# Inland Fisheries Habitat Management: Lessons Learned from Wildlife Ecology and a Proposal for Change

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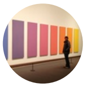
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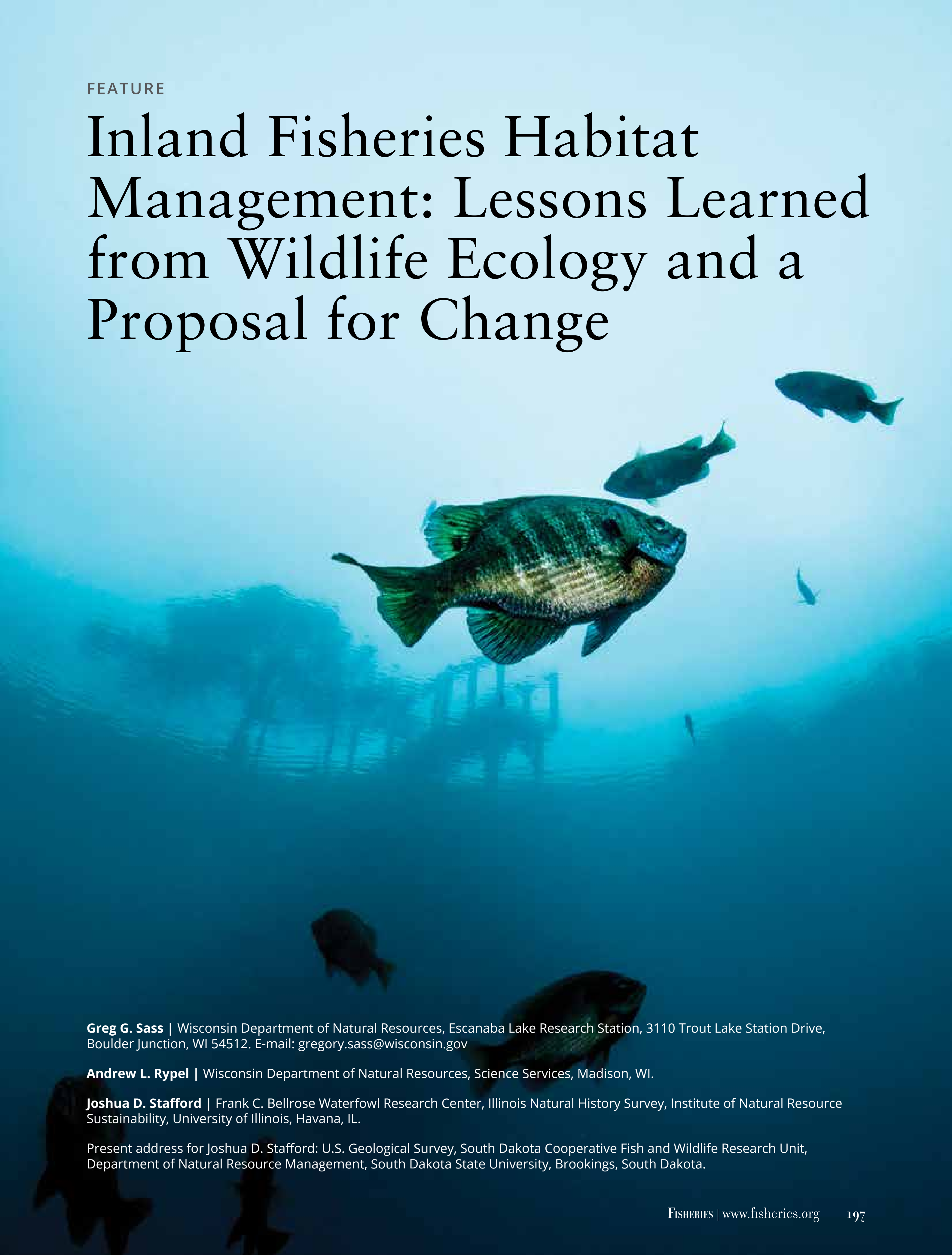
FEATURE

# Inland Fisheries Habitat Management: Lessons Learned from Wildlife Ecology and a Proposal for Change



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The habitat concept in inland fisheries has been less studied than wildlife ecology. Since 1950, the cumulative number of publications about "freshwater or inland habitat and fisheries management" has been 60%–95% less than those considering "habitat and wildlife management." The number of publications about "marine, river, and stream habitat and fisheries management" has also generally exceeded those for "lake habitat and fisheries management." We provide a perspective comparing inland fish and wildlife habitat management systems and highlight lessons from wildlife ecology that could benefit inland fisheries. We reason that wildlife habitat management has become widespread and accepted because humans share habitats with wildlife and positive/negative responses to habitat restorations/loss are directly observable. We recommend that inland fisheries habitat studies and restorations include opportunities for humans to directly observe the ecological benefits of such practices. To support aquatic habitat management efforts, we suggest that dedicated funding solutions be considered to mitigate aquatic habitat loss. In theory, such a system would provide benefits to inland fish populations that parallel those provided to wildlife through state and federal stamps. Although aquatic habitat conservation and restoration may not solve management issues as rapidly, it will promote long-term sustainability and resiliency of diverse inland fish populations.

## INTRODUCTION

Habitat has been defined in myriad ways and has been associated with ecological science for centuries. Dating to Aristotle (~350 BC), observations were made regarding organisms and their form, function, and relationship to habitat. Later, Darwin (1859) defined habitat as the locality in which a plant or animal naturally lives. Subsequent definitions of habitat have varied greatly with narrow and broad connotations (Block and Brennan 1993; Hall et al. 1997; Morrison et al. 2006). For example, commonly used ecological terms such as "niche" have often been used interchangeably with habitat, potentially conflating terminology and creating confusion (Whitaker et al. 1971; Block and Brennan 1993). The Merriam-Webster dictionary defines habitat as "the place or environment where a plant or animal naturally or normally lives and grows" (Merriam-Webster Dictionary, no date) and Wikipedia defines habitat as "an ecological or environmental area that is inhabited by a particular species of animal, plant, or other type of organism. It is the natural environment in which an organism lives, or the physical environment that surrounds a species population" (Wikipedia, no date-a).

We define habitat as "adequate abiotic and biotic conditions required to complete all aspects of a species life history during a generation or life span, which results in fitness." Our working definition of habitat encompasses all essential requirements of an organism to complete its life history and contribute to population sustainability (Figure 1). Further, it acknowledges that habitat conditions can wax and wane over time and that fitness may correspond with those changes in the long term (Stanford et al. 2005; Ando and Mallory 2012; Schindler et al. 2015). Our definition is independently derived yet similar to that of Safriel and Ben-Eliahu (1991) and Morrison et al. (2006) for wildlife habitat and quite different than the definition of fisheries habitat originally used by Hudson et al. (1992) and later by Hayes et al. (1999). The Hudson et al. (1992) definition was "habitat is simply the place where an organism lives. Physical, chemical, and biological variables (the environment) define the place where an organism lives," which is similar to the definition of a niche (p. 77). Habitat can also be subdefined into essential and nonessential components. Essential habitats are described by our definition. Nonessential habitats may also be important but not critical for an organism to complete its life history and have fitness.

Maintaining essential habitats for fish and wildlife populations is critical for long-term sustainability of all natural resources. As the human population grows, natural resource demands expand (Vitousek et al. 1997) and essential habitats are lost due to anthropogenic impacts on the environment (Figure 2). Managing fish and wildlife populations toward sustainability in the face of these threats is perhaps the principal future challenge of natural resource science and management (FAO 2012; Schindler and Hilborn 2015). Habitat conservation in inland fisheries is often less emphasized relative to other forms of responsive population management (e.g., stocking and harvest regulations; Lorenzen 2014; Schindler 2014), whereas wildlife science has recognized habitat as a fundamental, unifying concept (Guthery and Strickland 2015). As one iconic example, we cannot expect Pacific salmonid *Oncorhynchus* spp. populations to be self-sustaining when passage to natal habitats is blocked by dams or spawning habitat is destroyed (Lichatowich 1999; Figure 1). Stocking, along with commercial and recreational harvest regulations, has been a common tool used to sustain these populations; however, these strategies have had mixed success, have altered the genetics of individual stocks, and are labor intensive and expensive (Lorenzen 2014). Furthermore, they are impractical when the scale of habitat degradation is immense (e.g., whole-scale damming of large rivers; Winemiller et al. 2016). Herein, we compare and contrast inland fisheries and wildlife habitat management systems and offer suggestions to increase recognition of inland fisheries habitat management as a critical and needed component of sustainable fisheries similar to that of applied wildlife ecology.

All fish and wildlife populations require essential habitats to complete life histories and have fitness (see Figure 1 for life history examples of Pacific salmon, mallards *Anas platyrhynchos*, and unionid mussels). Fish and wildlife also move among complex and diverse habitats independent of spawning and ontogeny for foraging and refuge from predation (Ahrenstorff et al. 2009; Bentley et al. 2015). Beginning with adults, mature individuals must secure sufficient resources to produce offspring, which requires an energetic surplus in addition to standard metabolic costs (Kitchell et al. 1977; Post and Parkinson 2001; McBride et al. 2015). For most fishes, appropriate spawning habitat and ecological conditions are required for eggs to hatch and individuals to reach larval and juvenile stages (Cushing 1990; Schlosser 1991; Ciannelli et al. 2015). Adequate predation refugia and energy are then required to grow, mature, and reproduce (Walters and Juanes 1993; Sass et al. 2006b; Gaeta et al. 2014). During each life history stage, essential habitats may be local, regional, or intercontinental (e.g., migratory waterfowl and fishes) in scale (Lichatowich 1999; Safina 1997; Janke et al. 2015). Loss or degradation of essential habitats at any stage during this process can interrupt life cycles and stress fish and wildlife populations, which may then warrant corrective resource management actions.

