2-week period in July. By contrast, Blackett (1962) found the maximum age in an interior Yukon population to be 3–4 years old with maturity reached at age 1–2 but at much larger lengths than Aspinwall (1965) reported (Table 3). It was also concluded that spawning was a highly protracted event, possibly over several months from May to August (but this conclusion was difficult to fully support because no samples were collected in July). In support of the findings of Aspinwall (1965), Gudkov (1998) found the maximum age to be 8 years for populations in 13 Russian lakes but with highly variable length distributions (and age structure) depending on winter conditions and the presence of Arctic Char

(*Salvelinus alpinus taranetzi*) and Least Cisco (*Coregonus sardinella*) competitors (Table 3). Whether this variability across the range reflects study design (particularly the use of scales for aging, a technique that has been proved unreliable for mudminnows), habitat and rearing conditions, competition, or true population and life history diversity remains unclear.

It is thought that the extreme Arctic environment drove a highly unique adaptation in Alaska Blackfish. Air-breathing has been documented in all three *Umbra* species via modification of the swim bladder (Table 2); in contrast, Blackfish have a structure that allows absorption of air through the oesophagus (Crawford 1974). This modification for respiration is known in only one other fish, *Monopterus albus*, a tropical eel native to Asia. Crawford (1974) speculated that long periods of ice cover demanded aerial respiration to compensate for low dissolved oxygen but also a greater need for neutral buoyancy (and, hence, an unmodified swim bladder). It is likely that this unique adaptation led to stories of the ability of Alaska Blackfish to withstand freezing (Brown et al. 2010). Blackfish have never been commercially harvested but were an abundant and widely available subsistence food for Native Alaskans, particularly during times of low food stores, as animal feed, or as bait for other fish (Brown et al. 2010).

Olympic Mudminnow (*Novumbra hubbsi*)

The smallest (Table 2) and most highly endemic species of the group, Olympic Mudminnows (*Novumbra hubbsi*), occur only in a single state (Washington) in the United States (Figures 1 and 2E). Within this region, their range is primarily restricted to a single large river drainage (the Chehalis River), as well as more patchy occurrences in river drainages north toward the Puget Sound estuary and lowland habitats along the Washington coast (Harris 1974). Their distribution in Washington is largely dictated by areas of glacial refugia that existed during the Pleistocene Era; morphological differences between fish across drainages suggest very limited dispersal since that time (Meldrim 1968). Recent genetic analysis of fish throughout the range supports this view and noted that the genetic variation between all sites was high in comparison to other fish with comparable life histories (DeHaan et al. 2014), indicating that individual populations even in close geographic proximity can be genetically distinct. As with other mudminnow species, Olympic Mudminnows are strongly associated with shallow areas of dense vegetation and fine substrates (Meldrim 1968).

Although much information on the basic ecology (i.e., population size, diet, age structure, fecundity, habitat use) of the Olympic Mudminnow is currently poor or lacking (Table 1), some aspects of their biology have been closely studied and allow comparisons to other species. Egg and larval development were exhaustively documented and compared to other research, with the conclusion that development across the three mudminnow genera appeared very similar (Kendall and Mearns 1996). This same study presented intriguing evidence in the number and movement of oil globules in eggs (a stable character), which grouped *N. hubbsi* (and other umbrids) in a clade containing esociforms, osmerids, and salmonids.

Courtship and spawning behaviors of Olympic Mudminnows have been comprehensively studied in both lab and field experiments and (to our knowledge) represent the most detailed account for any species (Hagen et al. 1972). Males establish remarkably large (0.5–0.7 m^2) territories for their size and actively patrol and defend these territories for up to 7 weeks of spawning. A complicated courtship ritual (the “wigwag dance”) of 5–20 minutes results in fertilization of only one or two eggs at a time (Hagen et al. 1972), which are deposited on moss or stems of vegetation. Although it is unknown whether other species engage in this level of complex spawning, these behaviors may explain why mudminnows seem to routinely migrate to or seek out separate areas for spawning that are usually shallow and more protected from predators. *N. hubbsi* has been documented in high abundance in temporary flooded wetlands of the Chehalis River during March–May (peak spawning season; Henning et al. 2007). On a larger scale, this is consistent with reports of spawning movements to flooded stream margins and backwaters for other species (Becker 1983; Jenkins and Burkhead 1994), indicating the importance of these areas for successful reproduction.

CONSERVATION THREATS AND STATUS

Biotic Interactions with Native and Nonnative Species

Given their small size and lack of any apparent defenses, it is expected that mudminnows generally would be sensitive to

Table 3. Variability in life history and growth characteristics of *Dallia pectoralis* reported by three studies across the range. Blackett (1962) reported on an interior Yukon stream population, Aspinwall (1965) studied a coastal lake population near Bristol Bay, and Gudkov (1998) sampled 13 glacial and thermokarst lakes on the southern coastal Chukotka Peninsula in Russia. Method used in length measurements is indicated as either total (T) or standard (S) lengths.

	Blackett (1962) *n* = 126	Aspinwall (1965) *n* = 1,400	Gudkov (1998)[a] n = 394
Age method	Scales	Scales	Otoliths
Maximum length (mm) Method	165_T	135_T	228_s
Maximum age (years)	4	8	8
Length at age 3 (mm)	127	56	60/105[a]
Length at maturity (mm)	80	50	—
Age at maturity (years)	1.5	3	—
Spawning temperatures (°C)	10.0–16.0	8.3–16.9	—
Spawn timing	July 15–August 1	May–August	—
Spawning duration	2 weeks	3 months	—

[a]Gudkov (1998) noted significant within-region differences in length at age, where blackfish in lakes with Cisco and Char competitors exhibited significantly reduced growth compared to lakes without competitors; thus the two values are reported.

impacts of predation by and competition from nonnative species (Cucherousset and Olden 2011). The difficulty of demonstrating impacts of predation and/or competition seems to be confounded by the habitat specialization (shallow, highly vegetated areas) and broad environmental tolerances (dissolved oxygen and temperature) exhibited by mudminnows. Wanzenböck and Spindler (1995) demonstrated a negative association of European Mudminnows with other fish species, but mudminnow habitats also showed "pronounced oxygen deficiencies," making it difficult to determine whether the environment was excluding other fish or other fish excluded mudminnows. Other studies of European Mudminnows document associated fish assemblages but are qualitative in nature and result in no clear evidence of exclusion by other species (e.g., Bíró and Paulovits 1995). Although based on occurrence of nonnative Eastern Mudminnows in The Netherlands, a survey of fish assemblages reported a strongly negative association with other fish species; similar to Wanzenböck and Spindler (1995), however, these results are confounded in that mudminnows are one of very few fish species that can live (and even thrive) in the low-pH waters that were sampled (Dederen et al. 1986; Wendelaar Bonga et al. 1990).

Some compelling evidence, however, has focused on specific species interactions or mechanisms and accounted for important environmental variability. A study of Olympic Mudminnow occurrence demonstrated a strong negative relationship with nonnative fishes—in particular with Largemouth Bass (*Micropterus salmoides*)—in oxbow lakes, but the small sample size leaves room for more investigation (Beecher and Fernau 1983). In a study of Alaska Blackfish in glacial and thermokarst lakes, Gudkov (1998) demonstrated significantly reduced growth in lakes with Arctic Char and Least Cisco competitors. By far the most comprehensive and compelling research was conducted in small lakes in Wisconsin over 3 years and focused on relationships between Central Mudminnows and Yellow Perch. Tonn and Paszkowski (1986) demonstrated not only reduced densities of mudminnows in lakes where Yellow Perch co-occurred but also that only large mudminnows were found to coexist with perch, indicating size-specific predation. Furthermore, mudminnows became dominant briefly following winterkill events that affected perch more than mudminnows. This study was followed up by a laboratory experiment demonstrating superior foraging of young perch, suggesting a mechanism for negative competitive interactions (Paszkowski 1985). Although mudminnows have been found to exhibit flexible activity and feeding patterns—such as night foraging—depending on the presence of predators and competitors (Martin-Bergmann and Gee 1985; Jenkins and Burkhead 1994) and also use specialized habitats (Rahel and Magnuson 1983; Rahel and Nutzman 1994), nonnative introductions may well be a conservation concern, especially if they result (indirectly) in loss of suitable habitat. Like many aspects of mudminnow ecology, this area could bear more attention and research.

Pollution

Many studies and status review articles of European Mudminnows state that pollution is a primary and significant threat to population persistence (Bíró and Paulovits 1995; Leiner 1995; Sekulić et al. 1998), but research demonstrating causal mechanisms, particularly problematic pollutants or sources (e.g., industrial vs. agricultural), is sparse. (Note: Studies may be available in languages other than English, but because few citations pertaining to pollution impacts were found, we suspect that this research largely remains to be done.) However, European Mudminnows in the Danube (Europe's second largest river) and its tributaries are subject to numerous environmental pollutants associated with a large, economically important river and densely populated watershed (International Commission for the Protection of the Danube River 2009). These include high nitrogen and phosphorus loads, municipal wastewater, and hazardous substances from industrial sources.

A study in Austria demonstrated that European Mudminnows were found in side channel habitats with limited connectivity to the Danube (and greater groundwater influence) that were significantly lower in nitrate levels (Wanzenböck and Spindler 1995). A second study examined the impacts of water from the Rhine River on chromosome damage in Eastern Mudminnows; 11 days of exposure resulted in chromosome damage in 30% of cell divisions, suggesting mutagenic impacts as one mechanism by which pollution affects populations (Prein et al. 1978). Given that all mudminnow species inhabit lowland and floodplain regions that are often prime agricultural areas (e.g., the Chesapeake watershed or the Chehalis River basin in Washington State), an interesting area of research would be to determine more closely the impacts of those pollutants on habitat quality and population viability.

Water Regulation

Strongly intertwined with habitat alteration, water regulation likely poses the single largest threat to mudminnow populations, which rely on shallow and highly vegetated wetland, floodplain, and oxbow habitats. The mechanisms of impact of water management on mudminnow populations have also been the most comprehensively documented. The most obvious of these is upstream flooding of fish habitat when dams are created, inundating habitats such as isolated bog lakes or canals (Bíró and Paulovits 1995). A notable problem with this type of habitat alteration is loss of spawning areas, as Keresztessy (1995) found when mudminnows could apparently migrate to newly flooded areas but showed signs of reproductive failure in subsequent years. Even small water management projects such as those that convert small ponds to deeper lakes for recreation can result in disappearance of mudminnows from those areas (Bănărescu et al. 1995).

Complex downstream habitat is also lost to flood control measures, with drying out of side channels, floodplains, and emergent wetlands (Bunn and Arthington 2002) that provide nursery and rearing habitat for many fish, including mudminnows (Guti 1995; Henning et al. 2007). An example of this indirect effect is the disappearance of oxbow habitats in Slovenia, which become filled in with vegetation over time; upstream water regulation reduces the creation of new oxbows and this important mudminnow habitat has been permanently lost (Povž 1995). Another interaction with hydrologic alteration was recently brought to light with research on Austria's single remaining population of mudminnow, inhabiting approximately 5 km of side channel area of the Danube. Water regulation on the Danube has lowered groundwater levels (due to channel deepening); population modeling identified prevention of further groundwater reductions as the most important factor in persistence of this population (Wanzenböck 2004).

Habitat Loss and Degradation

In addition to water regulation, threats to mudminnow habitat exist from human activities such as draining of wetlands, or dredging lakes, rivers, or small canals (Becker 1983; Wanzenböck 2004). Although mudminnows are generally found in muddy habitats, turbidity is an apparent deterrent, so activities that increase turbidity may result in reduced habitat quality (Becker 1983). For both Olympic and European Mudminnows there is evidence of strong behavioral thermoregulation during summer months (Meldrim 1968; Povž 1995), indicating that changes in habitat that increase water temperatures could negatively impact populations. Given that much research also indicates broad environmental tolerances, however, sifting out the potential impact of warming on species of mudminnows could prove an interesting area for future research.

A significant type of habitat alteration for mudminnow populations may be losses in shallow spawning habitat. Research on mudminnow species consistently report (often substantial) movements in the spring to flooded margins of creeks, backwaters, or other shallow, protected, and densely vegetated zones for spawning (Table 2; Peckham and Dineen 1957; Henning et al. 2007; Brown et al. 2010). Given studies that also document relatively complex spawning behaviors across the family, long periods of spawning, and a high investment in parental care (Table 2; Hagen et al. 1972; Kováč 1997), the potential for increased vulnerability during this period is not surprising. In fact, Kováč (1997) pointedly suggested that these characteristics were key reasons that European Mudminnows were particularly sensitive to habitat disturbance.

Data Availability and Management

At least two species of mudminnows—European and Olympic—illuminate the conservation challenge that can arise for nongame species with limited dispersal ability and patchy distributions. Since 1996, European Mudminnows have been listed as Vulnerable on the IUCN Red List due to an estimated population decline of more than 30% over the past decades; however, our literature review indicates that this listing has not led to any significant increase in published research on European Mudminnow populations since that time.

Olympic Mudminnows share several conservation characteristics of European Mudminnow in terms of having a small native range primarily centered in a single river drainage. Their highly endemic nature suggests a need for conservation concern, but lack of economic value leads to a paucity of data with which to make management decisions. This was exemplified by a 1995 petition to the U.S. Department of Fish and Wildlife for listing of a local population of Olympic Mudminnow on the Endangered Species List. The petition was declined largely on the basis of insufficient information as to overall population sizes and genetic variation between populations, and the Olympic Mudminnow was ranked a Category 2 candidate species (a now defunct category that indicated a need for future research and potential for listing given additional evidence; U.S. Fish and Wildlife Service 1995).

CONCLUSION

In this review, we have sought to synthesize existing research across a unique but somewhat overlooked group of freshwater species in the scientific literature. In doing so, we have hopefully clarified the reasons why some of these species seem to be threatened or vulnerable while others are ubiquitous and abundant or—in the case of Eastern Mudminnows—may even be invasive outside of their native range. This synthesis was also intended to offer guidance to other researchers by highlighting research gaps for individual mudminnow species (Tables 1 and 2).

As a result of this review, we present the research and management priorities we believe best complement and advance the available science on mudminnow species and that also take into account current and future conservation issues. These are as follows:

Central Mudminnow:

- Improve knowledge of spawn timing, duration, and behaviors (Table 2).

Eastern Mudminnow:

- Improve basic ecological knowledge of behavior and habitat use.

European Mudminnow:

- Strong thermoregulatory behavior during summer months and an association with groundwater-fed habitats are indicated. Given that climate change may result in critical warming of rivers and lakes, as well as changes in groundwater supplies, we recommend research on temperature sensitivities and population vulnerability of European Mudminnow due to climate change.
- Determine causal mechanisms and impacts of agricultural and industrial pollutants to more specifically assess vulnerability of populations.
- Test efficacy of reconstruction and revitalization of off-channel habitats to increase populations. Management actions might include use of environmental flow regimes that promote periodic flooding and greater hydrologic connectivity in regulated systems.

Alaska Blackfish:

- Improve basic ecological knowledge of life history, behavior, and habitat use (Tables 1 and 2). Of particular interest is whether these vary critically between populations to help identify or confirm processes of speciation across the Beringian landscape.

Olympic Mudminnow:

- Improve basic knowledge of ecology and life history, particularly age structure, fecundity, and habitat use (Tables 1 and 2).
- Determine vulnerability to nonnative fish predators.
- Establish current distribution and changes in population size in recent decades. Given that this species also inhabits the smallest geographic range, we recommend that a conservation assessment be conducted using IUCN criteria to determine whether conservation concern is warranted and to prioritize needed research.

In tackling these outstanding research questions, scientists would not only contribute to knowledge regarding a group of species that exhibit a wide array of diversity within a very small species group but would also advance understanding as to how fish utilize wetlands, which are widely acknowledged as some of the most imperiled habitats worldwide.

