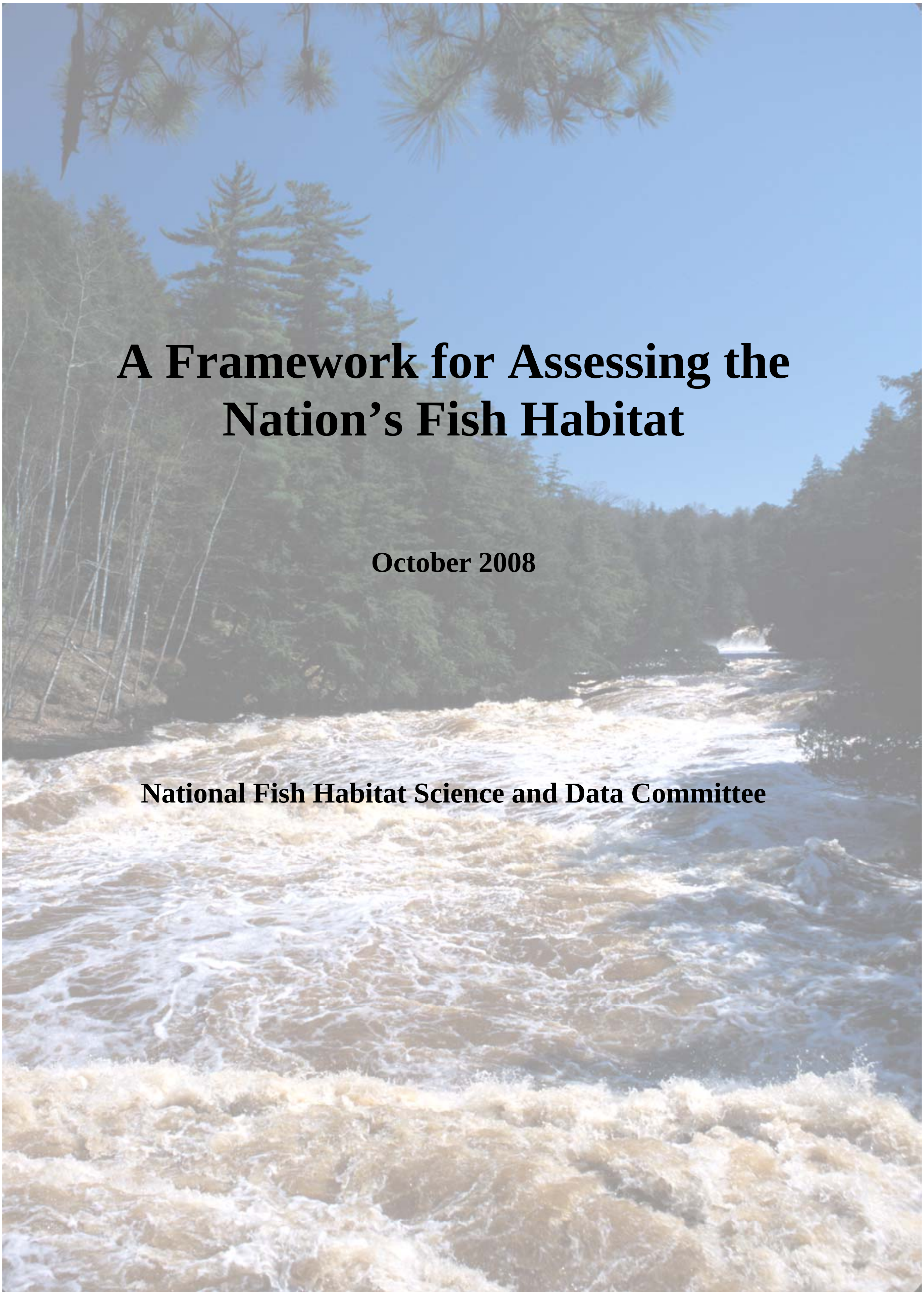

A Framework for Assessing the Nation's Fish Habitat

October 2008

National Fish Habitat Science and Data Committee

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Table of Contents

Preface

In the 1992 report *Restoration of Aquatic Ecosystems,* the National Research Council recommended that a national strategy for management of aquatic ecosystems be developed to establish a national process for ecosystem assessment. Developed by a coalition of federal, state, and non-governmental partners, this proposed strategy would set national restoration goals with the following elements:

1. Restoration goals and assessment strategies for each ecoregion.
2. A prioritization process for restoration proposals.
3. Emphasis on restoration within federal and state management programs.
4. An innovative financing system.
5. Active involvement from all levels of government and a broad range of partners.