Augmentation of inland fish and wildlife populations through stocking and reintroduction are long-standing natural resource management practices. For large mammals (e.g., white-tailed deer *Odocoileus virginianus*, elk *Cervus canadensis*), extensive augmentations may not be feasible or are impractical due to low fecundities and long gestation periods. Enhancements have been attempted for game birds; however, the returns from conserving,

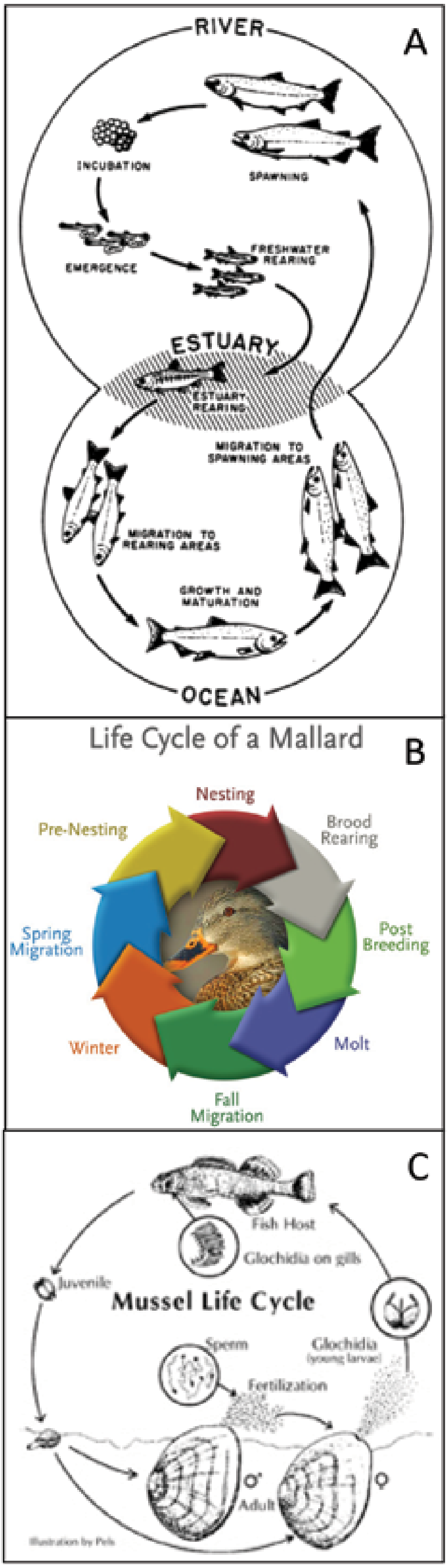


Figure 1. Examples of complex life cycles for (A) Chinook Salmon *Oncorhynchus tshawytscha*, adapted from Nicolas and Hankin (1988); (B) a mallard *Anas platyrhynchos*, adapted from ducks.org; and (C) a generalized unionid mussel, adapted from pubs.ext.vt.edu. Note the various stages of the life cycle for each organism that require interactions with essential habitats in order to have fitness.

enhancing, and restoring essential habitats often far outweigh returns from annual stocking and associated economic costs, particularly for waterfowl (Dunn et al. 1995). Thus, sustainable wildlife management has often been achieved by providing essential habitats to meet the life history needs of most species. Those wildlife habitat management components generally include direct consideration of the quantity, quality, and juxtapositions of habitats (Block and Brennan 1993).

Other than large river and trout stream habitat work and their wisely dedicated financial resources (e.g., via Trout Unlimited, state trout stamps, U.S. Army Corps of Engineers Habitat Rehabilitation and Enhancement Projects [O'Hara et al. 2008]; also see Summerfelt [1999] regarding lake and reservoir habitat management), fish stocking and harvest regulations have been the principal fisheries management tools used to enhance inland fish populations (Lorenzen 2014). In fact, only three pages within Hayes et al. (1999) are dedicated to in-lake fish habitat considerations (Kohler and Hubert 1999). In contrast to wildlife augmentation, fish stocking is more logistically feasible due to greater fecundities, which provides humans the ability to raise large quantities and different sizes of fish species through propagation. Further, considerable fish health, survival, and cost analysis research has led to economically feasible fisheries management models. For example, in many state natural resource management agencies, fishing license dollars are earmarked for fish stocking and hatchery infrastructure (Loomis and Fix 1998; Heidinger 1999). Yet, stocking is clearly not a panacea. Many important questions have arisen over genetic concerns (Krueger et al. 1981; Jennings et al. 2010; Metcalf et al. 2012), poststocking survival versus costs (Axon and Whitehurst 1985; Pearsons and Hopley 1999), and implications for intra- and interspecific population and community dynamics after fisheries are created or enhanced (Cowx 1994; Lorenzen 2014). Less attention has been focused on the conservation, enhancement, and restoration of essential inland fish habitats outside of those required by species-specific (often trout) stamp dollars (Adams and Whyte 1990; Smokorowski et al. 1998; but see Jacobson et al. 2016). Existing research has largely focused on interactions of fish with the presence, decline, or absence of structural habitats (Crowder and Cooper 1982; Sass et al. 2006a; Gaeta et al. 2014). Little research has been devoted to applied management implications of aquatic habitat change. For example, inland fish habitat research has investigated installations of coarse woody habitat (e.g., tree drops, fish cribs, brush piles; Riley and Fausch 1995; Sass et al. 2012), nutrient enhancements (Hyatt and Stockner 1985; Stockner and MacIsaac 1998), installation of spawning habitat (House and Boehne 1985), and aquatic macrophyte manipulations (Olson et al. 1998). Nonetheless, most inland fish habitat enhancement projects have failed to collect premanipulation data, monitor fish communities sufficiently, and/or conduct experiments for adequate amounts of time to test for potential long-term responses (Hilborn 2016). Thus, outcomes are frequently unknown and inadequately monitored.

Our objective is to compare and contrast inland fisheries and wildlife habitat management systems. We generally use examples from inland freshwater fish populations and primarily waterfowl (Anatidae) as our focal wildlife taxa. Herein, we highlight three model examples of complex life histories and essential habitat needs for Pacific salmon, dabbling ducks *Anas* spp., and unionid mussels and discuss the following themes: (1) habitat in the context of inland fish and wildlife management systems, (2) immediate versus delayed gratification in inland fisheries and wildlife management, (3) differences between inland fisheries and wildlife management systems, (4) stocking: is perception reality?, and

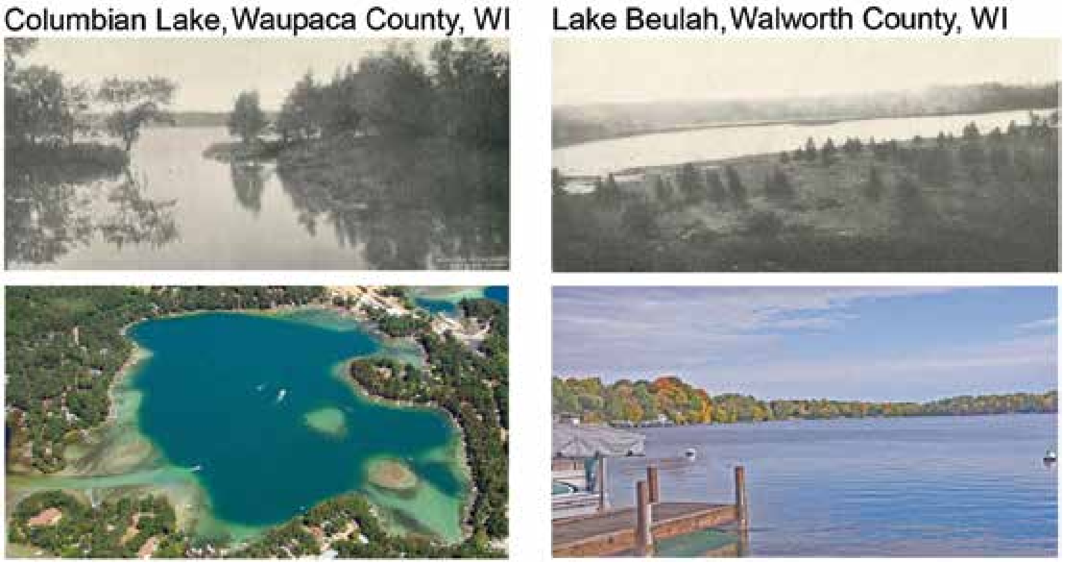


Figure 2. Inland fish habitat has changed greatly over the last 100 years. In Wisconsin, lakeshore residential development has skyrocketed. This has led to widespread depletions in littoral coarse woody habitat for fishes, loss of aquatic macrophytes, siltation, and eutrophication of water quality. Photo credit: Wisconsin Department of Natural Resources.

(5) when should stocking be prioritized and used. We use these themes to provide actionable opportunities to change perceptions and impediments to better understand the importance of essential inland fish habitat management for long-term sustainable fisheries.

## EXAMPLES OF COMPLEX LIFE HISTORIES AND ESSENTIAL HABITATS

Anadromous salmonids are the quintessential example of how essential habitats interact with a complex life history; they mature in oceans and transition to natal lotic freshwater environments and spawning sites to complete their life histories (Figure 1). After spawning, adult mortality, and hatching of eggs, salmonid smolts require freshwater lentic environments to grow prior to transitioning to marine environments (Lichatowich 1999; Figure 1). Essential habitats are required at every stage of these complex life histories (Lawson 1993; Armstrong et al. 2003). Blockage of natal spawning areas by dams and/or loss and degradation of natal spawning sites are two examples of essential habitat loss detrimental to some salmonid stocks (Raymond 1979; Maule et al. 1988).

Adult dabbling ducks require essential upland habitats to nest and precocial ducklings then transition to aquatic ecosystems to grow and fledge prior to migration (Afton and Paulus 1992; Kadlec and Smith 1992; Kaminski and Weller 1992; Figure 1). During migration, many stopover sites may be required to obtain energy and complete the journey, typically gained in the forms of carbohydrates and essential amino acids (Prince 1979; Reinecke et al. 1989). Spring (northward) migration may be particularly important to complete dabbling duck life histories, where essential habitats are required to garner exogenous resources for rapid follicle development and nesting (Arzel et al. 2006). Loss or degradation of nesting habitats (e.g., agriculture, draining wetlands, drought) and/or loss of energetically profitable migratory stopover sites provide two more examples of essential habitat degradation or loss detrimental to wildlife; in this case, duck populations (Kaminski and Gluesing 1987; Anteau and Afton 2004, 2009).