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FEATURE

Fish Community Responses to Mechanical Removal of Nonnative Fishes in a Large Southwestern River

Nathan R. Franssen

University of New Mexico, Department of Biology and Museum of Southwestern Biology, 167 Castetter Hall, Albuquerque, NM 87131. E-mail: nrfranssen@gmail.com

Jason E. Davis

U.S. Fish and Wildlife Service, New Mexico Fish and Wildlife Conservation Office, Albuquerque, NM

Dale W. Ryden

U.S. Fish and Wildlife Service, Colorado River Fisheries Project, Grand Junction, CO

Keith B. Gido

Kansas State University, Division of Biology, Manhattan, KS

ABSTRACT: *Establishment of nonnative fishes has contributed to the decline of native fishes worldwide. Efficacy of mechanical removal of nonnative fishes in large streams has been difficult to ascertain, and responses by native fishes after removal is equivocal. We summarize results of efforts on the San Juan River, New Mexico, Colorado, and Utah, to suppress nonnative Channel Catfish and Common Carp densities through removal via electrofishing. We assessed spatial and temporal trends in the densities of abundant fishes in relation to removal of nonnative fishes. Common Carp densities declined river-wide after removal but Channel Catfish densities only decreased in upper reaches. Sources of Channel Catfish juveniles and barriers to nonnative fish movement likely influenced the effectiveness of removal. Responses of native fishes to removal were not evident in most species and size classes. Results show that nonnative removal can be partly successful, but the complexity of large river systems limited the ability to completely remove Channel Catfish and document a positive response of native fishes. Nevertheless, these removal efforts coincided with increasing numbers of endangered species through a stocking program. We suggest that continued monitoring and experimentation will help managers untangle the efficacy of the program and its benefits for native fishes.*

Respuestas de la comunidad de peces a la remoción mecánica de peces no nativos en un gran río del suroeste

RESUMEN: *a nivel mundial, el establecimiento de peces no nativos ha contribuido a la reducción de peces nativos. La efectividad de la remoción mecánica de peces no nativos en grandes ríos ha sido difícil de determinar y la respuesta por parte de los peces nativos después de la remoción, es incierta. Aquí se resumen los resultados de los esfuerzos encaminados a suprimir, mediante electro-pesca, la densidad de poblaciones no nativas del bagre de canal y la carpa común en el Río San Juan, Nuevo Mexico, Colorado y Utah. Se evaluaron las tendencias espaciales y temporales de las densidades de los peces más abundantes en relación a la remoción de peces no nativos. Después de la remoción, la densidad de las poblaciones de carpa declinó a lo largo de todo el río, pero la densidad de los bagres sólo disminuyó río arriba. Los factores que posiblemente influenciaron la efectividad de la remoción fueron las fuentes de juveniles del bagre de canal y las barreras del movimiento de peces no nativos. La respuesta de los peces nativos a la remoción no fue evidente en la mayoría de las especies y clases de talla. Los resultados muestran que la remoción de individuos no nativos puede ser parcialmente exitosa, pero la complejidad de los sistemas fluviales, por un lado, ha limitado la habilidad para remover por completo al bagre de canal y, por otro, para documentar una respuesta positiva de los peces nativos. Sin embargo, estos esfuerzos de remoción coincidieron con un incremento en el número de individuos de especies amenazadas a través de un programa de cultivo. Se sugiere que la experimentación y un monitoreo continuo ayudarán a los manejadores a lograr una mayor eficacia en el programa, con el consecuente beneficio para los peces nativos.*

INTRODUCTION

The introduction and establishment of nonnative fishes independently or in concert with habitat degradation, loss, or fragmentation and altered flow regimes has contributed to the decline of native fishes worldwide (Dudgeon et al. 2006; Fullerton et al. 2010). Nonnative species have been cited 68% of the time as a contributing factor in the extinction of 40 taxa of North American fishes over the last 100 years (Miller et al. 1989), and species invasions seem particularly harmful in depauperate fish communities of the southwestern United States (Minckley and Deacon 1968; Clarkson et al. 2005). Moreover, approximately 40% of North American fishes are currently at risk (i.e., endangered, threatened, vulnerable; Jelks et al. 2008), and native fishes in the southwestern United States are exceptionally imperiled because of their high degree of endemism (Minckley and Deacon 1968; Holden and Stalnaker 1975; Fagan et al. 2002). Eradication or reduced densities of nonnative fishes in invaded systems would presumably benefit native fishes (Gozlan et al. 2010). In the Colorado River Basin, reducing densities of nonnative fishes that may prey on or compete with native fishes has been identified as a potential management action for recovery of threatened, endangered, and other native fishes (Tyus and Saunders 1996, 2000; U.S. Fish and Wildlife Service 2002a, 2002b).

The removal of nonnative organisms from aquatic systems to help conserve native taxa has been successfully implemented in headwater streams (Thompson and Rahel 1996; Britton et al. 2011) as well as lakes and reservoirs (Hoffman et al. 2004; Vrendenburg 2004; Lepak et al. 2006). Most successful eradication efforts have been associated with the use of piscicides, particularly rotenone (Gozlan et al. 2010). Complete eradication or effective control of nonnative fishes in large river systems has been greeted with limited success (Mueller 2005). Larger rivers are often more difficult to effectively sample and the use of piscicides is often not feasible due to large spatial scales, public concern, or the presence of state and federally protected species. Additionally, river systems may lack barriers that would limit recolonization of unwanted fishes into treated areas. For these reasons, prescribing long-term mechanical nonnative fish removal (NN removal hereafter) to reduce the abundance of nonnative fishes has been used extensively, especially in the Colorado River Basin, albeit documented success of NN removal efforts in this system are limited (Mueller 2005).

Published reports of NN removal programs are helping to identify the context in which these efforts can meet management objectives. Coggins et al. (2011) identified a reduction in the abundance of nonnative Rainbow Trout (*Oncorhynchus mykiss*) through NN removal in the Grand Canyon reach of the Colorado River, but their results suggested that increased flows and turbidity may have increased Rainbow Trout mortality, confounding the effects of NN removal. Intensive electrofishing efforts elsewhere also reduced and maintained lower densities of nonnative Flathead Catfish (*Pylodictis olivaris*) in the Satilla River, Georgia (Bonvechio et al. 2011). Although exploitation may be able to reduce the densities of nonnative fishes in some large rivers, selective removal of large individuals with size-biased gear (Colombo et al. 2008; Reynolds and Kolz 2012) may also reduce size and age structures of target populations (Pitlo 1997; Bonvechio et al. 2011). Therefore, NN removal efforts may inadvertently increase negative interactions (e.g., competition, predation on larvae or juveniles) between native and nonnative fishes by increasing the abundance of smaller nonnative individuals. Although the successes of NN removal in large, open systems are limited, species- and system-specific nuances will likely influence the efficacy of any removal program.

Similar to other aquatic systems in the American Southwest, anthropogenic disturbances have altered biotic and abiotic components of the San Juan River, New Mexico, Colorado, and Utah. Construction of Navajo Reservoir on the San Juan River (New Mexico and Colorado) in 1962 eliminated native fish habitat through inundation and lowered water temperatures below the dam with hypolimnetic releases. Additionally, just prior to impoundment in 1961, the New Mexico Department of Game and Fish applied a piscicide to 64.4 km of river below the dam to help establish trout for a recreational fishery (Olson 1962). This poisoning effectively purged most fishes from this reach, where six species were native (including now federally protected Colorado Pikeminnow [*Ptychocheilus lucius*]) and eight were nonnative (Olson 1962). In addition to reducing available habitats for native fishes, the dam modified the river's natural flow regime by lowering snowmelt-driven spring discharge and increasing summer flows (Franssen et al. 2007). However, reservoir releases since 1998 are currently managed, when possible, to mimic a natural flow regime characterized by high spring flows and low summer base flows (Propst and Gido 2004; Gido and Propst 2012), yet spring peak flows are still attenuated, and summer flows are higher compared to historical levels to support agricultural water diversions. In addition to a partially altered flow regime, two invasive Eurasian tree species have become established along much of the San Juan River's banks: salt cedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*). Similar to other rivers in the Colorado River Basin (Birken and Cooper 2006; Nagler et al. 2011), encroachment of salt cedar and Russian olive has likely confined, narrowed, and reduced channel braiding of the San Juan River's mainstem channel when compared to historical conditions.

Concurrent with altered flow regimes and habitats in the San Juan River, recent investigations documented the presence of 19 nonnative fishes (Ryden 2000), dwarfing the river's historical depauperate fish fauna of up to eight native species (Tyus et al. 1982). The exact time at which nonnative fishes invaded the San Juan River is unclear; however, the New Mexico Department of Game and Fish stocked over 9,000,000 nonnative Channel Catfish (*Ictalurus punctatus*) between 1910 and 1986 (New Mexico Department of Game and Fish unpublished data). Nonnative Common Carp (*Cyprinus carpio*) were first introduced into New Mexico waters in 1883 (Sublette et al. 1990) and their presence was reported in the Colorado River Basin in the late 1880s (Evermann and Rutter 1895). Monitoring, via electrofishing, of large-bodied fishes conducted in the mainstem San Juan River from 1991 to 1997 found that native Flannelmouth Sucker (*Catostomus latipinnis*) was the most abundant species, averaging 59% of the annual catch, followed by nonnative Channel Catfish (13%), native Bluehead Sucker (*Catostomus discobolus*; 12%), and nonnative Common Carp (9%); the remaining nonnative species only comprised 2% of the total catch (Ryden 2000). The two federally protected native species (Colorado Pikeminnow and Razorback Sucker [*Xyrauchen texanus*]) were likely among the river's native fish fauna (Jordan 1891), but later investigators reported these species as extremely rare or extirpated in the San Juan River drainage (Tyus et al. 1982; Holden and Wick 1982). Population restoration efforts via stocking hatchery-reared, mostly age-0 (i.e., young of year) Colorado Pikeminnows and subadult and adult Razorback Suckers began in the mid-1990s and continues today.

Nonnative Channel Catfish and Common Carp have both been identified as predators of early life stages of native fishes in the Colorado River Basin (Tyus and Saunders 1996) and have the potential to compete for resources with all life stages of native fishes (Tyus and Saunders 2000; Carey and Wahl 2010). Mechanical removal of these abundant nonnative fishes began in the San Juan River in the 1990s as a tool to reduce their negative effects on native fishes. A more intensive NN removal effort that began in the 2000s is ongoing.

Here, we summarize the results of long-term efforts on the San Juan River to suppress nonnative Channel Catfish and Common Carp densities through NN removal. The specific objectives of this study were to (1) assess spatial and temporal trends in the density of the most abundant native and nonnative fishes in relation to NN removal and (2) assess spatial and temporal trends in the size structure of Channel Catfish following NN removal.

METHODS

Study Sites

The San Juan River originates in southwest Colorado and is a major tributary to the Colorado River, draining 99,200 km^2 in Colorado, Utah, Arizona, and New Mexico (Carlson and Carlson 1982; Figure 1). Annual discharge between 1935 and 2012 averaged 56.5 m^3/s (U.S. Geological Survey gauging station 09368000). Longitudinal variation in the structure of large-bodied fishes occurs along the river course (quantified between 1994 and 2012; Figure 2) where water temperature and sand substrates increase and channel complexity decreases when moving downstream (Bliesner and Lamarra 2000). Densities of nonnative adult Common Carp and adult Channel Catfish generally increased upstream, whereas juvenile Channel Catfish densities increased downstream but were also more temporally variable (Figure 2). Juvenile Common Carp were infrequently collected during the study period but were not considered in this study.

Due to the longitudinal variation in the densities of fishes in the San Juan River and variable NN removal efforts, we assessed the effects of NN removal on one upstream and one downstream reach. The upper reach (with generally high densities of both nonnative and native fishes) was between river kilometer (rkm) 268.1 and 199.6 (river kilometers decrease moving downstream; Figure 1). This upper reach is generally characterized by extensive channel braiding dominated by cobble, gravel, and sand substrates with riffles, runs, and backwater mesohabitats (Bliesner and Lamarra 2000). The lower reach (with higher densities of nonnatives and lower densities of natives) was between rkm 103.0 and rkm 65.9 (Figure 1). The lower reach generally has more sand substrates with fewer riffles and backwater habitats and minimal channel braiding (Bliesner and Lamarra 2000). Rkm 0.0 is located at a waterfall that limits upstream movement of fishes near Lake Powell (Figure 1).

Nonnative Fish Removal

To accommodate adaptive management strategies and funding constraints, NN removal efforts varied spatially and temporally during the study period. Removal efforts were initially conducted in relatively short reaches of the river to assess its logistic feasibility and then expanded to other reaches in later years to target likely spawning habitats of Channel Catfish and areas of known higher abundance (Figure 3). However, expanding the spatial scale of removal efforts diminished the amount of effort that could be applied to any specific reach. Thus, we delineated different subreaches within the upstream and downstream

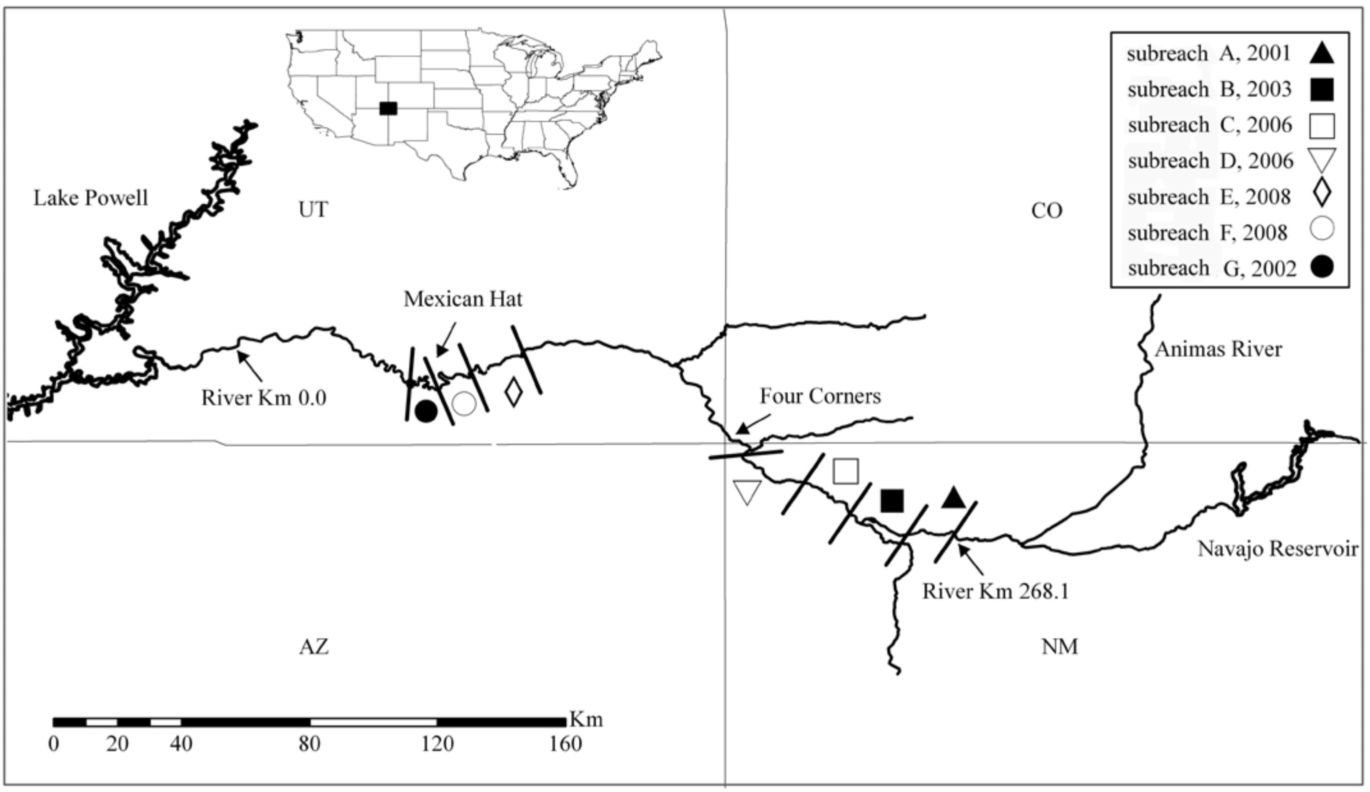

Figure 1. Map of study area on the San Juan River, New Mexico, Utah, and Colorado where intensive nonnative fish removal was implemented. The upper reach contained subreaches A–D and the lower reach contained subreaches E–G. Years next to subreaches in the legend indicate when intensive nonnative removal was implemented and continued through 2012.

reach that varied in temporal NN removal efforts. There were four subreaches at the upper reach (subreaches A–D) and three subreaches at the lower reach (subreaches E–G) that captured variable start dates of NN removal. At the upper reach, intensive NN removal efforts in subreach A (rkm 268.1–256.5) began in 2001, subreach B (rkm 256.5–239.8) in 2003, and subreach C (rkm 238.2–218.9) and subreach D (rkm 217.3–199.6) in 2006. The upstream limit of subreach A is demarcated by a weir and selective fish passage that limits upstream movement of nonnative fishes, at least during base flows. The lower reach consisted of three subreaches (E–G), where intensive removal began in 2002 in subreach G (rkm 82.1–65.9) downstream of subreach F (rkm 101.4–85.1) and subreach E (rkm 120.7–103.0). Intensive, river-wide removal from 2006 to 2012 subjected all subreaches to somewhat similar levels of NN removal (Figure 3). Habitat characteristics among the subreaches within upstream or downstream reaches were comparable. Prior to intensive NN removal in 2000, all subreaches had received moderate levels of NN removal since 1996, but this removal effort was usually limited to one electrofishing sampling per year during fall monitoring of large-bodied fishes.