In 2004, these elements were again proposed by participants of seven stakeholder meetings, convened to advance ideas of a National Fish Habitat Initiative (NFHI). This process was facilitated by the U.S. Fish and Wildlife Service and the International Association of Fish and Wildlife Agencies, and culminated in a workshop at the 2004 American Fisheries Society Annual Meeting in Madison, Wisconsin. These meetings produced the following specific recommendations:

1. Promote recognition that fisheries resources depend directly on habitat condition and that continued habitat loss is an urgent national problem.
2. Forge new partnerships among organizations that share this concern.
3. Recognize and deal effectively with the multi-scale processes that affect aquatic habitats.
4. Quantify fish habitat by developing a standard national assessment system that uses commonly available data and "grades" all of the following aspects of aquatic habitat: watershed land cover/use, water quantity, water quality, biological indicators, channel and stream network attributes, and socioeconomics. This system should be useful at national, regional, and local scales.
5. Identify national management priorities and highlight this information in national discussions of environmental problems.
6. Track, compile, and share the results of habitat management efforts.
7. Develop an ambitious, science-based national strategy to address aquatic habitat concerns.

During 2005–2008, members of the Science and Data Committee of the National Fish Habitat Action Plan (NFHAP) developed recommendations that would provide a sound scientific foundation for this critical new initiative. Our recommendations build upon and validate those provided in the thoughtful forums summarized above.

Gary Whelan and Doug Beard
Chairs, Science and Data Committee, NFHAP
October 2008

National Fish Habitat Action Plan
Executive Summary

Science and Data Strategy

This report is a companion product to, and science and data strategy for, the National Fish Habitat Action Plan (NFHAP) to achieve NFHAP's science-based goals. Those goals are:

1. Protect and maintain intact and healthy aquatic systems.

2. Prevent further degradation of fish habitats that have been adversely affected.

3. Reverse declines in the quality and quantity of aquatic habitats to improve the overall health of fish and other aquatic organisms.

4. Increase the quality and quantity of fish habitats that support a broad natural diversity of fish and other aquatic species.

A scientific basis for the NFHAP

Past strategies to prevent negative impacts to and rehabilitate fisheries habitat have relied on fixing symptoms of much larger scale process impairments and have been generally ineffective in stemming the continuing loss of fisheries habitat. The science and data strategy for the NFHAP focuses on process-level issues that are causative agents for the decline of fish and other aquatic species populations in freshwater and marine systems. The key to success for the plan will be to ensure that impaired and intact processes are clearly defined in each water, the partners understand what the impairments are and the potential methods to address them, and scientifically sound and legally defensible alternatives are developed to effectively protect intact habitat and improve the fisheries and aquatic habitat. These objectives will be accomplished by directly addressing the controlling processes, not just the symptoms, causing the demise of fisheries and aquatic resources in the nation's waters. This plan provides a process to describe all waters and grade their condition; options to address key factors; methods and mechanisms to properly prioritize and evaluate projects; and a process to establish measurable outcomes. This plan will guide the development of the National Fish Habitat Assessment and Action Plan Evaluation Reports.

The process

We will use an integrated landscape approach that allows appropriate linkages between inland and marine systems for evaluation of the interconnectedness of aquatic systems and their habitat condition from the headwaters to the ocean. A map-based interactive data system will be built using Geographic Information System (GIS) technology so partners can determine which waters are unimpaired and should be protected; identify impairments in their local waters; plan possible approaches to improving their waters; consider habitat approaches in similar habitats; and monitor progress toward NFHAP goals.

The condition of the nation's waters will be determined by first classifying all waters into similar groups based on published landscape classification systems from The Nature Conservancy (TNC) and the United States Geological Survey's Aquatic GAP Programs for inland systems, and from the National Oceanic and Atmospheric Administration (NOAA), TNC, and NatureServe for coastal systems. Approaches for habitat classification used in this plan are hierarchical, as controlling processes for aquatic systems are nested and integration of actions occurs across scales. The recommended classification system allows for the horizontal summaries of habitat condition and the vertical comparisons between similar systems.

All classified units will have a habitat condition assessment performed. Condition factors will be selected, such as the number of fish passage barriers within inland waters, which are indicators of the impairment of key processes. Classified units within groups will be compared with the best possible and highest existing scores in their classified group to establish goals or targets, allowing all classified units to have target habitat values. Condition factors will have direct linkages to rehabilitation measures, so improvements from project activities will change the score of the system. This method will allow for: 1) the direct and rapid assessment of the condition of the nation's waters; 2) the evaluation of project success using a standardized approach; 3) the ability to compare and learn from activities on similar systems within their classified group; and 4) the ability to integrate data from all levels into one data system. To advance this process, local and regional partnerships will be encouraged to develop condition factors to fit their needs, based on recommendations from the National Assessment Framework.