Freshwater mussels (Unionidae) are among the most endangered organisms on Earth and are especially sensitive to aquatic habitat change (Williams et al. 1993; Bogan 1996; Master et al. 2000; Figure 1). Larval mussels (i.e., glochidia) are dependent on the availability of fish hosts (in some cases, very specific fish host species) for parasitism and survival (Haag 2012). Thus, loss of specific fish hosts or availability of suitable mussel habitats, which can be mediated through the loss or degradation of fish host habitats, often precedes freshwater mussel declines (Williams et al. 1993). Additionally, freshwater mussels are extremely sensitive to changes in environmental condition of aquatic ecosystems more generally (e.g., chemical habitats; Mummert et al. 2003; Bringolf et al. 2007; Wang et al. 2007). Sedimentation, eutrophication, and physical habitat alterations have had direct negative effects on mussel populations and have been widely implicated in their global decline (Neves et al. 1997; Vaughn and Taylor 1999; Strayer et al. 2004). Thus, direct and indirect effects of habitat change are perhaps the central drivers of freshwater mussel declines and must be considered to better conserve this highly endangered group of animals at all scales.

## HABITAT IN THE CONTEXT OF FISH AND WILDLIFE MANAGEMENT SYSTEMS

Fish and wildlife management systems include organisms, the community of species to which the organism belongs, the humans who exploit or affect the organism within the ecosystem, and the habitats in which the organism exists. Sass and Allen (2014) provided a modified Venn diagram rendition of a fisheries management system (Nielsen 1993), and knowledge gaps related to fish habitat management identified in Sass and Allen (2014) were an impetus for writing this perspective. It is worth noting that this three-way interaction between people, habitat, and organisms was long-ago established in a parallel framework for wildlife management (Giles 1978). Another impetus for this perspective was the major discrepancy we identified through Google Scholar and Web of Science literature reviews investigating the cumulative number of publications with the key phrases "habitat and wildlife management," "habitat and fisheries management," "marine habitat and fisheries management," and "freshwater or inland habitat management and fisheries management" during 1950–2015 (Figure 3). Both search engines were included to incorporate only peer-reviewed literature in the case of Web of Science and peer-reviewed plus grey literature with Google Scholar. Based on the cumulative number of publications with these key phrases, wildlife ecologists have clearly placed a greater emphasis on habitat needs of wildlife for much longer than inland fisheries biologists (Figure 3). Further, and as just one example, only about 11% of the Fiscal Year 2017 Wisconsin Department of Natural Resources Fisheries Management budget was allocated to "habitat management and protection." Despite this large disparity, wildlife scientists have still claimed that wildlife habitat research has not changed much over the past half century, which places inland fisheries habitat management considerations even further behind those of wildlife ecologists and managers (Mathewson and Morrison 2015; but see Jacobson et al. [2016] for a recent fisheries example).

## IMMEDIATE VERSUS DELAYED GRATIFICATION IN FISHERIES AND WILDLIFE MANAGEMENT

Humans tend to desire abundant natural resources consistently and immediately when numbers decline below "acceptable" levels, regardless of the mechanism(s) for declines (e.g., overexploitation, essential habitat degradation/loss; Figure 4). At the same time, abundances of natural resources vary across spatiotemporal scales making realistic solutions to resource management issues long-term and expensive endeavors. A disconnect exists between natural variability in fish and wildlife population dynamics and human desires. For example, biologists are often called upon to develop plans to achieve consistency in meeting or exceeding demands for abundant and large game species (Figure 4). Human desires likely drove early stocking efforts in wildlife management but usually could not achieve long-term goals and are now of limited use. For example, stocking of mallards was used as a supplemental practice for a period of time (DGIF Mallard Release Committee 2007). Many unknowns remain regarding wildlife stocking, but some could be consequential. For example, Champagnon et al. (2012) reported on potential genetic consequences of such wildlife stocking, including the introduction of nonnative genes, loss of local adaptation, and genetic homogenization. Further, the effectiveness of such practices, particularly with respect to mallards, is poorly documented and considered largely ineffective (DGIF Mallard Release Committee 2007). Thus, wildlife habitat management became the most feasible approach to maintain consistency and meet public demand. Essential habitat management, along with harvest restrictions to prevent overexploitation, has been the tool most often demonstrated to successfully manage wildlife resources.

In contrast, fish stocking has been a long standing, cost-effective, and efficient way to augment fish populations. Thus, it is worth asking the question: Does stocking create inland fisheries consistency to meet public desires and demands as suggested conceptually by Figure 4? We believe that stocking has been and remains a pervasive practice in fisheries management because it is possible and is perceived as providing consistency to meet public demands and desires. Despite its popularity, stocking has often failed to meet these lofty goals. Dating to Swingle (1951), who stated in regards to stocking that it was untouched by common sense or the systematizing guidance of research and that the hatchery movement research its greatest absurdity it has long been recognized that fish stocking alone may not accomplish management goals and that stocking success is directly linked to essential habitats. More recently, Santucci and Wahl (1993) observed low contributions of stocked Walleye *Sander vitreus* of various sizes to year-class strength, and Li et al. (1996) found that Walleye stocking in lakes with poor natural reproduction did not contribute to year-classes significantly.

Unfortunately, stocking in conjunction with species- or guild-specific essential habitat management is rare. We contend that this approach may be considerably more effective at meeting management goals than stocking fish alone. Even when stocking meets defined goals, we believe that inland fisheries habitat management should still be considered and perhaps emphasized. Habitat conservation efforts are likely to increase ecosystem resiliency and provide additional consistency to meet public demand under variable environmental and human-dominated conditions.

## DIFFERENCES BETWEEN FISHERIES AND WILDLIFE MANAGEMENT SYSTEMS

Humans interact with fisheries versus wildlife management systems in several fundamentally different ways:

### Fishing Has a Voluntary Catch-and-Release Option; Hunting Does Not

Hunting wildlife essentially always results in death of the target organism. Although fishing results in death of harvested individuals and can result in catch-and-release mortality (Kerns et al. 2012), fish are frequently voluntarily released by anglers and survive (Allen et al. 2008; Gaeta et al. 2011; Landsman et al. 2011). Voluntary catch-and-release angling for many sport fishes (e.g., Largemouth Bass *Micropterus salmoides*, Muskellunge *Esox masquinongy*) has also increased in popularity over time (Allen et al. 2008; Hansen et al. 2015; Gilbert and Sass 2016). Because stocking wildlife has not typically been cost-effective or successful to sustain exploited populations, habitat management has been a cornerstone of effective wildlife management. Conversely, because catch-and-release angling has been effective at conserving and improving the density and size structure of certain fish populations, this angler behavior has been promoted as a solution on its own rather than focusing on habitats (Allen et al. 2008; Gaeta et al. 2011; Rypel et al. 2016). At the same time, abundance increases in fish populations due to catch-and-release preferences can also have undesirable outcomes due to density-dependent effects on fish growth (Hansen et al. 2015; Gilbert and Sass 2016).

### Humans Share Habitat with Wildlife

Humans directly interact with wildlife in many ways (e.g., hunting, bird watching, depredation events, agriculture and forestry, vehicle collisions, homes and properties). Humans do not interact with fishes in their aquatic environment as frequently. Thus, positive and negative wildlife responses to habitat manipulations are frequently and directly observed by the public. Yet, even for humans living in close association with water (e.g., lakeshore residents; coastal, port, and river cities), the dynamics of aquatic ecosystems, fisheries, and habitat often remain opaque and mysterious (Kipp 2006). It is not surprising that inland fish–habitat relationships and habitat manipulations are less understood and used because positive and negative outcomes are not easily and frequently observed by humans (Struthers et al. 2015).

### Segregation of Natural Resource Professionals

In our opinion, the lack of interdisciplinary collaboration between fisheries and wildlife scientists and other biologists is surprising and nonsensical. This is especially puzzling because scientists and biologists of both disciplines are often housed within the same agency programs, buildings, university departments, and colleges. Further, fish and wildlife populations often share common habitats. Thus, many applied habitat management actions may be mutually beneficial to fish and wildlife populations when considering a whole-ecosystem perspective and vice versa when