Nonnative fish removal efforts varied spatially and temporally due to adaptive management strategies enacted by the San Juan River Implementation Program (www.fws.gov/southwest/sjrip). Generally, original NN removal efforts were restricted to relatively short areas of the river and then expanded in later years with similar efforts river-wide (Figure 3). At subreach A, 30 passes were conducted annually in 2001 and 2002 (each pass consisted of two electrofishing rafts, one on each shoreline). Intensive NN removal in subreach B began in 2003 with 13 passes but, due to time constraints, the number of passes (and hours electrofishing) conducted in subreach A was reduced to 14 passes and less than 90 h electrofishing (Table 1). Intensive NN removal efforts in subreaches C and D began in 2006 with two to three passes annually until 2008, when at least eight passes were completed annually. Overall, the number of passes conducted in each subreach in the upper reach ranged from 2 to 15 passes, and the level of effort became more similar among reaches overtime. Nonnative removal began in the lower reach in 2002 (i.e., subreach G) with between six and nine passes between 2002 and 2005 (Table 2). Nonnative removal in subreaches E and F began in 2006 with only one pass in each year. River-wide NN removal began in 2008 where all reaches were exposed to at least six yearly electrofishing passes.

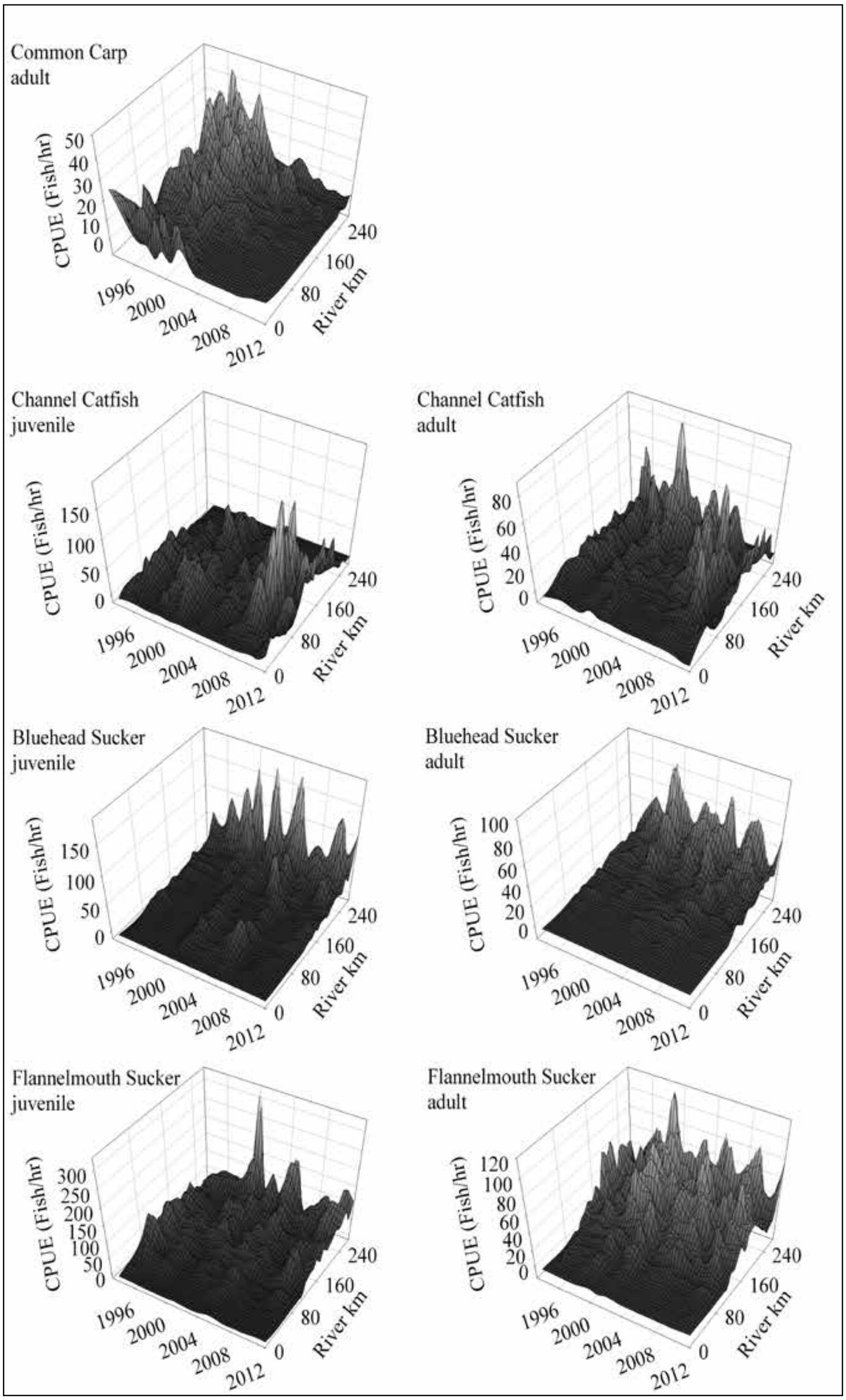

Figure 2. Mean CPUE (fish/h) along 8-rkm intervals for nonnative adult Common Carp, juvenile and adult Channel Catfish, as well as native juvenile and adult Bluehead Sucker and Flannelmouth Sucker longitudinally in the San Juan River from annual fall surveys between 1994 and 2012.

Nonnative fish removal occurred during daylight using raft-mounted electrofishing (Smith-Root 5.0 GPP, Vancouver, WA, USA), and NN removal efforts were spread out between March and October of each year. Electrofishing settings were standardized to run pulsed direct current on high range. Percentage of power was adjusted by raft operators to maintain an output current of 4 A. Two rafts sampled perpendicular to each shoreline and one netter per raft attempted to collect nonnative fishes encountered. Attempts were made to sample all available

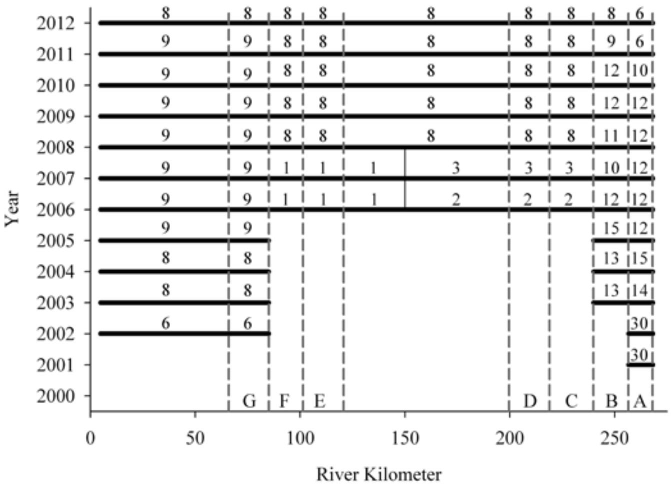

Figure 3. Spatial and temporal variation in the implementation of intensive nonnative fish removal in the San Juan River between 2001 and 2012. Horizontal lines are areas where intensive removal was implemented each year. The subreaches used in analyses are delineated by vertical gray dashed lines and lettered according to Figure 1. The number above each reach denotes the number of passes conducted by nonnative fish removal crews each year (one pass consisted of two electrofishing rafts sampling perpendicular to each shore). The vertical black line at rkm 150 demarcates a change in the number of passes in 2006 and 2007.

shoreline habitats in the main channel and any secondary channels accessible by raft. During NN removal at the selected subreaches, electrofishing proceeded downstream until live wells were filled to capacity or collectors reached diversion structures that required navigation. At stopping points, effort was recorded as seconds of electrofishing and all nonnative fishes were counted and removed from the river.

Response of Native and Nonnative Fishes

To assess the potential effects of NN removal on native and nonnative fishes, we used data from river-wide large-bodied fish surveys conducted every fall (September or October) via raft-mounted electrofishing units between 1994 and 2012. These data were independent of NN removal efforts and included counts of both native and nonnative fishes. During these surveys, two electrofishing rafts sampled each shoreline of the river and the number of fishes and effort (seconds) from both rafts were summed at the ends of each 1.6 rkm, but only three of every four 1.6 rkm were sampled each year. Furthermore, all fishes were weighed and measured (total length, TL, to the nearest millimeter) in one of these 1.6 rkm. Nonnative fishes were removed from the river during the fall surveys. These data allowed us to simultaneously assess densities of the most abundant native and nonnative fishes among subreaches after each year of NN removal. Additionally, these data were used to assess temporal variation in the size structure of Channel Catfish among subreaches. Changes in size structure of Common Carp were not investigated due to the extremely low densities after the initiation of NN removal (see results below). To assess potential size-specific effects of NN removal, we grouped fishes into age groups. For our study, adult Common Carp individuals were classified as ≥250 mm TL and juvenile Channel Catfish were ≤300 mm TL (De Roth 1965; Elrod 1974). Native fishes were grouped similarly with juvenile Bluehead Sucker ≤ 300 mm TL, juvenile Flannelmouth Sucker ≤ 410 mm TL, and all larger individuals were considered adults.

Data Analysis

We were specifically interested in assessing temporal trends of species and age groups in subreaches that varied in the duration and intensity of NN removal. We first calculated catch per unit effort (CPUE) as fish per hour for each 1.6 rkm sampled by the tandem electrofishing rafts each fall and then calculated the mean CPUE for each subreach from all river kilometers sampled in that subreach (i.e., subreaches A–G). Because of the distance between the upper and lower removal reaches, variation in densities of native and nonnative fishes between reaches, and the disparity in NN removal effort among years, we analyzed each reach separately. We assessed temporal and spatial variation (i.e., subreaches over time) in fall CPUE of each species and age group (seven groups total) using analysis of covariance (ANCOVA). We only included the years from 2000 to 2012 for the upper reach and 2001 to 2010 in the lower reach (subreach G was not sampled in the fall of 2011 and 2012). For each species–age group, we used $\text{Log}_{10}(x + 1)$ − transformed mean CPUE (to approximate normality of residuals) as the dependent variable, subreach as a fixed factor (to assess spatial variation in densities), year as a covariate (to assess overall temporal trends in densities), and their interaction (to test for subreach-specific responses to NN removal over time). A significant Subreach × Year interaction would indicate that the CPUE of a species–age group differed over time in at least one subreach. The interaction Subreach × Year was initially entered into each model but if not significant was removed from the final model. Effect sizes were estimated by use of partial eta^2 (η^2; the proportion of variance accounted for by each term in the model). Because most subreaches experienced differing temporal degrees and intensity of NN removal (i.e., some subreaches had received NN removal for longer periods of time), we predicted variable responses of fish densities among subreaches over time.

Size Structure of Channel Catfish

Because electrofishing is biased toward larger individuals (due to either susceptibility to the gear or netter biases toward larger individuals; Reynolds and Kolz 2012), we assessed whether NN removal had effects on the size structure of Channel Catfish among subreaches over time. Sample sizes were relatively small in individual subreaches at the upper reach in each year, especially in later years; therefore, we grouped fish collected from the upper two subreaches (A and B) and the two lower subreaches (C and D) between 2000 and 2012. Moreover, because we assumed that NN removal would have a cumulative effect on the size structure of Channel Catfish over time, we grouped subreaches that had a similar history of NN removal efforts (i.e., A and B, as well as C and D; Figure 2). Similarly, at the lower reach, fish from subreaches E and F were combined before analyses to better capture the full distribution of Channel Catfish sizes between 2001 and 2010. We calculated the median TL of Channel Catfish in each group of subreaches and year. We

Table 1. Number of Channel Catfish (Catfish) and Common Carp (Carp) removed from the river and electrofishing effort (hours) by year and subreach at the upper reach. Bold indicates intensive removal efforts in each subreach.

	(A) rkm 268.1–256.5			(B) rkm 256.5–239.8			(C) rkm 238.2–218.9			(D) rkm 217.3–199.6		
Year	Catfish	Carp	Effort	Catfish	Carp	Effort	Catfish	Carp	Effort	Catfish	Carp	Effort
1994	0	0	0.7	104	185	17.2	93	194	22.9	242	176	26.4
1995	0	0	0.0	240	271	20.8	206	275	26.0	245	188	26.3
1996	407	496	16.1	340	424	20.5	434	547	21.7	607	592	28.1
1997	256	322	13.1	373	461	17.5	460	797	24.6	603	571	24.3
1998	765	999	28.0	375	144	8.5	654	233	10.4	35	115	7.9
1999	564	1578	23.8	156	118	3.7	100	82	3.8	277	57	4.6
2000	665	280	56.5	329	130	5.9	406	155	5.8	175	143	4.5
2001	**4,213**	**3292**	**181.4**	467	166	5.2	284	143	6.4	247	97	6.4
2002	**3,641**	**1680**	**137.9**	147	87	5.0	228	75	7.5	148	98	7.0
2003	**2,250**	**659**	**85.1**	**4,092**	**2163**	**76.9**	169	87	5.5	60	25	5.1
2004	**2,907**	**474**	**87.5**	**4,048**	**775**	**81.8**	35	38	4.7	65	60	5.6
2005	**1,140**	**273**	**61.0**	**3,294**	**476**	**104.5**	488	64	6.0	302	49	4.2
2006	**674**	**185**	**52.7**	**2,458**	**401**	**102.5**	**949**	**220**	**20.6**	**723**	**76**	**13.0**
2007	**420**	**148**	**66.2**	**1,286**	**152**	**75.1**	**1,886**	**247**	**34.5**	**1,452**	**103**	**28.2**
2008	**424**	**82**	**62.9**	**1,120**	**189**	**101.7**	**1,448**	**266**	**77.9**	**2,331**	**132**	**91.5**
2009	**262**	**56**	**72.1**	**2,419**	**147**	**123.9**	**2,968**	**185**	**90.2**	**1,453**	**97**	**93.3**
2010	**132**	**36**	**60.7**	**832**	**68**	**122.2**	**1,317**	**85**	**60.8**	**902**	**65**	**61.0**
2011	**263**	**21**	**30.6**	**806**	**38**	**76.6**	**1,438**	**81**	**92.1**	**1,293**	**21**	**72.0**
2012	**301**	**18**	**36.5**	**1,166**	**44**	**83.1**	**4,523**	**39**	**80.1**	**3,985**	**25**	**88.7**

tested for changes to the size structure of Channel Catfish over time in the different subreaches with the use of two ANCOVA models. In each model (one for the upper and one for the lower reach), median TL of Channel Catfish (Log_{10}-transformed to approximate normality of residuals) was entered as the dependent variable with subreach as a fixed factor and year as a covariate. As above, the Subreach × Year interaction was included in each final model unless not significant. All analyses were conducted in R (R Development Core Team 2011).

RESULTS

Upper Reach

When using ANCOVAs to assess spatial and temporal variation in the densities of the seven species–age groups at the upper reach, all of the species–age groups showed significant influences of at least subreach or year but no significant interactions (Table 3, Figure 4). Year and subreach had significant effects on CPUE of Common Carp but year had a much stronger effect (η^2 = 0.88) than subreach (η^2 = 0.28). Generally, all subreaches (regardless of NN removal start dates) demonstrated drastic declines in the density of Common Carp over the study period. Both subreach and year were significant for juvenile and adult Channel Catfish. The density of both age classes of Channel Catfish tended to decline most sharply in subreaches A and B, whereas relatively little change was observed in the two lower reaches (subreaches C and D). The densities of juvenile Channel Catfish tended to be higher in the lower subreaches. Moreover, the variation in densities of both juvenile and adult Channel Catfish among subreaches was much higher after NN removal efforts compared to years before NN removal implementation. The CPUE of native juvenile Bluehead Sucker showed no temporal trends among subreaches, but their spatial variation in densities remained consistent through the study period. Subreach A had the highest densities of juvenile Bluehead Sucker and their densities decreased downstream. Adult Bluehead Sucker similarly demonstrated strong spatial variation in CPUE (η^2 = 0.54) and also showed no temporal trends in densities over the study period (η^2 = 0.02). The spatial structuring of juvenile Flannelmouth Sucker among subreaches also had strong effects on their CPUE (η^2 = 0.29), and their CPUE showed a significant but relatively weak positive relationship with time (η^2 = 0.07). Both subreach and year had strong significant effects on adult Flannelmouth Sucker, with their densities declining over the study period.

Lower Reach

When examining spatial and temporal variation of fishes at the lower reach, no species–age group exhibited a significant Subreach × Year interaction (Table 4, Figure 5). Similar to the upper reach, Common Carp demonstrated declines over the study period in all subreaches but had higher densities in the two upstream most subreaches. Densities of juvenile Channel Catfish did not significantly vary among subreaches or over time. Adult Channel Catfish did tend to have lower densities in the subreach G, but this lower density was consistent through the study period. The CPUE of juvenile Bluehead Sucker did not vary by subreach or over time and adult Bluehead Sucker only varied among subreaches. Juvenile Flannelmouth Sucker showed temporal declines (i.e., year had a significant effect) but did not demonstrate among subreach variation over time. Year and subreach had significant effects on adult Flannelmouth

Table 2. Number of Channel Catfish (Catfish) and Common Carp (Carp) removed from the river and electrofishing effort (hours) by year and subreach at the lower site. Bold indicates when removal effort increased in each subreach.