Project prioritization

This assessment tool will allow for the prioritization of projects from a scientific basis. In addition to this tool, the Science and Data Committee recommends that the National Fish Habitat Board and Fish Habitat Partnerships prioritize projects using additional filters that acknowledge the policy and socioeconomic aspects of fisheries and aquatic resources. Projects and systems should be prioritized, whenever possible, to achieve the following goals: 1) protect fully functioning aquatic systems including pristine sites and those that have been "manipulated" but have fully working aquatic processes; 2) rehabilitate aquatic systems that have only a minor number of impairments affecting one or more of the key processes that sustain them; 3) rehabilitate aquatic systems that have a number of impairments of one or more key processes; and 4) re-engineer modified systems to improve them for fisheries and aquatic production.

Monitoring progress

The systematic implementation of monitoring and evaluation can help focus actions to directly mitigate threats, increase the precision and value of investments, and assess progress on large scales. We propose a system to monitor and evaluate progress at multiple levels to provide an overarching view of the collective effects of our conservation and rehabilitation actions. Full involvement at all management levels will be necessary to ensure success of the NFHAP. Each project should be evaluated at three levels: 1) the effectiveness of individual projects in relation to clearly defined goals of the partnership; 2) the cumulative effects of individual projects at regional and national levels; and 3) the lessons learned and how they were used to inform conservation and rehabilitation actions elsewhere. Each of these scales should have clear roles and responsibilities with respect to prioritization and evaluation. This system will provide the crucial learning opportunity to refine and improve our methodologies to effectively measure success at multiple scales.

NFHAP data system

Ensuring successful implementation of the above system will require a detailed structural data system. The Science and Data Committee recommends the NFHAP Data System consist of four subsystems: 1) State of Fish Habitat Reporting System; 2) Progress toward NFHAP Goals Tracking System; 3) NFHAP Habitat Projects Priorities Data System; and 4) NFHAP Protection/Restoration/Enhancement Projects Data System. A single central, query-based geographic interface into the NFHAP system will be built to provide access and data/information within each subsystem. For proper operation, a single entity should maintain control over the national interface into the NFHAP system.

The data in the NFHAP system should be populated with data from existing online data systems, partnerships, and other data providers. Initial system development will depend on willing providers and the various entities that have existing conservation priorities databases, such as State Wildlife Action Plans, State Fisheries Management Plans, Marine Fisheries Council or Commission Plans, Watershed Assessments, and TNC Ecoregional Conservation Assessments. The classification data should be housed and maintained centrally for the national scale reporting, and the system should allow for integration of local, regional, and national scale classification data.

To be fully developed, some key challenges will need to be addressed in the database planning for the NFHAP system. These include: 1) identifying key data transfer standards; 2) providing key web services for integration of data into the assessment system from many sources; 3) determining how to efficiently work with different data providers; 4) properly scaling issues for initial development; 5) identifying mechanisms to integrate regional partnership and individual project information systems; and 6) differentiating and providing a weighting process for systems that have different scales or amounts of baseline data or other related information.

Implementation timeline

We expect that the initial prototype system, limited to the continental U.S. riverine systems, will be completed by November 2008. The next stage in development will be a second prototype, by January 2010, that includes lakes, coastal areas to the state or territorial boundary, Alaska, and Hawaii. A complete initial assessment will be ready by October 2010 and will include all waters of the United States and its territories. A national assessment should be updated in real time wherever possible. A full analysis should be done every 5 years to properly report changes in the condition of the nation's waters and the effectiveness of NFHAP projects in changing the condition of aquatic habitats.

Similarly, all database planning for existing and new priorities, along with evaluation information for NFHAP projects, should be completed by June 2009. A full prototype should be ready by September 2009 for testing and will be operational by February 2010. The database will be able to produce the first Annual NFHAP Project Evaluation Report by October 2010.

Introduction and Background Workshops

The idea for a focused effort to improve the nation's aquatic habitat has existed for over a decade, and the scientific basis of the National Fish Habitat Action Plan (NFHAP) employs a foundation of principles detailed in a 1992 report by the National Research Council (1992). This report recommended that federal and state agencies, in collaboration with non-governmental experts, develop a national aquatic ecosystem strategy that sets specific national restoration goals and provides a national assessment process. The report further states that the process must have careful planning, continuing financial support, active involvement from all levels of government, and a broad range of other partners. Many of these concepts have been imbedded into the overall NFHAP strategy and this framework report.