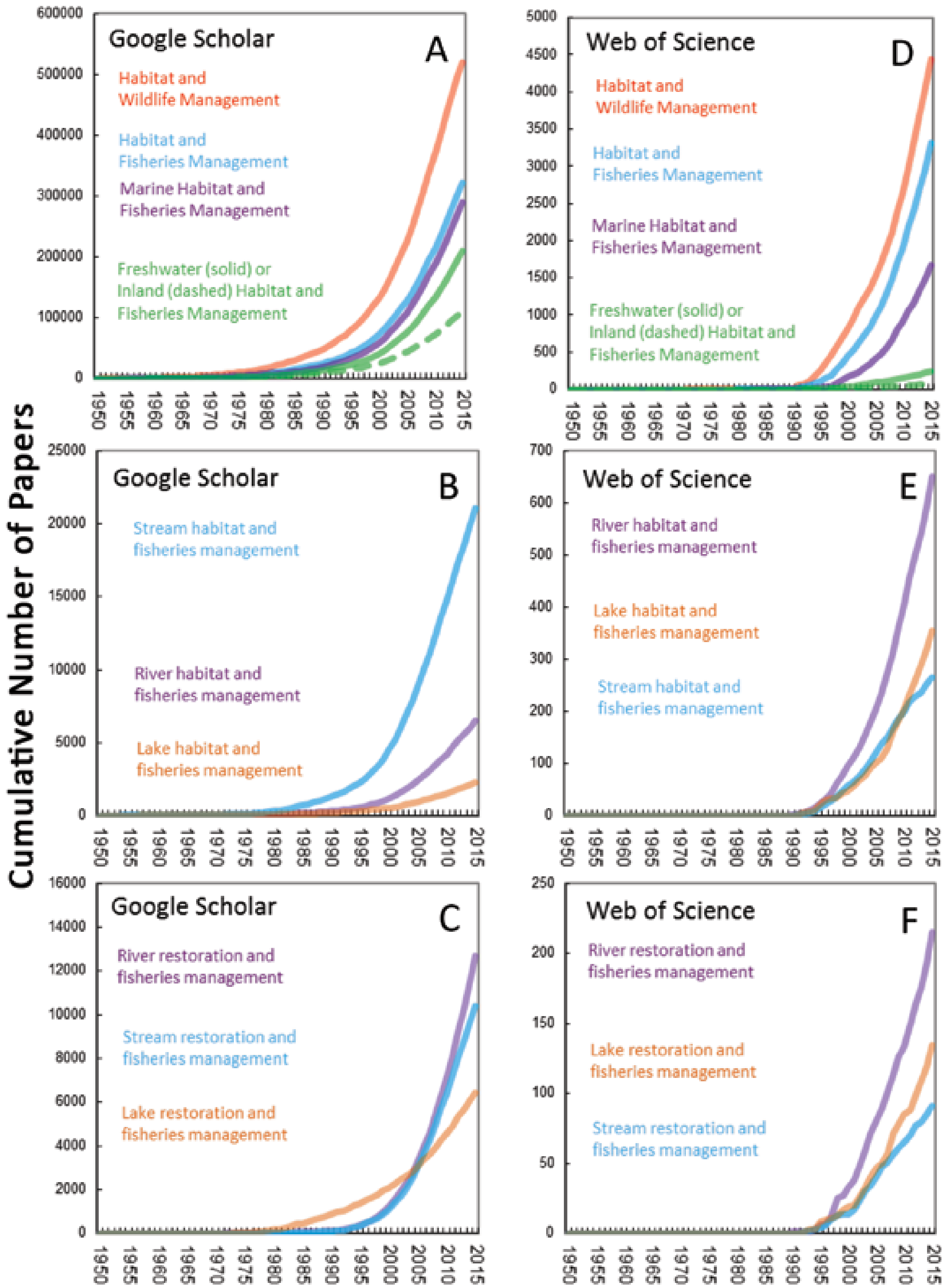


Figure 3. (A) Google Scholar and (D) Web of Science literature search results on the cumulative number of papers published including the key phrases "habitat and wildlife management" (red line), "habitat and fisheries management" (blue line), "marine habitat and fisheries management" (purple line), "freshwater habitat and fisheries management" (solid green line), and "inland habitat and fisheries management" (dashed green line), 1950–2015. (B) Google Scholar and (E) Web of Science literature search results on the cumulative number of papers published including the key phrases "stream habitat and fisheries management" (blue line), "river habitat and fisheries management" (purple line), and "lake habitat and fisheries management" (orange line), 1950–2015. (C) Google Scholar and (F) Web of Science literature search results on the cumulative number of papers published including the key phrases "river restoration and fisheries management" (purple line), "stream restoration and fisheries management" (blue line), and "lake restoration and fisheries management" (orange line), 1950–2015.

essential habitats are degraded or lost (Walters 1998; Mathewson and Morrison 2015). It is important to note that fisheries and wildlife scientists have had a long, collaborative history on statistical and modeling aspects of science (e.g., mark–recapture methods used in fisheries were derived from wildlife ecologists). Thus, our perceived segregation between the disciplines may be more a function of a lack of communication between ecologists of both disciplines and managers. For example, fisheries professionals in the United States too often leave habitat quality determinations to state and federal regulatory agencies partly because they are responsible for enforcing Clean Water Act standards.

### Valuation of Habitat and Funding

Important differences exist between inland fisheries and wildlife management systems, particularly in the valuation and management of essential habitats. In wildlife management, habitat conservation, restoration, and enhancements are commonly used and generally well received and supported by the public. We reason that wildlife habitat management has been successful for several reasons: (1) infeasibility and expense associated with stocking, (2) monetary incentives available to preserve habitats, (3) established funding sources to maintain wildlife habitats (e.g., Federal Migratory Bird Hunting and Conservation Stamp) in perpetuity, and (4) because humans can directly observe the benefits of wildlife management practices. The long-standing North American Model of Wildlife Conservation and two of its primary principals (e.g., fish and wildlife are for the noncommercial use of citizens, fish and wildlife should be managed scientifically such that they are available at sustainable levels in perpetuity) has also provided a historical underpinning that has put wildlife habitat management at the forefront of wildlife conservation for decades (although only precisely proposed in 2001; Wikipedia, no date-b). One of the key factors underlying differences in management systems is the tenet that providing essential habitats generates a response in wildlife that is observable and quantifiable by humans. For example, eastern wild turkey *Meleagris gallopavo silvestris* reintroductions have been incredibly successful coincident with reforestation of the eastern United States following near extirpation due to overharvest and habitat loss (Dickson 1992). Wetland restoration efforts in formerly degraded habitats, such as floodplain lake restorations on large rivers, have also been very successful in attracting waterfowl and increasing habitat use days (Hennepin-Hopper lakes, Illinois; The Nature Conservancy's Emiquon Preserve, Illinois; The National Wildlife Refuge System; land purchase under the U.S. Fish and Wildlife Service Wetland Management Districts; Bajer et al. 2009). We believe that observable outcomes of wildlife habitat management are a major reason for widespread public support and success of such actions, which stands in stark contrast to the lack of examples for inland fisheries habitat management, outside of lotic ecoystems (Figure 5). Federal and state habitat protection programs that provide monetary incentives for preserving essential habitats have been instrumental in driving positive wildlife conservation outcomes. For example, the Conservation Reserve Program in the Prairie Pothole Region of the United States (e.g., North and South Dakota) has been beneficial for continental waterfowl and grassland-dependent bird populations by converting marginal farm ground to grasslands (Ryan et al. 1998; Reynolds et al. 2001, 2006). Loss of such programs and consequences on waterfowl populations are unknown but are expected to decrease waterfowl production as a result of essential nesting habitat loss (Reynolds et al. 2001). Consequential loss of other wildlife habitats without these conservation incentives is also expected (e.g., wetlands).

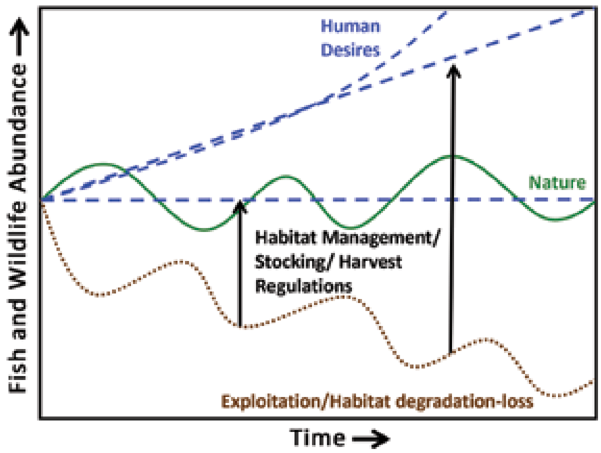


Figure 4. Conceptual model of the relationship between inland fish and wildlife abundances, human desires, inland fish and wildlife natural population dynamics, the effects of exploitation/habitat degradation/loss, and management tools used to improve declining fish and wildlife abundances over time. The solid green line represents fish and wildlife natural population dynamics where abundances tend to fluctuate around an equilibrium value when unaltered by anthropogenic disturbances. The blue dashed line represents human desires for fish and wildlife populations to remain stable or increase over time. The brown dotted line represents fish and wildlife abundances subjected to exploitation and/or habitat degradation/loss over time. The bold arrows represent habitat management, stocking, and harvest regulation efforts aimed to improve fish and wildlife abundances that are altered by anthropogenic disturbances.

Thus, observable positive outcomes of successful wildlife habitat management tend to be nearly as obvious as negative effects of habitat loss or degradation. Wildlife habitat conservation, restoration, and enhancement programs are well-funded ventures by private, state, and federal entities. Outside of the Conservation Reserve Program, private entities such as Ducks Unlimited, Inc., have also advanced the conservation, restoration, and enhancement of essential waterfowl habitats. State and federal stamps have allocated substantial revenue towards wildlife habitats. For example, 98% of the proceeds from the Federal Migratory Bird Hunting and Conservation Stamp go directly to the Migratory Bird Conservation Fund, which primarily funds the acquisition of migratory bird habitat. No federal analogue currently exists for inland fisheries and aquatic ecosystems. Last, conservation and enhancement of federal and state lands (e.g., forests, prairies, national parks, waterways) also serve as important providers of critical and sometimes unique wildlife habitats.

### STOCKING: IS PERCEPTION REALITY?

Stocking of fish and wildlife is conducted for a variety of reasons. Wildlife stocking is less common but is occasionally used for reintroducing formerly extirpated species (e.g., wild turkey, elk, endangered species) to native ranges. One key to long-term success of such stockings/reintroductions is identifying adequate essential habitats to increase the probability of natural reproduction and long-term sustainability. Success stories of wildlife reintroductions are numerous and have led to established recreational hunting seasons and enhanced biodiversity in wildlife communities. Other than reintroducing formerly extirpated species to native ranges, stocking is a seldom used wildlife-related management practice.

Figure 5. Upper left panel: Male eastern wild turkey *Meleagris gallopavo silvestris* strutting near a hardwood timber forest. Lower left panel: Waterfowl alighting on a restored wetland. Upper right panel: Above-water view of an undeveloped lake in northern Wisconsin. Photo credit: Greg G. Sass. Lower right panel: Underwater view of Largemouth Bass *Micropterus salmoides* and Bluegill *Lepomis macrochirus* using submersed aquatic vegetation and coarse woody habitat. Photo credit: Greg G. Sass.