	(E) rkm 120.7–103.0			(F) rkm 101.4–83.7			(G) rkm 82.1–65.9		
Year	Catfish	Carp	Effort	Catfish	Carp	Effort	Catfish	Carp	Effort
1994	478	71	26.9	367	43	22.0			
1995	999	194	27.3	571	67	18.5	254	85	5.3
1996	1,030	397	29.0	563	251	20.9	125	36	8.6
1997	1,071	264	25.8	501	77	19.5	59	59	9.0
1998	172	60	9.4	177	38	9.5	104	40	9.8
1999	319	93	6.4	373	48	6.6	327	29	5.3
2000	128	52	7.8	320	36	9.1	498	48	9.7
2001	422	94	8.6	300	73	9.5	329	52	6.3
2002	127	40	6.4	119	24	6.5	**2,989**	**268**	**68.6**
2003	133	29	7.6	**107**	**12**	**5.9**	**3,978**	**196**	**98.7**
2004	181	51	6.5	**165**	**41**	**7.4**	**3,566**	**37**	**92.7**
2005	164	26	6.6	**154**	**11**	**5.4**	**3,929**	**44**	**83.0**
2006	**228**	**19**	**5.4**	**20**	**2**	**4.6**	**2,402**	**5**	**99.2**
2007	**337**	**11**	**7.0**	**208**	**2**	**6.6**	**3,234**	**16**	**89.7**
2008	**2,624**	**108**	**82.3**	**1,539**	**104**	**78.6**	**2,168**	**22**	**93.8**
2009	**7,960**	**31**	**87.0**	**7,277**	**29**	**89.7**	**4,831**	**20**	**110.8**
2010	**3,542**	**28**	**79.8**	**3,098**	**27**	**82.3**	**3,736**	**5**	**108.9**

Sucker CPUE. Generally, subreach G had a lower adult Flannelmouth Sucker CPUE compared to the upper subreaches E and F, and all subreaches showed declines in their densities over time.

Size Structure of Channel Catfish

Shifts in the size structure of Channel Catfish in removal subreaches were not evident in the upper reach. Differences in median TL between grouped subreaches at the upper reach were only marginally significant (Table 5), with Channel Catfish being smaller in the lower two subreaches compared to the upper two subreaches (Figure 6). Conversely, the lower reach showed a marginally significant temporal decline in the median size of Channel Catfish (Table 5), with subreach G having consistently smaller Channel Catfish compared to subreaches E and F throughout the study period (Figure 6).

DISCUSSION

We assessed spatial and temporal trends in the densities of native and nonnative fishes in relation to NN removal at two reaches in the San Juan River, New Mexico and Utah. Our data suggested that NN removal reduced the densities of nonnative fishes, but effectiveness varied by species and spatial location in the river. We also found little, if any, impact on the size structure of Channel Catfish over the study period. Regardless of reduced densities of nonnative fishes, there was no marked positive response by native fishes as a result of NN removal.

The strongest pattern associated with NN removal was the decline in densities of adult Common Carp over the study period among all subreaches (Figures 4 and 5). The reduced densities of Common Carp following NN removal were not unexpected, because this species tends to be highly susceptible to electrofishing and recruitment might be limited by a lack of floodplain habitat, which are critical spawning and nursery habitats (Stuart and Jones 2006; Jones and Stuart 2008). This is evidenced by steeper declines in Common Carp densities in subreaches where removal efforts had been implemented for longer time periods (Figures 4 and 5). However, the widespread decline of this species in reaches not targeted by early removal efforts suggests that NN removal may not have been solely responsible for their decline. For example, Lake Powell is likely a source population for Common Carp, but migration from the lake during the study period was limited by a sediment waterfall that formed at rkm 0.0 following the drop in the surface elevation of Lake Powell in 2002 (this waterfall was breached in 2011 for only about a 2-week period). Although migration of Common Carp from Lake Powell was blocked in 2002, migration from tributaries into the river proper likely continued. Thus, the mainstem San Juan River is likely used by subadult and adult Common Carp emigrating from tributaries of the San Juan River or, historically, Lake Powell. However, NN removal efforts were probably efficient enough to decrease and keep densities of adult Common Carp low during the study period.

Compared to Common Carp, the relationship between NN removal and Channel Catfish densities was less apparent and exhibited contrasting results at the lower versus upper reaches. At the upper reach, both juvenile and adult Channel Catfish demonstrated significant declines over the study period. Although there was substantial variation among years and subreaches, juvenile and adult Channel Catfish tended to show stronger declines over time in subreaches that experienced longer removal periods compared to subreaches with shorter removal periods (i.e., subreaches A and B versus C and D, respectively; Figure 4). Conversely, no temporal trends in juvenile or adult Channel Catfish densities were evident at the lower reach. Because NN removal efforts were similar between reaches in later years (i.e., the number of passes in each year), the disparity in responses of Channel Catfish to NN removal in the two reaches was likely influenced by other factors.

Movement patterns and spatial location of preferred spawning habitats of Channel Catfish potentially influenced the effectiveness of NN removal between upper and lower reaches of the river. Channel Catfish can have large home ranges in rivers (Wendle and Kelsch 1999), and they generally make upstream movements in spring, localized movement in summer, and downstream movements in the fall in other systems (Dames et al. 1989; Newcomb 1989; Pellett et al. 1998). Movement patterns of Channel Catfish have not been extensively investigated in the San Juan River, but limited mark–recapture data show extensive migrations (i.e., >160 km in the summer;

J.E. Davis, USFWS, unpublished). Thus, movement of fish into subreaches after NN removal and before fall monitoring (on average 15 and 39 days for the upper and lower reach, respectively) may have obscured the effects of NN removal. In addition, location of spawning habitats and subsequent migration of recruiting juveniles may explain the disparate effects of NN removal in the upper reach versus the lower reach. Longitudinal variation in the densities of Channel Catfish in larval drift samples and age-0 individuals collected by seine indicate general areas of the river with the greatest amount of Channel Catfish spawning. Between 1991 and 1997, annual summer larval drift surveys near Four Corners (just downstream of the upper reach near the borders of New Mexico, Colorado, Utah, and Arizona) and Mexican Hat, Utah (near the upper limit of subreach G) demonstrated that the densities of drifting, larval Channel Catfish were, on average, 10 times higher at Mexican Hat compared to Four Corners (Platania et al. 2000). In addition, data from annual small-bodied fish surveys using seines between 2003 and 2012 indicated that the densities of age-0 Channel Catfish increased moving downstream and tended to peak in the lower portions of the river (Franssen and Durst 2013). Thus, it appears that the middle reaches of the river are the most productive spawning habitats for Channel Catfish and provide the majority of juvenile Channel Catfish recruits in this system. Moreover, Channel Catfish above subreach A are minimal to nonexistent because of the weir and selective fish passage. This might explain why the decline of Channel Catfish tended to be stronger in the upper two subreaches (which would experience lower immigration rates) compared to the lower two subreaches, and because these subreaches experienced the longest periods of NN removal. At the lower reach, juvenile Channel Catfish and any migrants were able to enter the study reaches from both up- and downstream (but likely not from the reservoir proper due to the presence of the waterfall), potentially obscuring any signal of effectiveness of NN removal. Indeed, we found little evidence for spatial variation in densities of juvenile Channel Catfish at the lower reach, but adult Channel Catfish tended to have higher densities in upstream subreaches. Though mechanisms behind the disparity in the effectiveness of NN removal between reaches are not certain, our data suggest that habitat heterogeneity (Speas et al. 2004), longitudinal connectivity (Wendel and Keltch 1999), and sources of recruiting juveniles are likely to influence the success of removal efforts in large river systems.

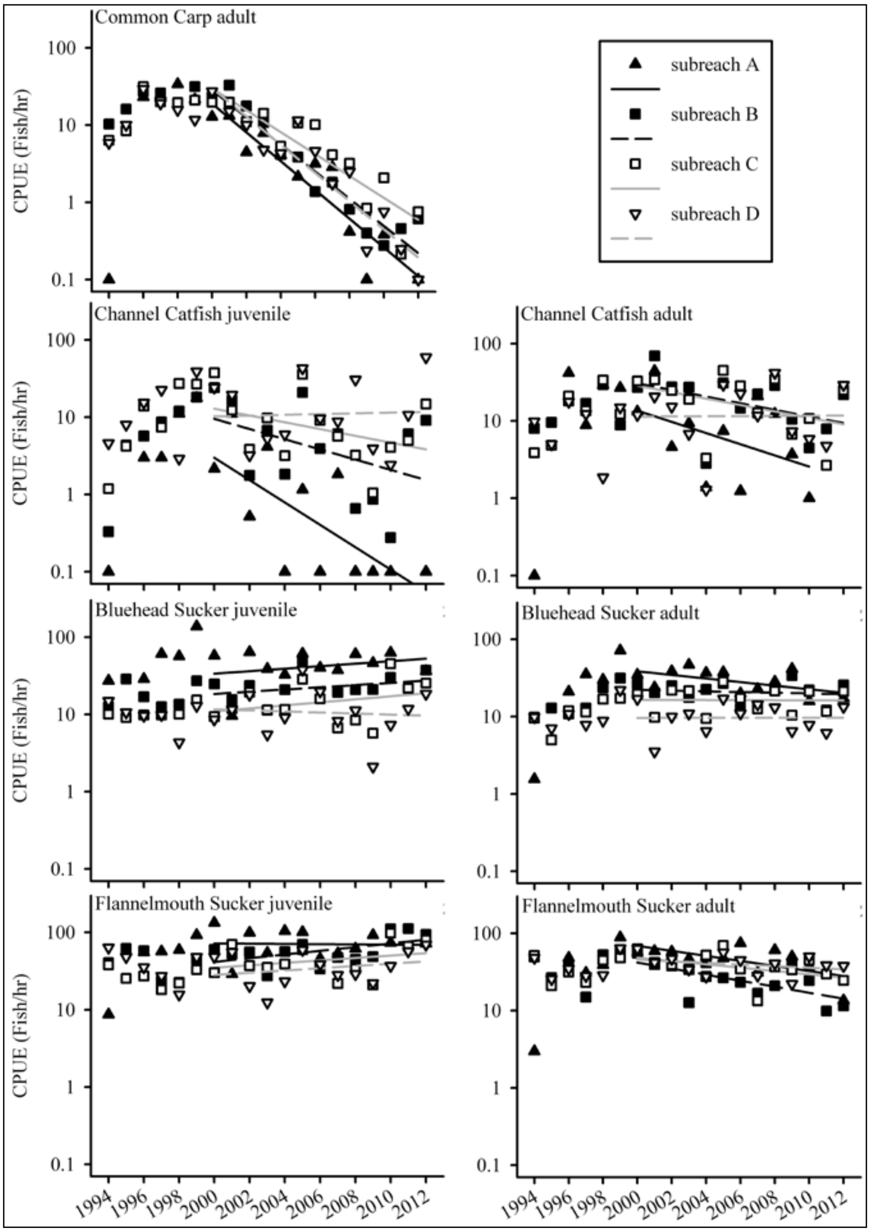

Figure 4. Catch per unit effort of fishes over time at the four subreaches at the upper reach. A value of 0.1 was added to each data point to facilitate plotting on a log-scale. Least square regression lines are plotted for each subreach from 2000 to 2012 (when year or subreach was significant from each ANCOVA). Nonnative fish removal began in subreach A in 2001, subreach B in 2003, and subreaches C and D in 2006.

We found little evidence for NN removal having positive effects on the densities of the native fishes we examined. However, juvenile Flannelmouth Sucker densities did increase over time at the upper reach (but decreased in abundance at the lower reach), and adults of this species showed declines at both the upper and lower reaches. On the contrary, juvenile and adult Bluehead Sucker densities were relatively stable through the study period and tended to maintain strong longitudinal patterns in their densities in both reaches. The removal of Channel Catfish could have potentially allowed increased densities of Flannelmouth Sucker in the upper reach through reduced competition for food or space or reduced predation rates by adult

Table 3. Results from species- and age group–specific ANCOVAs between 2000 and 2012 at the upper reach. For each model, the dependent variable was log-transformed CPUE. Models with nonsignificant interactions were reduced to include only main effects. Nonnative species are denoted with (*).

Group	Effect	η^2	F	p
Common Carp adult*	Year	0.88	$329.98_{(1,46)}$	<0.001
	Subreach	0.28	$6.01_{(3,46)}$	0.002
Channel Catfish juvenile*	Year	0.11	$4.67_{(1,46)}$	0.036
	Subreach	0.43	$11.35_{(3,46)}$	<0.001
Channel Catfish adult*	Year	0.13	$6.14_{(1,46)}$	0.017
	Subreach	0.22	$4.28_{(3,46)}$	0.010
Bluehead Sucker juvenile	Year	0.03	$0.91_{(1,46)}$	0.345
	Subreach	0.49	$14.49_{(3,46)}$	<0.001
Bluehead Sucker adult	Year	0.02	$1.76_{(1,46)}$	0.191
	Subreach	0.54	$18.01_{(3,46)}$	<0.001
Flannelmouth Sucker juvenile	Year	0.07	$2.88_{(1,46)}$	0.010
	Subreach	0.29	$6.35_{(3,46)}$	0.001
Flannelmouth Sucker adult	year	0.28	$18.49_{(1,46)}$	<0.001
	Subreach	0.28	$6.07_{(3,46)}$	0.001

Table 4. Results from species- and age group–specific ANCOVAs between 2000 and 2010 at the lower reach. For each model, the dependent variable was log-transformed CPUE. Models with nonsignificant interactions were reduced to include only main effects. Nonnative species are denoted with (*).

Group	Effect	η^2	F	p
Common Carp adult*	Year	0.75	$74.32_{(1,27)}$	<0.001
	Subreach	0.45	$11.11_{(2,27)}$	<0.001
Channel Catfish juvenile*	Year	0.06	$1.85_{(1,27)}$	0.185
	Subreach	0.06	$0.880_{(2,27)}$	0.426
Channel Catfish adult*	Year	0.05	$2.44_{(1,27)}$	0.130
	Subreach	0.35	$7.22_{(2,27)}$	0.003
Bluehead Sucker juvenile	Year	0.43	$21.54_{(1,27)}$	<0.001
	Subreach	0.03	$0.43_{(2,27)}$	0.652
Bluehead Sucker adult	Year	0.25	$7.95_{(1,27)}$	0.009
	Subreach	0.25	$4.59_{(2,27)}$	0.019
Flannelmouth Sucker juvenile	Year	0.33	$13.15_{(1,27)}$	0.001
	Subreach	0.05	$0.72_{(2,27)}$	0.496
Flannelmouth Sucker adult	year	0.60	$36.08_{(1,27)}$	<0.001
	Subreach	0.40	$8.85_{(2,27)}$	0.001

Channel Catfish. Similarly, lower densities of juvenile Channel Catfish may have reduced competition for food resources with juvenile Flannelmouth Sucker, allowing for their proliferation. Juveniles of Channel Catfish, Flannelmouth Sucker, and Bluehead Sucker tend to be highly omnivorous, foraging mainly on detritus, invertebrates, and algae (Sublette et al. 1990), and likely occupy the same habitats where they cooccur in the San Juan River (Gido and Propst 1999). However, such low-trophic-level resources are rarely limiting in aquatic systems (Moyle and Light 1996), and no positive responses in the densities of Bluehead Sucker were evident. On the other hand, the reduction in adult Channel Catfish may have reduced predation rates on juvenile Flannelmouth Sucker, allowing for their increase in densities. Indeed, fish in the diets of Channel Catfish tend to increase when individuals reach 300 mm TL (Bailey and Harrison 1945), and Gido and Propst (2012) identified a weak negative trend in the annual densities of adult Channel Catfish and other small-bodied fishes in the San Juan River. Determining the mechanisms behind the positive response of juvenile Flannelmouth Sucker, but a lack of response by juvenile Bluehead Sucker, is puzzling. Until a tight linkage through competitive or predatory interactions between juvenile Flannelmouth Sucker and Channel Catfish can be made, contributing the increased densities of juvenile Flannelmouth Sucker to NN removal is speculative. The increased densities of juvenile Flannelmouth Sucker at the upper reach and river-wide declines of adult Flannelmouth Sucker are more likely linked to other environmental conditions such as annual flow variation (Propst and Gido 2004; Gido and Propst 2012) that may drive spawning and recruitment success in this species. Moreover, we did not measure responses of native fishes that were too small to be effectively collected by raft-mounted electrofishing.

Other management activities implemented over the study period potentially confounded responses of native fishes to reduced densities of Channel Catfish and Common Carp. To supplement populations of federally protected Razorback Sucker and Colorado Pikeminnow, 114,649 Razorback Suckers (mostly subadult and adult fish) and over 4,000,000 Colorado Pikeminnows (mostly young of year) were stocked into the river between 1994 and 2011. The increased densities of omnivorous Razorback Suckers and invertivorous juvenile Colorado Pikeminnows during the study period may have reduced resources that were freed up by NN removal in the upper reach, leaving little extra resources for other native fishes. Though Colorado Pikeminnow and Razorback Sucker numbers increased river-wide over the study period (Schleicher and Ryden 2013), documentation of natural spawning and recruitment of these endangered fishes in the river is extremely limited to date. Because several management activities were operating during our study period (e.g., flow manipulation, NN removal, fish stockings), directly linking NN removal to higher numbers of Colorado Pikeminnows and Razorback Suckers in the river is problematic. Thus, it is difficult to assess whether NN removal is critical to the persistence of native fishes in the San Juan River.

No spatial or temporal trends in the median size of Channel Catfish were detected at the upper reach, and in the lower reach, all subreaches showed moderate declines in the size of Channel Catfish over the study period, despite having variable temporal NN removal efforts. This was a surprising result given the large number of individuals removed from the river each year and the presumed size selectivity of electrofishing. However, we did not efficiently sample the entire size range of Channel Catfish present in the river each fall (e.g., young of year, age-1 individuals), and thus if densities of smaller individuals increased over the study period we would have overlooked this trend. Moreover, migration of large individuals into the upper reach may have precluded detection of a reduced size structure. The general pattern of higher densities of adult Channel Catfish higher up in the river also implies that adults have a tendency to move upstream. We suggest that, although larger fish are likely more susceptible to electrofishing (Colombo et al. 2008; Reynolds and Kolz 2012), the relationship between size of fish and susceptibility to capture is likely not a linear relationship. Once individuals recruit in size to the electrofishing gear, they increase their susceptibility to capture, but after that size, an individual that is twice as large is not twice as susceptible to being captured. Thus, at least some large individuals are likely missed during NN removal each year. Conversely, there was a marginally significant negative trend in the median size of Channel Catfish in the lower reach, but this trend was similar in subreach G and in subreaches E and F, where NN removal had not been implemented as long. The decreased size structure at the lower reach was therefore likely due to the increased densities of juvenile Channel Catfish during the study period.

Similar to lentic and more-isolated systems, our results suggest that migration plays an important role in the effectiveness of reducing the densities of nonnative species, even with extensive removal efforts. Though removing nonnative fishes from selected habitats by definition lowers their densities, how fast migrants recolonize removal areas will determine how long these densities are diminished. The waterfall at rkm 0.0 halted migration between Lake Powell and the San Juan River proper during the study period and likely contributed to the decline of the adult Common Carp population by lowering immigration rates into the river. Similarly, only subreaches A and B at the upper reach demonstrated lower densities of Channel Catfish over time, where individuals can only recolonize these subreaches from downstream (due to a weir on the upstream side of subreach A). These results highlight how the spatial extent of barriers will play a large part in the effectiveness of NN removal to reduce the densities of nonnative fishes for substantial amounts of time.

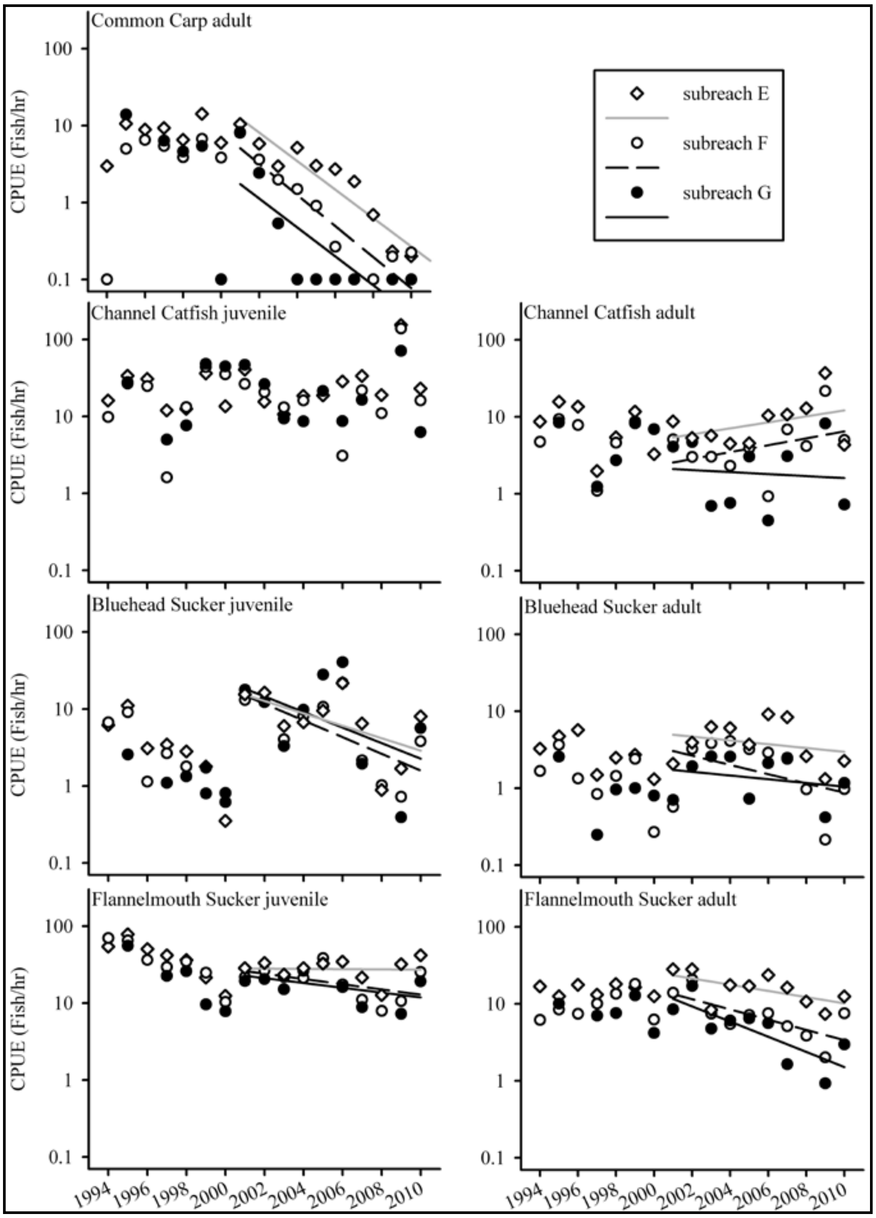

Figure 5. Catch per unit effort of fishes over time in the three subreaches at the lower reach. The value of 0.1 was added to each data point to facilitate plotting on a log-scale. Least square regression lines are plotted for each subreach from 2001 to 2010 (when year or subreach was significant from each ANCOVA). Nonnative fish removal began in subreach G in 2002 and subreaches E and F in 2008.

Management actions to reduce the densities of nonnative taxa for the benefit of native species will likely continue. The total cost of this ongoing large-scale nonnative fish removal program on the San Juan River between 2001 and 2012 was $4,218,000 and resulted in the removal of 314,710 Channel Catfish and 20,830 Common Carp. Though Common Carp densities were effectively reduced during NN removal, electrofishing will likely never totally eliminate Channel Catfish from the river. Targeting specific life stages and habitats might help increase the viability of a sustained removal program. Our data suggested that NN removal in the lower reach of the river had little effect on lowering nonnative fish densities for any appreciable amount of time, and production of larval and age-0 Channel Catfish is likely highest in middle portions of the river. Transfer of NN removal efforts into these middle reaches during peak spawning times of Channel Catfish (June–July) may stem off successful spawning and recruitment of fish. Furthermore, management actions would benefit from developing strategies to evaluate how NN fish removal may directly, or indirectly, influence population dynamics of native fishes. Though it is often problematic logistically, managers should strive to implement NN removal efforts with controls (e.g., no removal reaches), which would enable the effectiveness of efforts to be more easily evaluated. It is hoped that continued investigations, in a variety of systems, will help guide management actions to minimize effort and maximize efficiency of NN removal programs attempting to mitigate impacts of nonnative fishes.

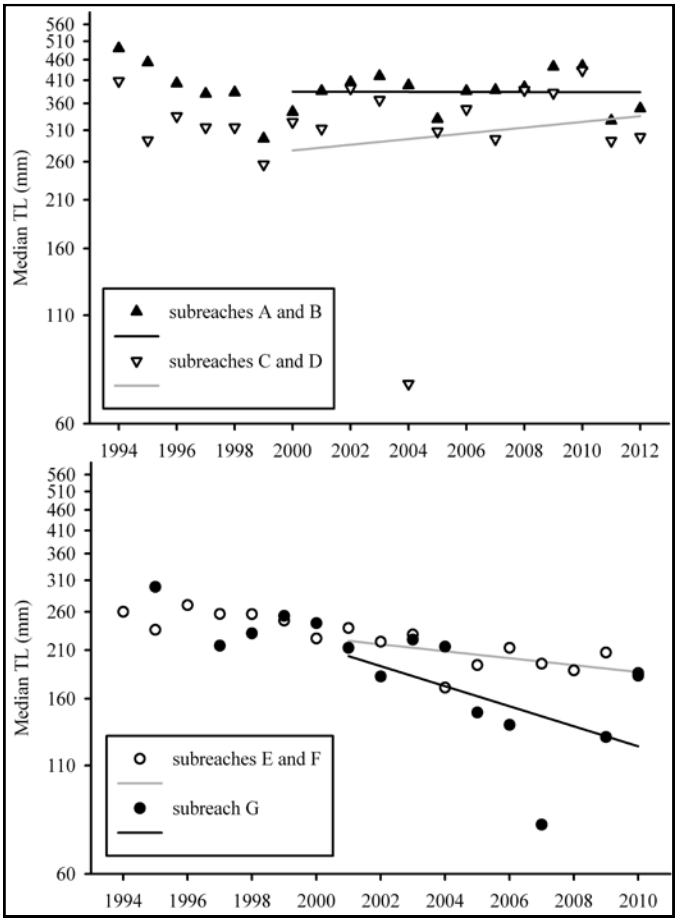

Figure 6. Annual median total length (mm) of Channel Catfish from the upper reach (upper panel) and lower reach (lower panel). Initiation of nonnative fish removal in the upper reach began in 2001, whereas nonnative fish removal in the lower reach began in 2002.

Table 5. ANCOVA results testing median TL of Channel Catfish between groups of subreaches and over time at the upper and lower reaches. Models with nonsignificant interactions were reduced to include only main effects.

Reach	Effect	η^2	F	*p*
Upper	Year	0.01	$0.215_{(1,23)}$	0.647
	Subreach	0.13	$3.292_{(1,23)}$	0.083
Lower	Year	0.22	$4.045_{(1,16)}$	0.061
	Subreach	0.27	$5.954_{(1,16)}$	0.027

Photo 1. The San Juan River demonstrates longitudinal changes in habitat conditions along the river's course. The upper reaches of the San Juan River, New Mexico, are characterized by shifting cobble, gravel, and sand substrates with extensive channel braiding (upper panel; rkm 209). Invasive Salt cedar and Russian olive dominate the riparian vegetation in the reach shown in the picture. The lower canyon-bound reaches of the San Juan River, Utah, tend to be deeper, with more sand substrate and minimal channel braiding (lower panel, rkm 103). The raft pictured in the lower panel is 4.9 m in length. Photo credits: upper panel, Nathan Franssen (University of New Mexico); lower panel, James Brooks (U.S. Fish and Wildlife Service).

ACKNOWLEDGMENTS

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Rachel Anne Morrison
1987–2014

Morrison Was a Legend in the Making

Try as we may, our lives cannot be forecast like the ocean tides. Rachel Anne Morrison, 27, was killed by a drunk driver while crossing a street on the evening of 28 March 2014 in Del Mar, California. Morrison was completing her fourth year as a candidate for a Ph.D. in marine biology at Scripps Institution of Oceanography (SIO) at the University of California–San Diego.

Morrison will be remembered by friends, family, and colleagues for her desire to learn and spread appreciation for the ocean's ecosystems.

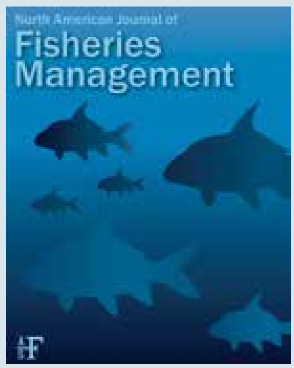
Her prestigious academic career eventually led to enrolling in the doctoral program at UC San Diego. She graduated high school from the Academy of Notre Dame in Tyngsboro, Massachusetts, in 2005 as valedictorian and received the Cardinal Medeiros scholarship for a full ride to Boston University. Her interest in fisheries management developed as an undergraduate and her curiosity with temperate fishes stems from her knowledge of the 1990s collapse of Atlantic Cod. She graduated magna cum laude with a B.A. in marine science in 2009 and went on to earn her master of science degree.

Morrison's academic accomplishments do not begin to describe the dedicated young scientist. She was also an athlete and planned to run her first marathon in Boston in April alongside her father. As an adventurer and marine researcher, she held integral roles on research cruises to Brazil, the Cook Islands, and the Republic of Kiribati. The goals of these oceanic missions were to discover links between marine populations, note the impact of fishing on the stress levels of captured fishes, and develop a means of evaluating the health of coral reef communities. Her dissertation research is focused on fishes in coral reefs and the effect of their feeding preferences on their rate of growth. She planned to apply her findings to help better understand the yields of reef systems in tropical developing countries dependent upon fishing.

A fund to help support Scripps graduate students was formed in memory of Morrison. The world at large and the field of marine biology lost an incredible person and researcher.

Bailey Edelstein

AFS SEEKS JOURNAL EDITOR



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

Duties include:

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

2. Soliciting manuscrips to ensure broad coverage;

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

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

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

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

AMERICAN FISHERIES SOCIETY

www.fisheries.org

2013 ANNUAL REPORT

MISSION

The AFS mission is to improve the conservation and sustainability of fishery resources and aquatic ecosystems by advancing fisheries and aquatic science and promoting the development of fisheries professionals.

TESTIMONIAL

"An organization like AFS provides that nexus for everyone in the fisheries world, linking to all professional folks in fisheries, government agencies, NGOs [nongovernmental organizations], and academia. Their journals, the presentations at the Annual Meeting, and symposia are all valuable [aspects of the organization]. Right now the NMFS [National Marine Fisheries Service] is in the middle of reauthorizing the Magnuson Stevens Act. It's hard to get everyone involved in fisheries at one single time. A group like AFS can provide that forum for professionals in fisheries to discuss and come together and establish goals of what they could change and refurbish within the act."

Steve Meyers
NMFS, Domestic Fisheries Division

Report from President Bob Hughes

2013–2014 THEME

The theme for 2013–2014 and the 2014 Annual Meeting was entitled *From Fisheries Research to Management: Thinking and Acting Locally and Globally*. Most of us think and act locally on a daily basis. To increase our global presence we have implemented the following this past year:

- Signed a formal cooperation agreement with the China Society of Fisheries (based on those signed late last year with the Fisheries Society of the British Isles, Japanese Society of Fisheries Science, Korean Society of Fisheries and Aquatic Science, and the Brazilian Society of Icthyology).
- Gave technical presentations at the 2013–2014 Annual Meetings of those societies and requested the same from their representatives at our Annual Meeting.
- Held the 2014 Western Division American Fisheries Society (WDAFS) Annual Meeting in Mazatlan, Sinaloa, Mexico (partly as a result of the $25,000 in Society matching travel funds, there were 441 registrants from 19 nations, including 199 students from 8 nations).
- Initiated an informal collaborative agreement with the Association for the Sciences of Limnology & Oceanography, Australian Society for Limnology, Desert Fishes Council, European Federation for Freshwater Sciences, International Society of Limnology, International Association for Danube Research, New Zealand Freshwater Sciences Society, Phycological Society of America, Society for Freshwater Science, Society of Wetland Scientists, and Society of EnvironmentalToxicology & Chemistry with the intent of developing a unified voice on global aquatic and fisheries policy.
- Organized the Annual Meeting in Québec City, which includes speakers from 46 nations (15% outside Canada and the United States), 41 symposia, with 10 being international in focus, and plenary speakers from 4 nations.
- Participated in second planning meetings for the World Fisheries Congress scheduled for 5–10 June 2016 in Busan, South Korea (the Society is expected to promote the meeting, seek North American sponsors, suggest plenary speakers, and develop a Society-sponsored/funded symposium in one of the five general theme areas: aquaculture, biological diversity and management, freshwater fisheries, marine fisheries and fish biology, and international collaboration and governance for sustainable fisheries and safe sea foods).

MAJOR ACCOMPLISHMENTS

The Society Leadership

- As approved at its Little Rock retreat and business meeting, the Society conducted much of its business via monthly Management Committee calls (with minutes sent to the Governing Board for discussion, approval, or rejection).
- Held an October meeting, the Fisheries Leadership Dialogue, with federal agency leaders and NGOs to discuss ways in which the Society can help them meet their technical and policy needs (one-on-one meetings have continued throughout the year as issues arise).
- Held its mid-year meeting colocated with the North Central Division Annual Meeting in Kansas City, with many members participating via GoToMeeting (thereby reducing the costs and duration of the meeting; the 2015 mid-year meeting will be colocated with the Southern Division Annual Meeting).
- Developed and approved a Society advocacy policy (based on that policy, letters were sent in support of fisheries science in the U.S. Environmental Protection Agency's Bristol Bay Watershed Assessment, the National Research Council's Decadal Survey of Ocean Sciences, and the United Nations' Global Ocean Observing System).

- Approved a Special Committee review and report (cochaired by Jesse Trushenski and Tom Bigford) of the U.S. Fish and Wildlife Service's (USFWS) National Fish Hatchery System (NFHS) *Strategic Hatchery and Workforce Planning Report.*

- Approved a new Society *Strategic Plan* (chaired by Margaret Murphy and including six major goals: science, education, communication, networking, advocacy, governance, and 15 strategies for attaining those goals).