Artificial propagation and stocking are pervasive tools in inland fisheries management to augment species-specific abundances. A common perception of fish stocking is that it will result in more harvestable fish and greater catch rates for recreational anglers and commercial fishers. Historical stockings were not well documented but often consisted of stocking the most "desirable" sport fishes (e.g., Walleye, Muskellunge, Black basses *Micropterus* spp.) across the landscape with little consideration of species-specific essential habitat requirements. As such, historical stockings achieved varying degrees of success in producing desired inland fisheries outcomes to meet human desires. Artificial propagation has been refined through time. Survival, genetic considerations, and the probability of rehabilitating former naturally reproducing inland fish populations are now considered. Further, cost–benefit analyses on fisheries returns based on whether fry, fingerling, or extended growth fingerlings are stocked have been well studied (Shaner et al. 1996; Changeux et al. 2001; Aprahamian et al. 2003). Currently, stocking is used to achieve the following inland fisheries management goals: (1) to create put-and-take recreational fishing opportunities (e.g., urban ponds); (2) to rehabilitate former naturally reproducing fish populations; (3) to augment poorly recruiting desirable fish populations; and (4) biomanipulation (Kitchell 1992; Gaeta et al. 2015; Stafford et al. 2016). In the cases of 2 and 3, loss or degradation of species-specific essential habitats has often been linked to prolonged recruitment failures or long-term poor and variable recruitment (Sass et al. 2006b; Reed and Pereira 2009). However, high exploitation rates on adults, predator–prey interactions, and abiotic factors may also influence recruitment (e.g., overfishing, cultivation-depensation effects, climate; Madenjian et al. 1996; Walters and Kitchell 2001).

Although natural recruitment variability and failures are commonly caused by loss or degradation of essential habitats, why has there been so little focus on improving essential habitats to enhance natural reproduction compared to stocking? We believe that this is due to the expense of habitat rehabilitation, the ease of stocking versus habitat projects, the perceived immediate benefit of stocking in enhancing inland fisheries in the short-term, and the fact that local, state, and federal agencies ultimately elect to allocate funding for stocking instead of habitat management. Habitat rehabilitation may not provide an easy solution but may be more likely to sustain fisheries in the long term. For example, species-specific studies testing for recruitment bottlenecks may be required prior to developing an informed habitat rehabilitation project with the greatest probability of reaching management goals. Yet, stocking is perceived as easy compared to habitat rehabilitation. Adult brood stock is stripped for eggs and milt, fish are raised in a hatchery to a defined stage or size, and the fish are stocked into a water body. Often, the success of stocking (fish reaching maturation and harvestable size) is not evaluated and outcomes are mixed. In contrast, successful habitat rehabilitation requires sufficient knowledge of the mechanisms causing recruitment variability or failure and designing experiments to improve those conditions. Human nature appears to dictate that stocking is a good thing (i.e., I observed the hatchery truck releasing fish into my lake, so the fishery has to be better). Further, license and stamp holders know that some portion of their fees go directly to hatchery infrastructure and stocking and thus this must be a good thing for fisheries. Are human perceptions of stocking reality? We believe that stocking has not been the panacea the public perceives it to be; there are numerous examples where stocking has consistently failed to achieve inland fisheries management goals, caused unforeseen problems, and incurred significant cost (Stewart et al. 1981; Weber and Brown 2009). In contrast, appropriate essential habitat management may have led to better and more naturally sustainable outcomes for some of these populations. What have we lost in inland fisheries management by prioritizing fish stocking overwhelmingly over habitat conservation? We reason that one major difference between the prioritization of these management systems is observable versus perceived results (e.g., wetland restoration = more waterfowl use after restoration versus fish stocking = perceived notion of more fish). Thus, increased prioritization for inland fisheries habitat management may require novel ways to make project outcomes directly observable to user groups and stakeholders (Struthers et al. 2015). As one example, real-time, web-enabled video feeds could be used to increase the visibility and public exposure of important inland fisheries habitat work.

## WHEN SHOULD STOCKING BE USED?

Although less feasible, cost-effective, and used for wildlife management, stocking will always be an important tool in inland fisheries management. Stocking will always have a role in put-and-take fisheries to create or enhance recreational fishing opportunities. As fishing license sales and angler participation decline in industrialized nations (Arlinghaus et al. 2015; Tufts et al. 2015), it is imperative that stocking be used to create new opportunities in nontraditional places where fishing opportunities are limited (e.g., urban areas). Stocking will also remain a critical tool in fishery rehabilitation scenarios such as those following a winterkill or rotenone chemical treatment of a waterbody. Biomanipulation using native fishes should also remain a priority. Stocking in an attempt to restore a former naturally reproducing fish population is also appropriate but should be coupled with studies to evaluate stocking success. For example, stocking should be discontinued if it is revealed that the probability of achieving the a priori restoration goal is unlikely. Stocking on top of a naturally reproducing fish populations (albeit low or variable recruitment) should be of low priority because this could disrupt genetics, create unbalanced fish communities, depress individual growth rates, and contribute little to the fishery (Gilbert and Sass 2016). If stocking is conducted under this scenario, local brood stocks should be used to avoid loss or dilution of local genetic adaptations (Jennings et al. 2010; Lorenzen 2014; Waterhouse et al. 2014). Aquatic ecosystems maintain “filters” that dictate fish community outcomes (Tonn and Magnuson 1982), and stocking on top of strong and consistent natural reproduction should not be conducted. Most important, any stocking effort should take place in concert with thoughtful consideration of how aquatic habitat conservation management might also be used. For example, inland fisheries habitat management should be prioritized over stocking when natural reproduction is low or variable.

## LOTIC AND MARINE FISHERIES HABITAT MANAGEMENT

Although outside of the scope of our perspective, it is important to recognize fisheries habitat management in lotic and marine systems. As shown by our Web of Science and Google Scholar literature searches, lotic and marine fisheries habitat management has generally been more studied than inland lake fisheries habitat management (Figure 3). Roni et al. (2008, 2014) listed five categories of stream habitat that are important and commonly rehabilitated. These include road improvements, riparian rehabilitation, floodplain connectivity and rehabilitation (e.g., Junk et al. 1989), in-stream habitat improvement (e.g., Poff et al. 1997), and nutrient enrichment. Lotic habitat management has increased exponentially over time and billions of dollars are allocated annually toward such efforts (Bernhardt et al. 2005). As part of these efforts, popular approaches have been developed for restoring stream habitats, particularly in “natural channel design” in the private sector (i.e., Rosgen 1996). However, these approaches continue to be controversial (e.g., Rosgen Wars) because they do not account for biogeochemical, ecological, and hydrogeomorphic processes (Lave 2012; Doyle 2013; Palmer et al. 2014). Furthermore, monitoring and the metrics that are actually monitored are also critical for evaluating restoration success. For example, only 7% of channel reconfiguration projects showed significant improvements in five metrics of water quality; however, studies using indicators of hydrogeologic or biogeochemical processes exhibited a higher success rate (Palmer et al. 2014).

The marine habitat literature is also expansive and highly developed. Most marine habitat classification systems are hierarchical in nature and attempt to preserve habitats at a diversity of spatial scales (Ball et al. 2006). For example, a marine habitat classification standard for the United States lists eight levels of habitat types within which there a multitude of additional habitats (Allee et al. 2000). The highest diversity of marine habitats is typically found in nearshore environments (e.g., mangroves, seagrass beds, coral reefs, surf zones, estuaries, salt marshes, oyster beds), which are also critical for juvenile nursery habitat and thus for later sustaining many commercial and recreational fisheries (Valentine-Rose et al. 2007; Grol et al. 2011). For these reasons, habitat improvement efforts such as artificial reefs, improved hydrologic connectivity, living shorelines, mangrove planting, seagrass restoration, and marine protected areas are common. For offshore marine fisheries, marine protected areas are increasingly used to conserve demersal and pelagic fisheries and can be successful if planned and monitored appropriately (Hilborn et al. 2004; Worm et al. 2009).

Inland lake habitat and fisheries management is also critical but less well studied. An important difference between these ecosystems is that lotic and marine fishes have the ability to disperse to new or alternative adequate habitats in response to changing conditions, whereas inland lake fishes have limited dispersal potential (Lynch et al. 2016). This difference underscores the importance of habitat conservation and management in inland fisheries and is one mechanism by which freshwater fish biodiversity is rapidly declining at a global scale (Dudgeon et al. 2006).

## FUTURE CONSIDERATIONS AND CONCLUSIONS

Despite a large body of research on the essential habitat requirements of diverse wildlife and inland fish populations, many lessons from successful wildlife habitat management could still be applied to benefit fisheries habitat management (Box 1). There is also still much to learn. Several key questions for areas of future research include the following: (1) What is the role of nonessential habitats in promoting diverse and sustainable inland fish populations?, (2) What is the relationship between inland fish populations and habitat quantity and diversity (e.g., Crowder and Cooper 1982; Olsen et al. 1998; Schindler et al. 2010)?, (3) How do we balance inland fish habitat management in the face of interacting human desires, needs, and effects?, (4) Can deliberate habitat manipulations create opportunities for experiential learning at all levels of education?, and (5) What mechanisms can be used to fund inland fish habitat research, which may lead to sustainable applied habitat management in the long term?