- Approved *Guidelines for the Use of Fish in Research* for publication on the Society website (chaired by Jill Jenkins and including chapters on general research considerations, statutory requirements, animal welfare, field and lab activities, marking/tagging, and final disposition).

- Approved *Guidelines for the Use of Hatcheries in the Management of Aquatic Resources* for publication in the *North American Journal of Aquaculture* (the committee was chaired by Jesse Trushenski, and the top three priorities identified by a scoping survey are comprehensive fishery management plans, biological and environmental feasibility, and risk–benefit analysis).

- Approved a policy for Society officer travel (focused on budgeting costs and detailing allowable expenditures).

- Approved funding to the Fisheries Information & Technology Section for upgrading the software for the Fisheries Analysis & Modeling Simulator from Windows XP to Windows 7.

- Via a special committee chaired by Ron Essig, published a list of North American colleges and universities with fisheries-related degrees on the Society website and surveyed major employers to determine coursework germane to hiring decisions.

- Completed revisions to the draft *Society Policy on Mining and Oil & Gas Extraction* following member review and comment.

- Resource policy efforts were led by Jesse Trushenski with technical expertise from the Resource Policy Committee and other AFS units. Work is underway to: finish revising the *Policy Statement on Mining and Fossil Fuel Extraction*; complete a draft revision of our *Policy on Introductions of Aquatic Species;* initiate a new effort to revise the *Policy on Nonpoint Source Pollution;* and initiate a review of our *Policy on the Concept of Marine Wilderness.*

- Signed a memorandum of understanding (MOU) with the Southeast Ecological Science Center of the U.S. Geological Survey (USGS) to maintain a website of imperiled North American aquatic fauna.

- Signed an MOU with the Chesapeake Conservancy to organize and implement the National Workshop on Large Landscape Conservation being held 23–24 October 2014 in Washington, D.C. (www.largelandscapenetwork.org/2014-national-workshop).

- Declared January 2014 to be "Fishery Safety Month," encouraging AFS members to think safely about field research and laboratory science.

- Improved communications between Society staff, Officers, and Unit leaders, tasking staff to bring their level of expertise and knowledge to the corresponding committees, in order to ensure that staff is available to make important changes and offer help as needed.

PARTNERSHIPS WITH OTHER ORGANIZATIONS

- In May 2014, AFS attended the Joint Aquatic Sciences Meeting in Portland, Oregon, where leaders from four leading aquatic scientific societies (Society for Freshwater Science, Phycological Society of America, Association for the Sciences of Limnology and Oceanography, and Society of Wetland Scientists) gathered together with representatives from other societies with aquatic interest.

- AFS is now an active partner in the Policy Council of the Theodore Roosevelt Conservation Partnership (TRCP; www.trcp.org), a large group of resource professionals spanning our nation's waters, lands, and air. TRCP's Policy Council leads the discussion concerning research and conservation budgets, policy development, and trends across sectors—often with a direct connection to fish. We participated in the council's semiannual meeting in April 2014 and attended the council's annual retreat in June 2014.

- AFS employee Beth Beard is working with partners to coordinate the Global Conference on Inland Fisheries at the United Nation's Food and Agriculture Organization in Rome, Italy, on 26–30 January 2015. The event is organized by FAO and Michigan State University under the leadership of AFS Past President Bill Taylor.

- AFS has been an active participant in the National Fish Habitat Partnership since its creation in 2001. The past year marked Stan Moberly's (another AFS Past President) retirement as the AFS delegate to the National Fish Habitat Partnership (NFHP) Board. Stan left a lasting impression on NFHP through his contributions and expectations. AFS will remain engaged, with AFS Executive Director Doug Austen and AFS Policy Director Tom Bigford sliding into Stan's seat.

COOPERATIVE EFFORTS WITH FEDERAL AGENCIES



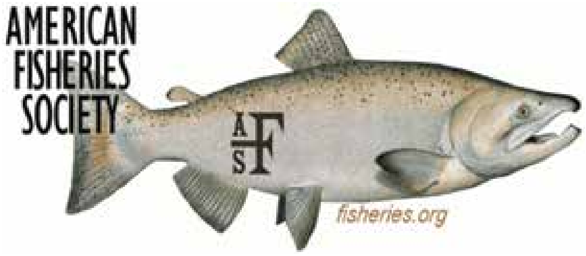

- Our long partnership with the U.S. Forest Service's (USFS) fish programs remains strong since they began sponsoring the Hutton Junior Fisheries Biology Program in 2001. The program matches aspiring students with a mentor and a research project. AFS Administrative Director Denise Spencer and Executive Director Doug Austen continue to sponsor the USFS's "Rise to the Future" event that honors achievements by agency employees. The April 2014 ceremony included several awards for career achievements in fish science.

- AFS also continues its support of the National Marine Fisheries Service. Based on a long-term cooperative agreement, AFS supports NMFS interests in conveying science and management information via congressional briefings, using our Annual Meeting to address agency priorities and expanding the Hutton Junior Fisheries Biology Program to encourage young enthusiasts to pursue careers related to fish.

- AFS Executive Director Doug Austen led an interagency and academic review team for the USFWS's Warm Springs Fisheries Technology Center (www.fws.gov/warmsprings/FishTechno).

MEMBER SERVICES

- The Society has integrated the membership tool and the website so that, with one sign-on, all membership information will now be easier to access.
- The Society has tasked AFS Content Director Sarah Fox to implement new strategies to integrate the Units with the Society, by building complementary Unit websites and implementing new content additions on the Society site.
- The Society has also implemented a biweekly electronic newsletter that provides a great method for the Society to communicate regularly with all 8,000 AFS members, along with social media interaction on Facebook, Twitter, LinkedIn, etc.
- After experiencing a substantial membership growth over nearly four decades and then experiencing a decline in the late 1990s, AFS membership numbers have settled into an unstable level that varies with the size of the Annual Meeting. No single membership category has changed dramatically in recent years, but we've seen a general decline in regular membership but generally slightly larger but fluctuating numbers for Young Professional and Student Members.
- AFS initiated a membership campaign targeting lapsed members with 2,500-person mailing sent to past members who have not renewed. This has been followed with targeted e-mails and have resulted in numerous renewals to the society.
- The Little Rock Annual Meeting ended up with 1,085 registrants and guests. An astounding 31% were students. The event total income was $484,632 and total expenses of $440,026. This resulted in a meeting revenue of $44,606 that was shared (70:30) between the Arkansas Chapter ($13,381.80) and AFS ($31,224.20). There was also a trade show profit of $54,125 that supports AFS activities.



Year	Life	Regular	Young Professional	Student	Developing Country	Retired	Honorary	Totals
2004	737	5,651	537	1,350	n/a	369	19	8,663
2005	738	5,425	579	1,326	n/a	364	18	8,450
2006	753	5,651	537	1,350	n/a	369	19	8,679
2007	755	5,311	715	1,649	n/a	395	15	8,840
2008	755	5,418	388	1,574	n/a	396	15	8,546
2009	750	4,543	380	1,241	n/a	354	15	7,283
2010	753	4,211	567	1,562	47	280	12	7,432
2011	754	5,472	690	1,815	54	399	12	9,196
2012	756	5,167	667	1,739	40	395	13	8,777
2013	762	4,032	594	1,545	31	366	13	7,343

POLICY HIGHLIGHTS

From January 2013 through (and anticipated by) August 2014:

- With leadership from Jesse Trushenski (Chair, Resource Policy Committee) and lead author Paul Radomski, AFS adopted its 34th policy in August 2013 to encourage efforts to limit the effects of lead in sport fishing tackle on fish and wildlife. Our intent is to encourage the use of alternative materials so less lead enters the food chain to affect birds and the habitats they share with fish.

- Major revision of our existing Policy Statement #13 (approved in 1983, revised in 1988 and again in 1995) on the effects of surface mining on fish and other aquatic resources in North America are nearly finished. President Bob Hughes, a long-time member of the Resource Policy Committee, led the revision effortusing the content to strengthen Society input on a contentious mining proposal in Alaska

- Policy Director Tom Bigford is working with AFS officers to implement a Policy Fellow program. The intent is to match interested AFS members with specific, short-term opportunities for professional growth.

POSITION STATEMENTS AND RELATED ACCOMPLISHMENTS

- Past-President John Boreman wrote President Obama in April 2013 to encourage an active response to the effects of climate change on fish. The President responded with a pledge to address scientific gaps and to pursue natural resource management options.

- In March 2013, AFS passed a resolution on "Federal Funding for Programs to Prevent, Control, and Manage Aquatic Invasive Species." Thanks to the AFS Resolutions Committee and Dennis K. Riecke, Kristen H. Ferry. Jill M. Hardiman, Robert M. Hughes, Cynthia S. Kolar, Philip Moy, Donna L. Parrish, Gregory D. Pitchford, and Kirk Schroeder.

TESTIMONIAL

"The Wildlife Society recognizes AFS as a complementary and very important organization. We are pursuing avenues for deeper collaboration between our societies on issues of mutual interest, through publications, outreach efforts, technical assessments, and conferences. The conservation community is moving to a more holistic concept of natural resources conservation, one that encourages the integration of aquatic and adjacent upland systems along with the fish and wildlife that depend on them. An enhanced level of cooperation between TWS [The Wildlife Society] and AFS has great potential to promote a deeper understanding of these systems, with the consequence of better, more informed management of them. AFS is a key player in bringing science to conservation and management, and TWS will continue to partner with the Society in that critical effort."

Ken Williams
Executive Director, The Wildlife Society

NOTEWORTHY PUBLICATIONS

- The AFS Book Publications Team (Aaron Lerner, Kurt West, and Debby Lehman) published three noteworthy volumes since early 2013. First was the seventh edition of *Common and Scientific Names of Fishes from the United States, Canada, and Mexico*, in 2013. Published second was the massive *Foundations of Fisheries Science* volume in 2014 and the most recent release of *Future of Fisheries: Perspectives for Emerging Professionals.*

- *Fisheries* magazine published an article that made news on a global scale: "Gutting Canada's Fisheries Act: No Fishery, No Fish Habitat Production" (Jeffrey A. Hutchings and John R. Post, 2013, *Fisheries* 38(11)).

AFS WEB SITE: WWW.FISHERIES.ORG

Visit www.fisheries.org for the latest on fisheries science and the profession.

AFS MAGAZINE: *FISHERIES*

The AFS membership journal, *Fisheries*, offers up-to-date information on fisheries science, management, and research, as well as AFS and professional activities. Featuring peer-reviewed scientific articles, analysis of national and international policy, chapter news, job listings, interviews with prominent professionals (as well as new members), archived content dating back to the beginning of AFS, and more. *Fisheries* gives AFS members the professional edge in their careers as researchers, regulators, and managers of local, national, and world fisheries.

Fisheries is available to members online at www.fisheries.org.

Publishes monthly, Volume 38
27 peer-reviewed articles published in 2013 (253 pages)
Impact Factor: 2.87

AFS JOURNALS

- **TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY**
  bimonthly, Volume 143
  153 articles published in 2013 (1773 pages)
  Impact Factor: 1.54

- **NORTH AMERICAN JOURNAL OF AQUACULTURE**
  quarterly, Volume 76
  71 articles published in 2013 (581 pages)
  Impact Factor: .75

- **NORTH AMERICAN JOURNAL OF FISHERIES MANAGEMENT**
  bimonthly, Volume 34
  135 articles published in 2013 (1300 pages)
  Impact Factor: 1.17

- **JOURNAL OF AQUATIC ANIMAL HEALTH**
  quarterly, Volume 26
  34 articles published in 2013 (294 pages)
  Impact Factor: 1.55

(Journals are also available to subscribing members online at http://afsjournals.org)

- **MARINE AND COASTAL FISHERIES: DYNAMICS, MANAGEMENT, AND ECOSYSTEM SCIENCE**
  annually, Volume 6. Online-only, open access
  29 articles published in 2013 (328 pages)
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The Fisheries InfoBase now includes all AFS journals back to 1872, including the complete contents of all issues of *Fisheries*.

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- *Foundations of Fisheries Science*
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- *Biology and Management of Inland Striped Bass and Hybrid Striped Bass*
- *Common and Scientific Names of Fishes from the United States, Canada, and Mexico*, Seventh Edition
- *Native Fishes of Idaho*
- *Fisheries Techniques*, Third Edition
- *Small Impoundment Management in North America*
- *Telemetry Techniques: A User's Guide for Fisheries Research*

TESTIMONIAL

"AFS taps into the greatest collection of fisheries scientists I know of. One of my primary responsibilities is to organize sportsmen's advocacy in Washington, D.C., in support of federal funding programs that conserve aquatic habitat and species. AFS is the best source of expertise about many of these programs, especially those at NOAA [National Oceanic and Atmospheric Administration]. This kind of consensus and coalition building that AFS coordinates is what sportsmen must do to protect habitat, species, and our access to sporting opportunities."

Jimmy Hague
Director, Center for Water Resources
Initiative manager for water resources conservation

SOCIETY AWARDS

Congratulations to the 2013 AFS Award Recipients. Awards were announced during the Annual Meeting in Little Rock, Arkansas, 8–12 September. They were honored for their contributions to the American Fisheries Society, to their profession, and to resource conservation.

AWARD OF EXCELLENCE—Presented to an AFS member for original and outstanding contributions to fisheries science and aquatic biology.

Bonnie J. McCay, Rutgers University

PRESIDENT'S FISHERY CONSERVATION AWARD—Presented in two categories: (1) an AFS individual or unit or (2) a non-AFS individual or entity, for singular accomplishments or long-term contributions that advance aquatic resource conservation at a regional or local level.

AFS Member Category—**Larry L. Olmsted**, Duke Energy Company, retired

Non-Member Category—**James R. Nassar**, Coordinator, Lower Mississippi River Conservation Committee

WILLIAM E. RICKER RESOURCE CONSERVATION AWARD—Presented to an individual or organization for singular accomplishments or long-term contributions that advance aquatic resource conservation at a national or international level.

Brian J. Shuter, University of Toronto

CARL R. SULLIVAN FISHERY CONSERVATION AWARD—Presented to an individual or organization for outstanding contributions to the conservation of fishery resources.

Richard D. Methot, **Jr.**, Northwest Fisheries Science Center

MERITORIOUS SERVICE AWARD—Presented to an individual for loyalty, dedication, and meritorious service to the Society throughout the years and for exceptional commitment to AFS's programs, objectives, and goals.

Ira R. Adelman, University of Minnesota, retired

THE EMMELINE MOORE PRIZE— Named after the first female AFS president, Emmeline Moore (1927–1928), this award recognizes career achievement in the promotion of demographic diversity in the Society.

Steve E. Lochmann, University of Arkansas at Pine Bluff

DISTINGUISHED SERVICE AWARD—Recognizes outstanding contributions of time and energy for special projects or activities by AFS members.

The Executive Director Search Committee

HONORARY MEMBERSHIP—Presented to individuals who have achieved outstanding professional accomplishments or have given outstanding service to the Society.

Charlie E. Smith, U.S. Fish & Wildlife Service, retired

OUTSTANDING CHAPTER AWARD—Recognizes outstanding professionalism, active resource protection and enhancement programs, and commitment to the mission of the Society.

Oregon Chapter

OUTSTANDING STUDENT SUBUNIT AWARD—Recognizes outstanding professionalism, active resource protection and enhancement programs, and commitment to the mission of the Society.

Lake Superior State University

EXCELLENCE IN PUBLIC OUTREACH AWARD—Presented to an AFS member who goes the "extra mile" in sharing the value of fisheries science/research with the general public through the popular media and other communication channels.

Lauri Monnot, Idaho Department of Environmental Quality and **U. Rashid Sumaila**, Fisheries Centre, University of British Columbia

GOLDEN MEMBERSHIP AWARDS: THE CLASS OF 1964—Recognizes individuals who have been AFS members for 50 years.

Kenneth Beal	Richard Hansen	William Neill
Kirk Beiningen	Richard Heimann	Richard Noble
Frank Bulow	Edward Houde	Arthur Oakley
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R. John Gibson	John Merriner	Douglas Wilson
James Gift	Peter Minta	James Woodey
John Grover	Stanley Moberly	
Jerry Hamelink	Robert Mullen	

EXCELLENCE IN FISHERIES EDUCATION—Recognizes excellence in organized teaching and advising in a field of fisheries.

Frederick Scharf, University of North Carolina, Wilmington

SKINNER AWARD—The John E. Skinner Memorial Fund was established to provide monetary travel awards for deserving graduate students or exceptional undergraduate students to attend the AFS Annual Meeting.