Wildlife ecologists and managers acknowledge that actual habitat is affected by a number of components, most importantly the quantity, quality, distribution, and juxtaposition of resources (Block and Brennan 1993). Habitat also changes over time and may be better described as a “shifting mosaic” (Stanford et al. 2005), where population resilience and sustainability may be dependent on the productivity and arrangement of habitat mosaics over time (Ando and Mallory 2012; Schindler et al. 2015). Maintaining disturbance regimes is crucial for the existence of

Box 1. Lessons learned from wildlife ecology and proposed changes to benefit fisheries habitat management.

| Lesson learned from wildlife ecology | Proposed change for fisheries management |
|---|---|
| Critical habitat needs should be established prior to wildlife reintroduction | Greater consideration of critical habitat, probability of success, and genetic concerns needed prior to stocking |
| Dedicated funding sources are essential to conserve, restore, and enhance wildlife habitat | Establish dedicated funding sources to conserve, restore, and enhance inland fisheries habitat |
| Wildlife responses to habitat restoration and degradation have been visible to the public | Create new opportunities for the public to directly observe the benefits of inland fisheries habitat management |
| Wildlife ecologists have long understood that wildlife habitat is affected by the quantity, quality, distribution, and juxtaposition of resources. This has resulted in defined models for wildlife management that explicitly incorporate habitat | Establish a North American Model of Fisheries Conservation similar to the North American Model of Wildlife Conservation |
| Many wildlife species have the ability to disperse to alternative habitats | Inland fishes have limited dispersal potential, thus habitat management may be more critical for sustainability and resilience of fisheries |

habitat mosaics and the creation of habitat. Thus, habitat management in the long term may be better served to focus on the maintenance of disturbance regimes versus the use of short-term applied management actions (e.g., wetland mitigations, adding complex structures to lakes and streams). We believe that the lack of emphasis on inland fish habitat management stems from roadblocks related to human desires of immediate gratification, lack of consistent and sustained funding, and the perceived difficulty of enhancing fish habitats. Organizations and mechanisms do exist that prioritize and fund fish habitat work (e.g., National Fish Habitat Partnership, National Fish and Wildlife Foundation, mitigation banks, the proposed Recovering America's Wildlife Act (H.R. 5650)), and attempts are currently underway to protect and restore inland fish habitats at large scales (e.g., Great Lakes Restoration Initiative, Minnesota lakes; Jacobson et al. 2016) similar to the joint venture partnerships developed for waterfowl in 1986 under the North American Waterfowl Management Plan and subsequent revisions (e.g., U.S. Department of the Interior and Environment Canada 1986; North American Waterfowl Management Plan, Plan Committee 2004; Lave et al. 2008; Doyle and Shields 2012). Nonetheless, we believe that a much more aggressive and comprehensive approach is needed to protect essential inland fisheries habitats in the face of environmental change. Gaining increased public acceptance will be crucial to advancing inland fisheries habitat conservation work. Central to this acceptance needs to be a realization, by the public and conservationists alike, that aquatic habitat conservation and restoration may not be a quick fix but will promote long-term sustainability and resiliency of diverse fish populations. Of the utmost importance is dedicated and consistent funding to conduct inland fisheries-related habitat work, while ensuring that this funding is specifically used for fish habitat enhancements (i.e., avoiding dedicated funding streams leading to dedicated spending versus real management actions). Many inland fish habitat projects will inherently be difficult and expensive, as are many wildlife habitat management projects, but can be achieved through a greater appreciation of fish–habitat relationships, dedicated funding, collaborations between fisheries professionals and major regulatory agencies dealing with habitat management, and sound science that uses these projects as deliberate learning tools for the public. The Migratory Bird Hunting and Conservation Stamp and private entities such as Ducks Unlimited, Inc., have been effective at achieving waterfowl conservation goals and we suggest that an analogous model be considered for inland fisheries.


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## REFERENCES


Adams, M. A., and I. W. Whyte. 1990. Fish habitat enhancement: a manual for freshwater, estuarine, and marine habitats. Department of Fisheries and Oceans Canada, DFO 44744, Ottawa.

Afton, A. D., and S. L. Paulus. 1992. Incubation and brood care. Pages 62–108 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis.

Ahrenstorff, T. D., G. G. Sass, and M. R. Helmus. 2009. The influence of littoral zone coarse woody habitat on home range size, spatial distribution, and feeding ecology of Largemouth Bass (*Micropterus salmoides*). Hydrobiologia 623:223–233.

Allee, R. J., M. Dethier, D. Brown, L. Deegan, R. G. Ford, T. F. Hourigan, J. Maragas, C. Schoch, K. Sealey, R. Twilley, M. P. Weinstein, and M. Yoklavich. 2000. Marine and estuarine ecosystem and habitat classification. NOAA Technical Memorandum NMFS-F/SPO-43.

Allen, M. S., C. J. Walters, and R. Myers. 2008. Temporal trends in Largemouth Bass mortality, with fishery implications. North American Journal of Fisheries Management 28:418–427.

Ando, A. W., and M. L. Mallory. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. Proceedings of the National Academy of Science of the United States of America 109:6484–6489.

Anteau, M. J., and A. D. Afton. 2004. Nutrient reserves of lesser scaup (*Aythya affinis*) during spring migration in the Mississippi Flyway: a test of the spring condition hypothesis. Auk 121:917–929.

———. 2009. Lipid reserves of lesser scaup (*Aythya affinis*) migrating across a large landscape are consistent with the "spring condition" hypothesis. Auk 126:873–883.

Aprahamian, M. W., K. M. Smith, P. McGinnity, S. McKelvey, and J. Taylor. 2003. Restocking of salmonids—opportunities and limitations. Fisheries Research 62(2):211–227.

Arlinghaus, R., R. Tillner, and M. Bork. 2015. Explaining participation rates in recreational fishing across industrialised countries. Fisheries Management and Ecology 22:45–55.

Armstrong, J. D., P. S. Kemp, G. J. A. Kennedy, M. Ladle, and N. J. Milner. 2003. Habitat requirements of Atlantic Salmon and Brown Trout in rivers and streams. Fisheries Research 62(2):143–170.

Arzel, C., J. Emberg, and M. Guillemain. 2006. Ecology of spring-migrating Anatidae: a review. Journal of Ornithology 147:167–184.

Axon, J. R., and D. K. Whitehurst. 1985. Striped Bass management in lakes with emphasis on management problems. Transactions of the American Fisheries Society 114(1):8–11.

Bajer, P. G., G. Sullivan, and P. W. Sorensen. 2009. Effects of a rapidly increasing population of Common Carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632:235–245.

Ball, D., S. Blake, and A. Plummer. 2006. Review of marine habitat classification systems. Parks Victoria, Technical Series No. 26, Melbourne, Australia

Bentley, K. T., D. E. Schindler, J. B. Armstrong, T. J. Cline, and G. T. Brooks. 2015. Inter-tributary movements by resident salmonids across a boreal riverscape. PLoS ONE 10(9):e0136985.
Bernhardt, E. S., M. A. Palmer, J. D. Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, B. Powell, and E. Sudduth. 2005. Synthesizing U.S. river restoration efforts. Science 308:636–637.
Block, W. M., and L. A. Brennan. 1993. The habitat concept in ornithology. Pages 35–91 *in* D. M. Power, editor. Current ornithology, volume 11. Plenum Press, New York.
Bogan, A. E. 1996. Decline and decimation: the extirpation of the unionid bivalves of North America. Journal of Shellfish Research 15:484.
Bringolf, R. B., W. G. Cope, S. Mosher, M. C. Barnhart, and D. Shea. 2007. Acute and chronic toxicity of glyphosate compounds to glochidia and juveniles of *Lampsilis siliquoidea* (Unionidae). Environmental Toxicology and Chemistry 26(10):2094–2100.
Champagnon, J., J. Elmberg, M. Guillemain, M. Gauthier-Clerc, and J.-D. Lebreton. 2012. Conspecifics can be aliens too: a review of effects of restocking practices in vertebrates. Journal for Nature Conservation 20:231–241.
Changeux, T., F. Bonnieux, and C. Armand. 2001. Cost benefit analysis of fisheries management plans. Fisheries Management and Ecology 8(4–5):425–434.
Ciannelli, L., K. Bailey, and E. Moland Olsen. 2015. Evolutionary and ecological constraints of fish spawning habitats. ICES Journal of Marine Science 72:285–296.
Cowx, I. G. 1994. Stocking strategies. Fisheries Management and Ecology 1:15–30.
Crowder, L. B., and W. E. Cooper. 1982. Habitat structural complexity and the interaction between Bluegills and their prey. Ecology 63:1802–1813.
Cushing, D. H. 1990. Plankton production and year-class strength in fish populations: an update of the match–mismatch hypothesis. Advances in Marine Biology 26:249–293.
Darwin, C. 1859. On the origins of species, by means of natural selection, or the preservation of favoured races in the struggle for life. John Murray, London.
DGIF (Department of Game and Inland Fisheries). Mallard Release Committee. 2007. An evaluation of captive-reared mallard releases in Virginia. Available: www.dgif.virginia.gov/wp-content/uploads/mallard-release-areas-evaluation.pdf. (March 2017).
Dickson, J. G. 1992. The wild turkey: biology and management. Stackpole Books, Mechanicsburg, Pennsylvania.
Doyle, M. W. 2013. Book review: Fields and streams: stream restoration, neoliberalism, and the future status of environmental science. Eos 94:92–93.
Doyle, M. W., and F. D. Shields. 2012. Compensatory mitigation for streams under the Clean Water Act: reassessing science and redirecting policy. Journal of the American Water Resources Association 2012:1–16.
Dudgeon, D., A. H. Arthington, M. O. Gessner, Z.-I. Kawabata, D. J. Knowler, C. Leveque, R. J. Naiman, A.-H. Prieur-Richard, D. Soto, M. L. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163–182.
Dunn, J. P., D. R. Diefenbach, and F. E. Hartman. 1995. Survival and recovery distribution of wild and captive-reared mallards in Pennsylvania. Transactions of the Northeastern Section of the Wildlife Society 52:21–28.
FAO (Food and Agriculture Organization) of the United Nations. 2012. The state of world fisheries and aquaculture 2012. Food and Agriculture Organization of the United Nations, Rome.
Gaeta, J. W., B. Beardmore, A. W. Latzka, B. Provencher, and S. R. Carpenter. 2011. Catch-and-release rates of sport fishes in northern Wisconsin from an angler diary survey. North American Journal of Fisheries Management 33:606–614.
Gaeta, J. W., T. R. Hrabik, G. G. Sass, B. M. Roth, S. J. Gilbert, and M. J. Vander Zanden. 2015. A whole-lake experiment to control invasive Rainbow Smelt (Actinoptergyii, Osmeridae) via overharvest and food web manipulation. Hydrobiologia 746:433–444.
Gaeta, J. W., G. G. Sass, and S. R. Carpenter. 2014. Drought-drive lake level decline: effects on coarse woody habitat and fishes. Canadian Journal of Fisheries and Aquatic Sciences 71:1–11.
Gilbert, S. J., and G. G. Sass. 2016. Trends in a northern Wisconsin Muskellunge fishery: results from a county-wide angling contest, 1964–2010. Fisheries Management and Ecology 23:172–176.
Giles, R. H., Jr. 1978. Wildlife management. W.H. Freeman and Company, San Francisco, California.
Grol, M. G. G., I. Nagelkerken, A. L. Rypel, and C. A. Layman. 2011. Simple ecological trade-offs give rise to emergent cross-ecosystem distributions of coral reef fish. Oecologia 165:79–88.
Guthery, F. S., and B. K. Strickland. 2015. Exploration and critique of habitat and habitat quality. Pages 9–18 *in* M. L. Morrison and H. A. Mathewson, editors. Wildlife habitat conservation: concepts, challenges, and solutions. John Hopkins University Press, Baltimore, Maryland.
Haag, W. R. 2012. North American freshwater mussels: natural history, ecology, and conservation. Cambridge University Press, Cambridge, UK.
Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25(1):173–182.
Hansen, J. F., G. G. Sass, J. W. Gaeta, G. A. Hansen, D. A. Isermann, J. Lyons, and M. J. Vander Zanden. 2015. Largemouth Bass management in Wisconsin: intra- and inter-specific implications of abundance increases. Pages 193–206 *in* M. D. Tringali, J. M. Long, T. W. Birdsong, and M. S. Allen, editors. Black bass diversity: multidisciplinary science for conservation. American Fisheries Society, Symposium 82, Bethesda, Maryland.
Hayes, D. B., W. W. Taylor, and P. A. Sorrano. 1999. Natural lakes and impoundments. Pages 589–622 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.
Heidinger, R. C. 1999. Stocking for sport fisheries enhancement. Pages 375–401 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.
Hilborn, R. 2016. Correlation and causation in fisheries and watershed management. Fisheries 41:18–25.
Hilborn, R., K. Stokes, J.-J. Maguire, T. Smith, L. W. Botsford, M. Mangel, J. Orensanz, A. Parma, J. Rice, J. Bell, K. L. Cochrane, S. Garcia, S. J. Hall, G. P. Kirkwood, K. Sainsbury, G. Stefansson, and C. Walters. 2004. When can marine reserves improve fisheries management? Ocean and Coastal Management 47:197–205.
House, R. A., and P. L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management 5(2B):283–295.
Hudson, P. L., R. W. Griffiths, and T. J. Wheaton. 1992. Review of habitat classification schemes appropriate to streams, rivers, and connecting channels in the Great Lakes drainage basin. Pages 73–107 *in* W. D. N. Busch and P. G. Sly, editors. The development of an aquatic habitat classification system for lakes. CRC Press, Ann Arbor, Michigan.
Hyatt, K. D., and J. G. Stockner. 1985. Responses of Sockeye Salmon (*Oncorhynchus nerka*) to fertilization of British Columbia coastal lakes. Canadian Journal of Fisheries and Aquatic Sciences 42(2):320–331.
Jacobson, P. C., T. K. Cross, D. L. Dustin, and M. Duval. 2016. A fish habitat conservation framework for Minnesota lakes. Fisheries 41:302–317.
Janke, A. K., M. J. Anteau, N. Markl, and J. D. Stafford. 2015. Is income breeding an appropriate construct for waterfowl? Journal of Ornithology 156:755–762.
Jennings, M. J., B. L. Sloss, G. R. Hatzenbeler, J. M. Kampa, T. D. Simonson, S. P. Avelallement, G. A. Lindenberger, and B. D. Underwood. 2010. Implementation of genetic conservation practices in a Muskellunge propagation and stocking program. Fisheries 35:388–395.
Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river–floodplain systems. Pages 110–127 *in* D. P. Dodge, editor. Proceedings of the international large river symposium, Canadian Special Publication of Fisheries and Aquatic Sciences 106.
Kadlec, J. A., and L. A. Smith. 1992. Habitat management for breeding areas. Pages 590–601 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis.
Kaminski, R. M., and E. A. Gluesing. 1987. Density and habitat-related recruitment in mallards. Journal of Wildlife Management 51:141–148.
Kaminski, R. M., and M. W. Weller. 1992. Breeding habitats of Nearctic waterfowl. Pages 568–589 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis.

Kerns, J. A., M. S. Allen, and J. E. Harris. 2012. Importance of assessing population-level impact of catch-and-release mortality. Fisheries 37:502–503.
Kipp, S. W. 2006. Living near urban lakes. Federation of Alberta Naturalists, Edmonton, Alberta, Canada.
Kitchell, J. F. 1992. Food web management: a case study of Lake Mendota. Springer-Verlag, New York.
Kitchell, J. F., D. J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to Yellow Perch (*Perca flavescensi*) and Walleye (*Stizostedion vitreum*). Journal of the Fisheries Research Board of Canada 34:1910–1921.
Kohler, C. C., and W. A. Hubert. 1999. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.
Krueger, C. C., A. J. Gharrett, T. R. Dehring, and F. W. Allendorf. 1981. Genetic aspects of fisheries rehabilitation programs. Canadian Journal of Fisheries and Aquatic Sciences 38:1877–1881.
Landsman, S. J., H. J. Wachelka, C. D. Suski, and S. J. Cooke. 2011. Evaluation of the physiology, behavior, and survival of adult Muskellunge (*Esox masquinongy*) captured and released by specialized anglers. Fisheries Research 110:377–386.
Lave, R. 2012. Fields and streams: stream restoration, neoliberalism, and the future of environmental science. The University of Georgia Press, Athens.
Lave, R., M. M. Robertson, and M. W. Doyle. 2008. Why you should pay attention to stream mitigation banking. Ecological Restoration 26:287–289.
Lawson, P. W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries 18(8):6–10.
Li, J., Y. Cohen, D. H. Schupp, and I. R. Adelman. 1996. Effects of Walleye stocking on year class strength. North American Journal of Fisheries Management 16:840–850.
Lichatowich, J. A. 1999. Salmon without rivers: a history of the Pacific salmon crisis. Island Press, Washington, D.C.
Loomis, J., and P. Fix. 1998. Testing the importance of fish stocking as a determinant of the demand for fishing licenses and fishing effort in Colorado. Human Dimensions of Wildlife: An International Journal 3:46–61.
Lorenzen, K. 2014. Managing fisheries enhancements. Pages 649–794 *in* G. G. Sass and M. S. Allen, editors. Foundations of fisheries science. American Fisheries Society, Bethesda, Maryland.
Lynch, A. J., B. J. E. Myers, C. Chu, L. A. Eby, J. A. Falke, R. P. Kovach, T. J. Krabbenhoft, T. J. Kwak, J. Lyons, C. P. Paukert, and J. E. Whitney. 2016. Climate change effects on North American inland fish assemblages. Fisheries 41:346–361.
Madenjian, C. P., J. T. Tyson, R. L. Knight, M. W. Kershner, and M. J. Hansen. 1996. First-year growth, recruitment, and maturity of Walleyes in western Lake Erie. Transactions of the American Fisheries Society 125(6):821–830.
Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammerson. 2000. Vanishing assets: conservation status of U.S. species. Pages 93–118 *in* B. A. Stein, L. S. Kutner, and J. S. Adams, editors. Precious heritage: the status of biodiversity in the United States. Oxford University Press, Oxford, UK.
Mathewson, H. A., and M. L. Morrison. 2015. The misunderstanding of habitat. Pages 3–8 *in* M. L. Morrison and H. A. Mathewson, editors. Wildlife habitat conservation: concepts, challenges, and solutions. John Hopkins University Press, Baltimore, Maryland.
Maule, A. G., C. B. Schreck, C. S. Bradford, and B. A. Barton. 1988. Physiological effects of collecting and transmitting emigrating juvenile Chinook Salmon past dams on the Columbia River. Transactions of the American Fisheries Society 117(3):245–261.
McBride, R. S., S. Somarakis, G. R. Fitzhugh, A. Albert, N. A. Yaragina, M. J. Wuenschel, A. Alonso-Fernandez, and G. Basilone. 2015. Energy acquisition and allocation to egg production in relation to fish reproductive strategies. Fish and Fisheries 16:23–57.
Merriam-Webster Dictionary. no date. Habitat. Available: www.merriamwebster.com/dictionary/habitat?utm_campaign=sd&utm_medium=serp&utm_source=jsonld. (March 2017).
Metcalf, J. L., S. Love Stowell, C. M. Kennedy, K. B. Rodgers, D. McDonald, J. Epp, K. Keepers, A. Cooper, J. J. Austin, and A. P. Martin. 2012. Historical stocking data and 19th century DNA reveal human-induced changes to native diversity and distribution of Cutthroat Trout. Molecular Ecology 21:5194–5207.
Morrison, M. L., B. G. Marcot, and R. W. Mannan. 2006. Wildlife–habitat relationships: concepts and applications, 3rd edition. Island Press, Washington, D.C.
Mummert, A. K., Neves, R. J., Newcomb, T. J., and D. S. Cherry. 2003. Sensitivity to juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environmental Toxicology and Chemistry 22(11):2545–2553.
Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt, and P. W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. Pages 43–86 *in* G. W. Benz and D. E. Collins, editors. Aquatic fauna in peril: the southeastern perspective. Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, Georgia.
Nicholas, J. W., and D. G. Hankin. 1988. Chinook Salmon populations in Oregon coastal river basins: description of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife, Information Report No. 88-1, Salem.
Nielsen, L. A. 1993. History of inland fisheries management in North America. Pages 33–54 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.
North American Waterfowl Management Plan, Plan Committee. 2004. North American Waterfowl Management Plan 2004. Implementation framework: strengthening the biological foundation. Canadian Wildlife Service, Gatineau, Quebec; U.S. Fish and Wildlife Service, Washington, D.C.; and Secretaria de Medio Ambiente y Recursos Naturales, Mexico City.
O'Hara, T. M., M. A. McClelland, K. S. Irons, T. R. Cook, and G. G. Sass. 2008. Effect of a recently completed habitat rehabilitation and enhancement project on fish abundances in La Grange Pool of the Illinois River using Long Term Resource Monitoring Program data. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, LTRMP Technical Report 2008-T001, La Crosse, Wisconsin.
Olson, M. H., S. R. Carpenter, P. Cunningham, S. Gafny, B. R. Herwig, N. P. Nibbelink, T. Pellett, C. Storlie, A. S. Trebitz, and K. A. Wilson. 1998. Managing macrophytes to improve fish growth: a multi-lake experiment. Fisheries 23(2):6–12.
Palmer, M. A., K. L. Hondula, and B. J. Koch. 2014. Ecological restoration of streams and rivers: shifting strategies and shifting goals. Annual Review of Ecology, Evolution, and Systematics 45:247–269.
Pearsons, T. N., and C. W. Hopley. 1999. A practical approach for assessing ecological risks associated with fish stocking programs. Fisheries 24(9):16–23.
Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47:769–784.
Post, J. R., and E. A. Parkinson. 2001. Energy allocation strategy in young fish: allometry and survival. Ecology 82:1040–1051.
Prince, H. H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 103–117 *in* T. A. Bookhout, editor. Waterfowl and wetlands—an integrated review. The Wildlife Society, Madison, Wisconsin.
Raymond, H. L. 1979. Effects of dams and impoundments on migration of juvenile Chinook Salmon and steelhead from the Snake River, 1966–1975. Transactions of the American Fisheries Society 108(6):505–529.
Reed, J. R., and D. L. Pereira. 2009. Relationships between shoreline development and nest site selection by Black Crappie and Largemouth Bass. North American Journal of Fisheries Management 29(4):943–948.
Reinecke, K. J., R. M. Kaminski, D. J. Moorhead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi alluvial valley. Pages 203–247 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.
Reynolds, R. E., T. L. Shaffer, C. R. Loesch, and R. R. Cox, Jr. 2006. The farm bill and duck production in the Prairie Pothole Region: increasing the benefits. Wildlife Society Bulletin 34:963–974.
Reynolds, R. E., T. L. Shaffer, R. W. Renner, W. E. Newton, and B. D. J. Batt. 2001. Impact of the conservation reserve program on duck recruitment in the U.S. Prairie Pothole Region. Journal of Wildlife Management 65:765–780.
Riley, S. C., and K. D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Canadian Journal of Fisheries and Aquatic Sciences 52:34–53.
Roni, P., K. Hanson, and T. Beechie. 2008. Global review of the physical and biological Effectiveness of stream habitat rehabilitation tech-