Recipients:

Andrew Carlson, South Dakota State University
Patrick Cooney, North Carolina State University
Carlin Fenn, Southern Illinois University
Sally Petre, University of Arizona
Kristopher Stahr, Oklahoma State University
David (Randy) Stewart, Oklahoma State University
Heather Stewart, Mississippi State University
Lynn Waterhouse, University of California–San Diego
Tracy Wendt, University of Montana
Lisa Winters, Utah State University

Honorable Mention:

Caroline Andrews, Mississippi State University
Katharine DeVilbiss, State University of New York
Abigail Lynch, Michigan State University
Tanner Stevens, South Dakota State University
Joy Young, Florida Atlantic University

J. FRANCES ALLEN SCHOLARSHIP—Awarded to a female AFS Member and doctoral candidate who is conducting aquatic research.

Winner: Abigail Lynch, Michigan State University
Runner-up: Cari-Ann Hayer, South Dakota State University

STEVEN BERKELEY MARINE CONSERVATION FELLOWSHIP

Recipient: Christian Conroy, Northeastern University
Honorable Mention: Alex Filous, University of Hawaii Manoa and **Alexis Jackson**, University of California–Santa Cruz

STUDENT WRITING CONTEST

Best Paper: Abigail Lynch, Michigan State University, "One Fish, Two Fish, Where Fish for Whitefish? Designing a Climate Change Decision-Support Tool for Great Lakes Lake Whitefish"
Runner-up tie:
Gerard Camona-Catot, Universidad de Girona, Spain, "Fish Go Wild in California"
Patrick Cooney, North Carolina State University, "A Southern Revival: Researchers and Young Anglers Contribute to the Revival of Southern Appalachian Trout Fishing"

2012 BEST PAPER AWARDS

MERCER PATRIARCHE AWARD FOR THE BEST PAPER IN THE *NORTH AMERICAN JOURNAL OF FISHERIES MANAGEMENT*

A. L. Haakand and J. E. Williams
Spreading the Risk: Native Trout Management in a Warmer and Less-Certain Future. *North American Journal of Fisheries Management* 32(2):387–401.

ROBERT L. KENDALL BEST PAPER IN *TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY*

S. Eyler, N. P. Hitt, and J. E. B. Wofford
Dam Removal Increases American Eel Abundance in Distant Headwater Streams. *Transactions of the American Fisheries Society* 141(5):1171–1179.

BEST PAPER IN THE *JOURNAL OF AQUATIC ANIMAL HEALTH*

Mark A. Drawbridge, Ronald S. Kaufmann, Mark S. Okihiro, and Jeffrey E. Smiley
Pathology of Ocular Lesions Associated with Gas Supersaturation in White Seabass. *Journal of Aquatic Animal Health* 24(1):1–10.

BEST PAPER IN THE *NORTH AMERICAN JOURNAL OF AQUACULTURE*

B. G. Bosworth
Effects of Winter Feeding on Growth, Body Composition and Processing Traits of Co-Cultured Blue Catfish, Channel Catfish, and Channel × Blue Catfish Hybrids. *North American Journal of Aquaculture* 74(4):553–559.

SECTION AWARDS

BIOENGINEERING SECTION

Career Achievement Award: Charles Coutant
Ned Taft Scholarship: Elsa Goerig, Institut national de la recherchescientifique (INRS)

CANADIAN AQUATIC RESOURCES SECTION

Peter A. Larkin Award
Ph.D. level—Jake Brownscombe, Carleton University; **Runner up: Graham Raby**
M.Sc. levels—Samantha Wilson, Carleton University; **Runners up: Nicholas Burnett,** Carleton University and **Sean Naman**

EDUCATION SECTION

Young Professional Achievement Award: Michelle Walsh
AFS Best Student Poster Award (at the 2012 Annual Meeting in Saint Paul, Minnesota)
Winner: Geoffrey H. Smith, Jr., University of Florida
Honorable Mentions: Liza R. Walleser, University of Wisconsin–La Crosse
AFS/SEA Grant Best Student Paper—2012 Annual Meeting, Saint Paul, Minnesota
Winner: Jason R. Neuswanger, University of Alaska Fairbanks
Honorable Mention: Ashley Stasko, Laurentian University

ESTUARIES SECTION

Student Travel Award: Shelley Edmundson, Shane Ramee, Konstantine John Rountos, and Ryan W. Schloesser

FISHERIES AND INFORMATION TECHNOLOGY SECTION

Best Student Poster Award: Brittany Schwartzkopf, Louisiana State University

FISH CULTURE SECTION

Student Travel Award: Shane Ramee and Alichia Sunflower Wilson

Best Paper in NAJA: Brian Bosworth

FISH HEALTH SECTION

Snieszko Student Travel Award: Amy Teffer, University of Victoria

FISHERIES ADMINISTRATION SECTION

2013 Outstanding Sport Fish Restoration Sport Fishery Development and Management

- **Habitat Acquisition or Improvement Category:** Nebraska Game and Parks Commission, Nebraska's New Reservoir Construction Program
- **Access Category:** Tennessee Wildlife Resources Agency, Morris Ferry Boat and Bank Fishing Access: Revived and Alive Again! Project
- **Research and Surveys Category:** North Carolina Wildlife Resources Commission, Project using the DIDSON to Evaluate the Effectiveness of Different Fish Attractors in Turbid Reservoirs
- **Aquatic Education Category:** Florida Fish and Wildlife Conservation Commission, Fishing and Basic Boating Skills Camp Pilot and Expansion Project

FISHERIES MANAGEMENT SECTION

Award of Excellence: Brian Murphy and Dennis Scarnecchia

Conservation Achievement Award: John G. Shedd Aquarium, Chicago, Illinois

Hall of Excellence: Bob Ditton and Dave Philipp

GENETICS SECTION

James E. Wright Graduate Award: Darren Wood and Cassidy Hahn

Stevan Phelps Memorial Award: Michael Donofrio, Robert Elliott, Jared Homola, Jeannette Kanefsky, James McNair, Kim Scribner, and Kregg Smith for their paper titled, "Genetically Derived Estimates of Contemporary Natural Straying Rates and Historical Gene Flow among Lake Michigan Sturgeon Populations." *Transactions of the American Fisheries Society* 141:1374–1388.

MARINE FISHERIES SECTION

Steven Berkeley Marine Conservation Fellowship Winner: Christian William Conroy, Northeastern University

Honorable Mention: Alex Filous, University of Hawaii and **Alexis Jackson**, University of California–Santa Cruz

Oscar E. Sette Award: Phillip Goodyear

Student Travel Award: Pablo Granados-Dieseldorff and Christopher Hollenbeck

SOCIOECONOMICS SECTION

A. Stephen Weithman Best Student Paper Award Winner: Ed Camp, University of Florida

Honorable Mentions: Julia Beaty, University of Maine

Ingrid Biedron, Cornell University

WATER QUALITY SECTION

Best Student Poster Award: Brandy Bossle, University of South Carolina Aiken

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North Carolina Wildlife Resources Commission
Ohio Department of Natural Resources
Oregon Department of Fish & Wildlife
Pennsylvania Fish & Boat Commission
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South Dakota Game Fish & Parks
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Q&A: Halamid® Aqua (Chloramine-T) Approved by FDA to Treat Fish Diseases—What It Means for Fisheries

Jesse T. Trushenski

Southern Illinois University Carbondale, Center for Fisheries, Aquaculture, and Aquatic Sciences, 1125 Lincoln Drive, Room 173, Carbondale, IL 62901. E-mail: saluski@siu.edu

James D. Bowker

U.S. Fish and Wildlife Service Aquatic Animal Drug Approval Partnership Program, Bozeman, MT

Axcentive SARL announced recently that the U.S. Food and Drug Administration (FDA) has approved Halamid® Aqua (100% chloramine-T) as a new therapeutic drug for use in fish. Halamid® Aqua is an important weapon in the arsenal fisheries professionals use to combat fish diseases, and its approval is a major advance in fish health management. Below, Jesse Trushenski, president of the Fish Culture Section, discusses the approval with Western Division Vice President James Bowker, who has played a leadership role in fish drug approval efforts for the past 20 years.

What is chloramine-T and what is it used for?

Chloramine-T is a chlorine-releasing product that's used as a sanitizing agent in hospitals, other medical and dental facilities, laboratories, and veterinary facilities. Chloramine-T kills microbes through nonselective, oxidative processes. In other words, it's a disinfectant and not an antibiotic. Chloramine-T kills gram-negative bacteria, including the fish pathogens associated with bacterial gill disease and columnaris. After more than 20 years in development, Halamid® Aqua (100% chloramine-T) has been approved by the FDA to control mortality in freshwater-reared salmonids caused by bacterial gill disease and in Walleye and freshwater-reared warmwater finfish caused by columnaris.

This seems like very good news for fish culture and fish health types, but why does it matter to "Joe Fish Biologist"?

Whether it's for creating new fishing opportunities or restoring imperiled species, fish culture and hatchery-reared fish are central to fisheries management. Many fish pathogens are ubiquitous and, like all of us, when fish are crowded together like they are in intensive rearing systems, they become more susceptible to infections. When disease outbreaks occur, it's essential that we have a well-stocked medicine chest to treat the infections, ensure that production goals are met, and ensure that fish are healthy when they are released into our waters. Stocking healthy fish should not only matter to Joe Fish Biologist but to anglers and all those interested in fisheries conservation.

Billions of fish are stocked in the United States annually, mostly for sportfishing, but also for restoration and recovery of threatened and endangered fish. FDA-approved fish drugs, like Halamid Aqua, help culturists safely and effectively control mortality in the hatchery. That means that time and money are not wasted on rearing fish that succumb to disease. We all know that resources are limited in fisheries conservation; Halamid Aqua isn't a silver bullet, but judicious use of chloramine-T and other approved drugs can help hatcheries operate more effectively.

Twenty-plus years seems like a long time for a drug to be in development. What did it take to secure this approval?

That's a question that has been asked for…well, about 20 years! Approval of a chloramine-T product has been the number one priority of the Association of Fish and Wildlife Agencies Drug Approval Working Group since its inception, and it has been a long road. The FDA takes a precautionary approach to drug approvals and proving a drug is safe and effective requires volumes of data generated under strict regulatory oversight. Chloramine-T was the first Association of Fish and Wildlife Agencies drug priority we tackled collectively, and we charted new territory in the process. Without the commitment of the sponsor, several research entities, and the National New Animal Drug Application Coordinator, Halamid Aqua would never have been approved.

What have you learned during the development of chloramine-T? Will the process always be this laborious?

We learned from our mistakes. We now communicate more frequently with the FDA, and we have learned to ask the right questions. We've become experts in the drug approval process and have developed expertise in the related fisheries disciplines, and that has made the process much less laborious and lengthy. For example, we're currently working toward an approval for an immediate-release fish sedative, and we anticipate that this drug will be approved in less than half the time it took for Halamid Aqua.

AADAP staff collecting data in support of the Halamid Aqua approval. Photo credit: U.S. Fish and Wildlife Service.

Does this mean that the fisheries medicine chest is now full?

Unfortunately, no. Several more fish drugs are still critically needed, including another antibiotic to better address issues such as antimicrobial resistance. We've got a handful of options for freshwater fish, but the medicine chest for marine fish is empty.

Congratulations and thanks are due to all those who have contributed to this approval over the years. What can fisheries professionals do to express our gratitude for those who toil in the field of aquatic animal drug approvals?

Thank you. First, it is critical that fisheries professionals use only FDA-approved drugs and that they use them judiciously. Second, make a commitment to help groups like the U.S. Fish and Wildlife Service Aquatic Animal Drug Approval Partnership Program to conduct field effectiveness trials. If you don't help prove a drug is effective in treating a disease in your fish, it's unlikely that it will be approved for that use. Opportunities to conduct scientifically valid, statistically defensible field effectiveness trials are the biggest limiting factor in getting drugs approved for new uses. Halamid Aqua is now approved for a few uses, but by helping us conduct the necessary experiments, you can help expand the label, enabling use by more fisheries professionals in need.

The International Wild Trout Symposium: The Past and the Future

Stephen E. Moore

Retired; 3523 Lawson Lane, Sevierville, TN 37862. E-mail: smoore4fish@comcast.net

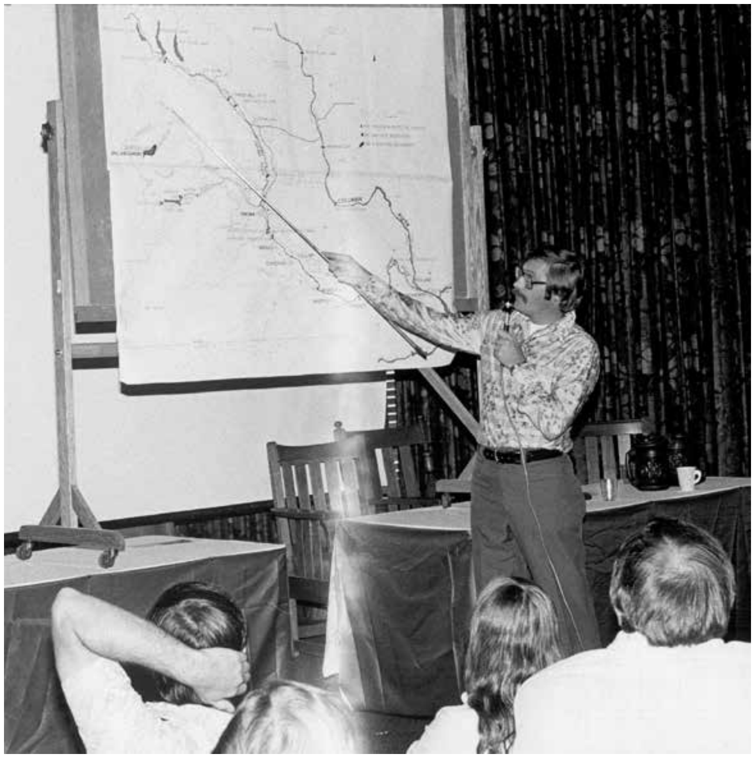
Daniel J. Schill

Wild Trout XI Symposium Chair; 600 S. Walnut, Boise, ID 83712

Robert F. Carline

Retired; 123 Gibson Place, Port Matilda, PA 16870

This fall, 22–25 September 2014, Wild Trout XI will convene at the Holiday Inn, West Yellowstone, Montana, and begin by celebrating the 40th anniversary of the International Wild Trout Symposium series. The first meeting was held in 1974 and brought together wild trout biologists and anglers to foster improved management of wild trout resources in the United States and Canada. From this modest beginning, the Wild Trout Symposium has subsequently been held every 3 to 5 years and has become an important sounding board for the conservation of wild trout. Wild Trout XI offers another unique opportunity for professional biologists from around the world to interact with educators, anglers, nonprofit conservation groups, and businesses keenly interested in wild trout populations and their associated fisheries.



HISTORY

Prior to Wild Trout I, discussions related to wild trout management occurred for decades at regional fisheries meetings across the United States and around the world. However, the idea for a broader meeting focused solely on wild trout began when three visionaries, Frank Richardson, U.S. Fish and Wildlife Service, Trout Unlimited Executive Director Pete Van Gytenbeek, and John Peters of the U.S. Environmental Protection Agency, met for lunch in Denver in 1973 and discussed ways to advance the cause of wild trout. Their idea, to hold a geographically diverse conclave dedicated exclusively to wild trout management while staying in one of North America's most sacred wild trout sanctuaries, was presented to Nathaniel P. Reed, Assistant Secretary of the Interior for Fish, Wildlife and Parks. Reed enthusiastically endorsed the concept and based on his support, Richardson soon met with Jack Anderson, superintendent of Yellowstone National Park, and planning for the event began immediately.

As envisioned by the founders of the meeting, the mission of the Wild Trout Symposium was, and remains, to provide a forum for professional wild trout biologists, conservationists, and anglers to get to know each other in an informal setting and be exposed to the latest wild trout science and research. The originators intended that the attendees would establish contacts across the United States and Canada and that they would communicate and share ideas related to the management of wild trout resources and the anglers who use and enjoy them.

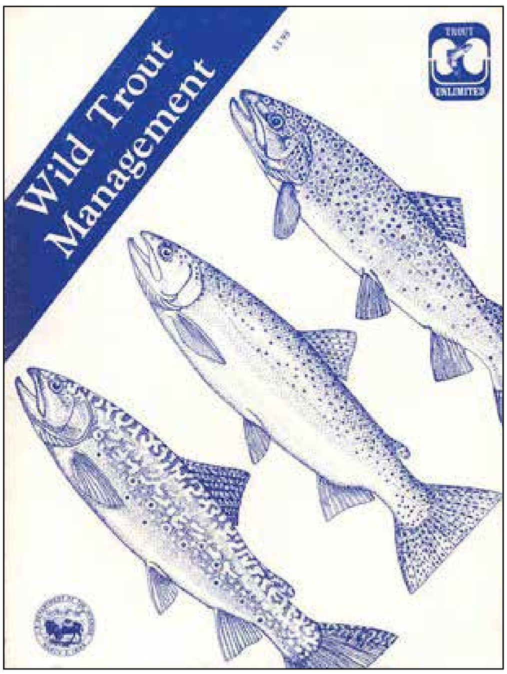
The first symposium was held 25–26 September 1974 at Mammoth Hot Springs Hotel in Yellowstone National Park. Over 300 anglers, writers, students, and professionals from every trout-supporting region in the United States and Canada met on common ground to talk about wild trout and establish a new tradition. In his keynote remarks, Willis King noted that if the meeting was to determine what attendees thought was "the right thing to do for wild trout," it should center around two themes. First, "How do we perpetuate a natural fishery?" In other words, what tools are available to ensure the preservation of this valuable resource? Second, "What can we do to provide a satisfactory angling experience?" In Kivv0ng's view, to accomplish this task, biologists first needed to understand the basic life history of the fish they are working with; next, develop a sound knowledge of the aquatic ecosystems they live in; and, lastly, we must understand how this information relates to anglers. King's insights and challenges sound strikingly similar to those that wild trout managers face today.