niques. North American Journal of Fisheries Management 28:856–890.
Roni, P., G. R. Pess, T. J. Beechie, and K. M. Hanson. 2014. Fish–habitat relationships and the effectiveness of habitat restoration. NOAA Technical Memorandum NMFS-NWFSC-127.
Rosgen, D. 1996. Applied river morphology. Wildland Hydrology, Pogosa Spring, Colorado.
Ryan, M. R., L. W. Burger, and E. W. Kurzejeski. 1998. The impact of CRP on avian wildlife: a review. Journal of Production Agriculture 11:61–66.
Rypel, A. L., J. Lyons, J. D. Tober Griffin, and T. D. Simonson. 2016. Seventy-year retrospective on size–structure changes in the recreational fisheries of Wisconsin. Fisheries 41:230–243.
Safina, C. 1997. Song for the blue ocean: encounters along the world's coasts and beneath the seas. Henry Holt and Company, New York.
Safriel, U. N., and M. N. Ben-Eliahu. 1991. The influence of habitat structure and environmental stability on the species diversity of polychaetes in vermetid reefs. Pages 349–369 *in* S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors. Habitat structure. Chapman and Hall, New York.
Santucci, V. J., and D. H. Wahl. 1993. Factors influencing survival and growth of stocked Walleye (*Stizostedion vitreum*) in a centrarchid dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50:1548–1558.
Sass, G. G., and M. S. Allen. 2014. Foundations of fisheries science. American Fisheries Society, Bethesda, Maryland.
Sass, G. G., S. R. Carpenter, J. W. Gaeta, J. F. Kitchell, and T. D. Ahrenstorff. 2012. Whole-lake addition of coarse woody habitat: response of fish populations. Aquatic Sciences - Research across Boundaries 74:255–266.
Sass, G. G., C. M. Gille, J. T. Hinke, and J. F. Kitchell. 2006a. Whole-lake influences of littoral structural complexity and prey body morphology on fish predator–prey interactions. Ecology of Freshwater Fish 15:301–308.
Sass, G. G., J. F. Kitchell, S. R. Carpenter, T. R. Hrabik, A. E. Marburg, and M. G. Turner. 2006b. Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries 31(7):321–330.
Schindler, D. E. 2014. Managing fish habitat. Pages 445–542 *in* G. G. Sass and M. S. Allen, editors. Foundations of fisheries science. American Fisheries Society, Bethesda, Maryland.
Schindler, D. E., J. B. Armstrong, and T. E. Reed. 2015. The portfolio concept in ecology and evolution. Frontiers in Ecology and the Environment 13:257–263.
Schindler, D. E., and R. Hilborn. 2015. Prediction, precaution, and policy under global change. Science 347:953–954.
Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609–612.
Schlosser, I. J. 1991. Stream fish ecology: a landscape prospective. BioScience 41:704–712.
Shaner, B. L., M. J. Maceina, J. J. McHugh, and S. F. Cook. 1996. Assessment of catfish stocking in public fishing lakes in Alabama. North American Journal of Fisheries Management 16(4):880–887.
Smokorowski, K. E., K. J. Withers, and J. R. M. Kelso. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences No. 2249, Ottawa.
Stafford, J. D., A. K. Janke, E. B. Webb, and S. R. Chipps. 2016. Invertebrates in managed waterfowl marshes. Pages 565–600 *in* D. Batzer and D. Boix, editors. Invertebrates in freshwater wetlands. Springer, Cham, Switzerland.
Stanford, J. A., M. S. Lorang, and F. R. Hauer. 2005. The shifting habitat mosaic of river ecosystems. Internationale Vereinigung fuer Theoretische and Angewandte Limnologie Verhandlungen 29:1123–1136.
Stewart, D. J., J. F. Kitchell, and L. B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Transactions of the American Fisheries Society 110(6):751–763.
Stockner, J. G., and E. A. MacIsaac. 1998. British Columbia lake enrichment programme: two decades of habitat enhancement for Sockeye Salmon. Regulated Rivers: Research and Management 12:547–561.
Strayer, D. L., J. A. Downing, W. R. Haag, T. L. King, J. B. Layzer, T. J. Newton, and S. J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioScience 54(5):429–439.
Struthers, D. P., A. J. Danylchuk, A. D. M. Wilson, and S. J. Cooke. 2015. Action cameras: bringing aquatic and fisheries research into view. Fisheries 40:502–512.
Summerfelt, R. C. 1999. Lake and reservoir habitat management. Pages 285–320 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.
Swingle, H. S. 1951. Experiments with various rates of stocking Bluegills, *Lepomis macrochirus* Rafinesque, and Largemouth Bass, *Micropterus salmoides* (Lacepede) in ponds. Transactions of the American Fisheries Society 80(1):218–230.
Tonn, W. M., and J. J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. Ecology 63:1149–1166.
Tufts, B. L., J. Holden, and M. DeMille. 2015. Benefits arising from sustainable use of North America's fishery resources: economic and conservation impacts of recreational angling. International Journal of Environmental Studies 72(5):850–868.
U.S. Department of the Interior and Environment Canada. 1986. North American Waterfowl Management Plan, Washington, D.C.
Valentine-Rose, L., C. A. Layman, D. A. Arrington, and A. L. Rypel. 2007. Habitat fragmentation decreases fish secondary production in Bahamian tidal creeks. Bulletin of Marine Science 80:863–877.
Vaughn, C. C., and C. M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology 13(4):912–920.
Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494–499.
Walters, C. J. 1998. Improving links between ecosystem scientists and managers. Pages 272–286 *in* M. L. Pace and P. M. Groffman, editors. Successes, limitations, and frontiers in ecosystem science. Springer-Verlag, New York.
Walters, C. J., and F. Juanes. 1993. Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk-taking by juvenile fishes. Canadian Journal of Fisheries and Aquatic Sciences 50(10):2058–2070.
Walters, C. J., and J. F. Kitchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Canadian Journal of Fisheries and Aquatic Sciences 58(1):39–50.
Wang, N., C. G. Ingersoll, D. K. Hardesty, C. D. Ivey, J. L. Kunz, T. W. May, F. J. Dwyer, A. D. Roberts, T. Augspurger, C. M. Kane, R. J. Neves, and M. C. Barnhart. 2007. Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2036–2047.
Waterhouse, M. D., B. L. Sloss, and D. A. Isermann. 2014. Relationships among Walleye population characteristics and genetic diversity in northern Wisconsin lakes. Transactions of the American Fisheries Society 143:744–756.
Weber, M. J., and M. L. Brown. 2009. Effects of Common Carp on aquatic ecosystems 80 years after "carp as a dominant": ecological insights for fisheries management. Reviews in Fisheries Science 17(4):524–537.
Whitaker, R. L., S. A. Levin, and R. B. Root. 1971. Niche, habitat, and ecotope. The American Naturalist 107:321–338.
Wikipedia. No date-a. Habitat. Available: en.wikipedia.org/wiki/Habitat. (March 2017).
——. No date-b. North American Model of Wildlife Consensus. Available: en.wikipedia.org/wiki/North_American_Model_of_Wildlife_Conservation. (March 2017)
Williams, J. D., M. L. Warren, K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.
Winemiller, K. D., P. B. McIntyre, L. Castello, E. Fluet-Chouinard, T. Giarizzo, S. Nam, I. G. Baird, W. Darwall, N. K. Lujan, I. Harrison, M. L. J. Stiassny, R. A. M. Silvano, D. B. Fitzgerald, F. M. Pelicice, A. A. Agostinho, L. C. Gomes, J. S. Albert, E. Baran, M. Petrere, Jr., C. Zarfl, M. Mulligan, J. P. Sullivan, C. C. Arantes, L. M. Sousa, A. A. Koning, D. J. Hoeinghaus, M. Sabaj, J. G. Lundberg, J. Armbruster, M. L. Thieme, P. Petry, J. Zuanon, G. Torrente Vilara, J. Snoeks, C. Ou, W. Rainboth, C. S. Pavanelli, A. Akama, A. Van Soesbergen, and L. Saeuz. 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Science 351:128–129.
Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, and D. Zeller. 2009. Rebuilding global fisheries. Science 325:578–585. AFS