The first several symposia focused primarily on managing fish and anglers, water quality, watershed management, and possible deleterious consequences of stocked hatchery trout on wild trout populations. The use of special regulations to protect wild trout populations from overharvest was also a key meeting topic during the early years. However, there was little data to support many of the claims of special regulation proponents. Early state agency studies in California, Michigan, Wisconsin, Pennsylvania, and Idaho, along with those in Yellowstone and Great Smoky Mountains national parks, provided much of the initial information related to the use of special trout regulations. Many of these initial studies, reported on at the first few Wild Trout Symposia, paved the way for later studies that included more detailed information on response of the fish populations to special regulations and rapidly changing angler opinions and desires.

The symposia that followed the first few meetings have focused on many of the key issues still affecting wild trout populations. These issues include native species restoration, conservation genetics, partnerships for watershed management, regulations and their appropriateness, educational tools for schools and the public, global warming, and acid rain. Each symposium has brought together many of the leading authorities on wild trout management and research from around the world as well as conservation leaders and students to discuss the latest challenges and opportunities related to wild trout resources. For four decades now, attendees have left these meetings and returned home armed with new ideas and tools that help protect and preserve these resources in the face of a rapidly changing environment that places more demands on shrinking resources.

WILD TROUT XI: "LOOKING BACK AND MOVING FORWARD" SLATED FOR SEPTEMBER 2014

Wild Trout XI will celebrate the 40th anniversary of this prestigious event. As with the earlier gatherings, a diverse group of leaders in wild trout management and research, educators, nonprofit conservation staff, and others from across the United States, Canada, and the world will meet to talk morning to midnight on their favorite topic, wild trout. The symposium will be kicked off with a plenary session highlighting the meeting history and lessons learned in the past four decades, along with an insightful look forward to the future of wild trout management. Based on past results, this meeting promises to provide the most up-to-date information available regarding future wild trout management, regardless of where these resources occur. Though several other wild trout–centric meetings of lesser



vintage are also of note, this meeting is arguably the premier meeting for the working wild trout biologist and other enthusiasts to attend. Although the meeting is no longer officially being held in Yellowstone National Park, the entrance gate lies only about a half mile from this year's venue, so there will be plenty of opportunities before, during, and after the meeting to explore the world's first national park. See you there!

Photo credits: Joe Facendola, Liz Mamer, Wild Trout Historical Archives.

WT Symposium XI

Looking Back and Moving Forward

22–25 September 2014

West Yellowstone, MT

For more meeting information and a list of session topics please visit

www.wildtroutsymposium.com

The Oyster and the Pearl: The Annual Report and Your Input

Doug Austen, AFS Executive Director

AFS Executive Director Doug Austen can be contacted at: dausten@fisheries.org

It would be a mistake for you to have so easily skipped over the thirteen pages in this issue that make up the annual report. I'm not telling you this because there is some exceptional prose found in those few pages. Nor is there likely to be any quotable phrase that will inspire you to great heights of fisheries science or conservation. It would be exceedingly surprising to me that you would quote anything from this report in a motivational speech that you will impart upon your employees or graduation students. Rather, think of these pages as something along the lines of an annual evaluation in the most constructive, helpful, and introspective manner. In other words, we're providing this to you not as a means of simply conveying a one-sided communication about the activities of the Society. Rather, this is meant to be part of an ongoing conversation about what you want to get out of your American Fisheries Society (AFS). In these 13 pages we're providing you a sense, actually a small slice or sample, of what has been happening with AFS this past year. With this report, we are looking to you for your feedback, ideas, creative thoughts, and, yes, your help to make important changes come to life. I'll start the conversation with some observations I've noted as I close my first year working for AFS. Then I'll provide some ideas for how you can provide us with feedback.

There is a hunger for AFS to be present, active, and involved, but there is also a fundamental challenge that we are experiencing in an evolving relationship between people and their membership (as is happening with all traditional organizations). I've heard from faculty at a number of universities that they feel that it's inappropriate to talk with students about an expectation of membership in a scientific society. We've seen this challenge while visiting numerous agencies, searching for AFS members among dozens or hundreds of fisheries professionals. Obviously, we can't ask for members to raise their hands so that we can differentiate the members from non-members. That would be a little embarrassing (more for us than them). We can talk about value propositions (as I did in the April 2014 issue of *Fisheries*) and we can explore generational changes (see the plenary lecture by Kelly Millenbah from the AFS Annual Meeting in Little Rock: vimeo.com/74636831), but the impact of not having a greater outreach is clear. AFS's total membership, once at 10,000, has recently been in the 7,000–8,000 range. Is this a new norm? Is a membership model simply not viable as a pillar of the Society? Should we be exploring provision of services with an *a la carte* fee model? The annual report identifies the problem, but the real challenge is finding the path forward.

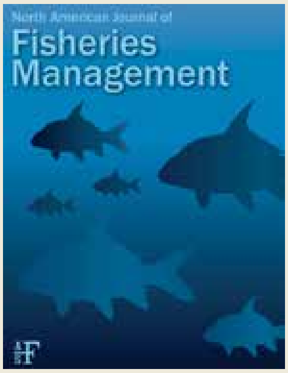
Contrast this lackluster membership position with an increasingly active AFS. Just a quick look at the long list of accomplishments this past year that President Bob Hughes has compiled would give anyone the accurate impression that your Society is increasingly engaged and active. We have improved partnership efforts with our sister fisheries societies in Japan, Korea, Europe, Mexico, and elsewhere. We've reengaged with our federal and state agency partners and have positioned AFS to be working on critical policy issues that reflect the values and mission of the Society. The Society has a new strategic plan and new policy papers on key topics. This past year has seen strong growth in Student Subunits and student registration at our Annual Meetings have been strong (31% of all registrants). All of these are signs that AFS is vital and engaging.

Finally, we are obligated to look at the budget numbers. By all measures, the current fiscal position of your Society is good. We have well more than a year of operating funds in the bank. Our investments are doing well and we have a stable of healthy restricted funds for programs like Skinner, Berkley, and others. Yet we need to keep a close eye on trajectories. With membership numbers down, we could be seeing income dropping by $50,000 to $100,000 in upcoming years. Journal subscriptions haven't been keeping pace and our Annual Meetings have fluctuated substantially in the income that they provide. Our current health is good, but if we don't do something about future trends, the outlook is not as positive as we would like. In other words, we need to look at AFS with the same critical eye that one does for any business. Our mission is clear; we are about fisheries science, development of professionals, and the profession and the conservation of our aquatic resources. In order to advance our mission, we need funds and people to be successful.

So how can we get your thoughts and ideas? There are more ways now than ever. If you can make it to Québec City for the Annual Meeting, please track down any of the officers or me to chat. We'll all be busy, but everyone one of us wants to talk with members and explore new approaches. E-mails are always good (dausten@fisheries.org) and the officers are found at fisheries.org/aboutus_societyofficers. Finally, plug into the AFS social media options (particularly our Facebook page: www.facebook.com/AmericanFisheriesSociety; and Twitter: @AmFisheriesSoc). We're utilizing these avenues more and more as a means of keeping in touch. If you post, we guarantee we're watching!

JOURNAL HIGHLIGHTS

North American Journal of Fisheries Management
Volume 34, Number 3, June 2014



Retardation of Reproduction in the Red Shiner Due to Electroshock. *Christine T. Stewart and Marvin M. F. Lutnesky*. 34:463–470.

Lipid and Moisture Content Modeling of Amphidromous Dolly Varden Using Bioelectrical Impedance Analysis. *J. T. Stolarski, F. J. Margraf, J. G. Carlson, and T. M. Sutton*. 34:471–481.

Population Changes after 14 Years of Harvest Closure on a Migratory Population of Bull Trout in Idaho. *John M. Erhardt and Dennis L. Scarnecchia*. 34:482–492.

Reductions in Instream Wood in Streams near Roads in the Interior Columbia River Basin. *Christy Meredith, Brett Roper, and Eric Archer*. 34:493–506.

Status of Redband Trout in the Upper Snake River Basin of Idaho. *Kevin A. Meyer, Daniel J. Schill, Elizabeth R. J. M. Mamer, Christine C. Kozfkay, and Matthew R. Campbell*. 34:507–523.

Movements of Striped Bass between the Exclusive Economic Zone and Massachusetts State Waters. *Jeff Kneebone, William S. Hoffman, Micah J. Dean, and Michael P. Armstrong*. 34:524–534.

An Empirical Approach for Estimating the Precision of Hydroacoustic Fish Counts by Systematic Hourly Sampling. *Yunbo Xie and Fiona J. Martens*. 34:535–545.

Downstream Passage of Lake Sturgeon through a Hydroelectric Generating Station: Route Determination, Survival, and Fine-Scale Movements. *C. A. McDougall, W. G. Anderson, and S. J. Peake*. 34:546–558.

Factors Affecting Partial Migration in Puget Sound Coho Salmon. *Jessica Rohde, Kurt L. Fresh, and Thomas P. Quinn*. 34:559–570.

Laboratory Investigations on the Use of Strobe Lights and Bubble Curtains to Deter Dam Escapes of Age-0 Muskellunge. *Heather A. Stewart, Max H. Wolter, and David H. Wahl*. 34:571–575.

Performance of a Surface Bypass Structure to Enhance Juvenile Steelhead Passage and Survival at Lower Granite Dam, Washington. *Noah S. Adams, John M. Plumb, Russell W. Perry, and Dennis W. Rondorf*. 34:576–594.

[Management Brief] Quantification and Evaluation of Factors Influencing Largemouth Bass Predation of Stocked Advanced Fingerling Yellow Perch. *Seth A. Lundgren, Casey W. Schoenebeck, Keith D. Koupal, Jared A. Lorensen, and Caleb G. Huber*. 34:595–601.

[Management Brief] An Estimate of Postrelease Mortality of School-Size Bluefin Tuna in the U.S. Recreational Troll Fishery. *Benjamin J. Marcek and John E. Graves*. 34:602–608.

Loss of Genetic Integrity in Hatchery Steelhead Produced by Juvenile-Based Broodstock and Wild Integration: Conflicts in Production and Conservation Goals. *Daniel M. Bingham, Benjamen M. Kennedy, Kyle C. Hanson, and Christian T. Smith*. 34:609–620.

Genetic Identification of Chinook Salmon in the Columbia River Estuary: Stock-Specific Distributions of Juveniles in Shallow Tidal Freshwater Habitats. *David J. Teel, Daniel L. Bottom, Susan A. Hinton, David R. Kuligowski, George T. McCabe, Regan McNatt, G. Curtis Roegner, Lia A. Stamatiou, and Charles A. Simenstad*. 34:621–641.

[Management Brief] Quantifying the Effectiveness of Conservation Measures to Control the Spread of Anthropogenic Hybridization in Stream Salmonids: a Climate Adaptation Case Study. *Robert Al-Chokhachy, Clint C. Muhlfeld, Matthew C. Boyer, Leslie A. Jones, Amber Steed, and Jeffrey L. Kershner*. 34:642–652.

Genetic Structure of Striped Bass in the Southeastern United States and Effects from Stock Enhancement. *Andrew P. Anderson, Michael R. Denson, and Tanya L. Darden*. 34:653–667.

Feeding Habits, Daily Ration, and Potential Predatory Impact of Mature Female Spiny Dogfish in North Carolina Coastal Waters. *Charles W. Bangley and Roger A. Rulifson*. 34:668–677.

Fishing for Northern Pike in Minnesota: Comparing Anglers and Dark House Spearers. *Susan A. Schroeder and David C. Fulton*. 34:678–691.

CALENDAR
Fisheries Events

To submit upcoming events for inclusion on the AFS web site calendar, send event name, dates, city, state/province, web address, and contact information to sgilbertfox@fisheries.org.

(If space is available, events will also be printed in *Fisheries* magazine.)

More events listed at www.fisheries.org

DATE	EVENT	LOCATION	WEBSITE
August 16–20, 2014	AFS Annual Meeting 2014	Québec City, Canada	afs2014.org
August 16–20, 2014	38th Annual Larval Fish Conference (AFS Early Life History Section)	Québec City, Canada	larvalfishcon.org
August 31–September 4, 2014	AFS-FHS – International Symposium on Aquatic Animal Health (ISAAH)	Portland, OR	afs-fhs.org/meetings/meetings.php
September 15–19, 2014	ICES Annual Science Conference 2014	A Coruña, Spain	ices.dk/news-and-events/asc/ASC-2014/Pages/default.aspx
September 22–25 2014	Wild Trout Symposium XI	West Yellowstone, MT	www.wildtroutsymposium.com
September 26–30, 2014	Aquatic Resources Education Association Conference	Traverse City, MI	www.areanet.org/conferences.htm
October 14–17, 2014	Aquaculture Europe 2014	San Sebastian, Spain	www.marevent.com
October 23–24, 2014	National Workshop on Large Landscape Conservation	Washington, DC	http://www.largelandscapenetwork.org/2014-national-workshop/
December 3–4, 2014	14th Flatfish Biology Conference	Westbrook, CT	http://nefsc.noaa.gov/nefsc/Milford/flatfishbiologyworkshop.html
January 21–23, 2015	Texas Aquaculture Association–45th Annual Conference & Trade Show	Kemah, TX	www.texasaquaculture.org
January 26–30, 2015	Global Inland Fisheries Conference	Rome, Italy	inlandfisheries.org
February 19–22, 2015	Aquaculture America 2015	New Orleans, LA	www.marevent.com
May 26–30, 2015	World Aquaculture 2015	Jeju Island, Korea	www.was.org
July 26–31, 2015	World of Trout	Bozeman, MT	
August 16–20, 2015	AFS Annual Meeting	Portland, OR	
February 22–26, 2016	Aquaculture 2016	Las Vegas, NV	www.marevent.com
February 19–22, 2017	Aquaculture America 2017	San Antonio, TX	www.marevent.com

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needed to support an animal unit month as in humid lands. That means that for ranches to be economical, they must be huge or have access to cheap forage and be dependent on irrigated forage for much of the year. As a result, irrigated livestock feed crops consume most of the water in the western United States (Wuerthner 2002). Because cattle evolved in the moist landscapes of Eurasia, they congregate in wetlands and riparian zones rather than disperse across the landscape or they require construction of expensive reservoirs and water diversions (typically at public expense). Although stream density is lower by definition in arid lands, it would be enormously costly to fence (or have cowboys continuously drive) livestock from the extensive network of streams draining those lands. Climate change projections indicate that western rangelands will become even drier and subject to more extreme flood, drought, and fire events. Livestock grazing exacerbates climate change effects on stream, riparian, and upland natural resources. Greatly reducing public land livestock grazing would greatly reduce this spatially extensive pressure and thereby reduce the susceptibility of those resources to climate change. It could also free up that $144 million for more fish- and wildlife-friendly landscape rehabilitation.

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applications. Many evaluations still trend toward the qualitative, but there are fewer holes in our efforts to quantify ecological parameters in stock assessments. As a result, fishery management organizations are becoming more able to include forage or other ecological factors in their production models. The old problem of focusing mostly on fishing mortality and less on environmental mortality is shifting. The forage fish are finally having their say.

This maturation is evident in meetings, literature, and action. Scientists and managers across the fish realm are focusing increasingly on forage fish issues. In 2012, a global symposium convened to discuss tools to advance forage in ecosystem-based management of marine systems (Peck et al. 2014). Comparable efforts for freshwater forage have proven elusive, but we at AFS have tried to fill the holes. Most AFS Annual Meetings include technical sessions on forage, most recently at the 143rd Annual Meeting with a symposium on "Ecosystem Connections: Watershed Health, Anadromous Species, and Ocean Production" that connected fresh and salt water. The literature documents our knowledge and supports decisions such as those cited above.

Forage issues are unlikely to drift away from our mainstream priorities. We'll do well to consider the full implications of forage species, whether they be schooling fish like Menhaden or small morsels that nourish sniper predators. Most food chains lead to us, and we are responsible for understanding the implications of our actions, whether as scientists or consumers. Or both.

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Is the study proposal feasible?
If your study proposal presents unique challenges (e.g., tracking in noisy aquatic environments, tracking in shallow waters needing fine-scale resolution, or acoustically tagging an untested species), we recommend conducting a feasibility test. It's easier than you might think.
To find out if your study objectives can be achieved with acoustic telemetry, call us to discuss potential challenges, solutions, equipment recommendations and lease details.
Find out if it's feasible; connect with our fisheries scientists at (206) 633-3383 or support@HTIsonar.com.
School of Sockeye Salmon Spawning in the Kenai River, Alaska Image Courtesy: Pete Niesen
Experience,
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