The principles outlined in the National Research Council report were echoed in seven stakeholder meetings, including a symposium at the August 22, 2004, American Fisheries Society (AFS) Meeting in Madison, Wisconsin. This symposium was attended by 130 individuals from 20 states, 16 universities, seven federal agencies, several Canadian agencies, and non-governmental organizations. The symposium provided recommendations for detailed habitat condition analysis, to be considered by the National Fish Habitat Science and Data Team (now Committee). The consensus at the meeting was that any habitat condition matrix must be:

1. Usable at local, regional, and national scales
2. Measurable, quantitative, and repeatable
3. Meaningful in scientific, management, and policy settings

The group consensus was that any system must have a basis in sound science, allow for regular progress measurement, **and** be transferable for use in public communications and policy decisions.

The symposium attendees recommended developing a system that measures the health of watersheds across the nation using a set of common criteria. The variables should include commonly measured conditions for which data are already available and include the following general categories:

1. Watershed characteristics
2. Water quantity
3. Water quality
4. Biological attributes
5. Physical attributes
6. Socioeconomic attributes
7. Miscellaneous

Implying a hierarchical organization to the condition variables, the AFS symposium attendees recommended consideration of the condition variables under each of the general categories in Table 1.

Table 1. Recommended variables for consideration by the AFS National Fish Habitat symposium attendees.

Classification	Variable
Water Quantity	a) Hydrologic flow indicators b) Water volume
Water Quality	a) Chemical parameters (O_2, pH, temperature, etc.) b) Indices of sediment/turbidity/solids
Physical Attributes	a) Geomorphology/channel characteristics b) Cover/woody debris c) Habitat connectivity d) Connectivity with fluvial processes e) Quantity/quality/trends of specific habitat
Biological Attributes	a) Fish Stock Assessment b) Fish diversity (including indices) c) Fish community structure (related to recreational fishing) d) Invertebrate index e) Presence/absence of indicator species f) Measurement of biological integrity g) Invasive species
Watershed Characteristics	a) Riparian habitat quality (including canopy, land cover, etc.) b) Land use patterns c) Watershed integrity
Socioeconomic Parameters	a) Fishing participation b) Risk assessment/public perception of waterbody
Miscellaneous	a) Sustainability b) Changes in benchmark indicators c) Absence/presence of outlined conditions

For each variable, the symposium attendees suggested that numeric values could be assigned that describe an acceptable range, a threatened zone, and an unacceptable range (note that the "acceptable" range would allow some level of imperfection). Using the individual criteria, each watershed would be characterized as green, yellow, or red based upon its performance against the optimum value in each area. A watershed would be characterized based upon the most limiting factor.

Finally, the symposium attendees recommended that:

1. Watersheds should be classified into broad geographic and/or type categories.
2. For each category, specific thresholds would be articulated based upon the best scientific input available.
3. The assignment of threshold criteria for available data should be based specifically on the requirements of fish communities and the combination of multiple data sets that would create a more complete picture of the habitat value and constraints of a given watershed.
4. The system should be scaleable to broader or more discrete geographic levels, based upon scientific, management, and communication needs of partners.

Nearly all of these recommendations have been incorporated in some way into this report and will be incorporated into the science approach for the NFHAP.

The Problem: Declining Aquatic Populations and Quality of Aquatic Habitat

Key Points:

- There are numerous factors for the decline of fish stocks, including physical habitat alteration, invasive species, hybridization, and overharvest.
- The quality and quantity of aquatic habitats globally are declining; in particular, aquatic habitats of nearly all types within the United States have been reduced significantly during the past 100 years, except for reservoirs and impoundments.
- The five major categories of threats to functioning habitats are physical habitat modification, flow alteration, pollution, invasive species, and climate change.

Fish stocks declining

Many U.S. inland fisheries and their supporting populations are in decline, with about 22% of the biota that rely on waterways being imperiled or critically imperiled (Heinz Center in press). In addition, approximately 37% of the fish fauna are considered at risk or vulnerable (Stein et al. 2000). Thus, nearly four of every 10 native freshwater fishes is at risk of extinction, but population trends for many species are unknown, and these estimates are likely to increase with further studies on the population biology of species. Declining or at-risk species occur throughout the United States, with the highest proportion being in Hawaii and the Southeast (Heinz Center 2002). An analysis by Miller et al. (1989) revealed that physical habitat alteration was the most common cause implicated in the extinction of America’s freshwater fishes (73% of extinctions), followed by introduced species effects (68%), chemical alteration of habitat (38%), hybridization (38%) and overharvest (15%). While these kinds of threat analyses are useful, it is often impossible to isolate specific threats in aquatic habitats, as they tend to compound each other.

For coastal commercial fisheries, the largest declines occurred in the Pacific Northwest (excluding Alaska), where 80% of the known fish stocks are declining. In this region, 214 salmon and steelhead stocks representing genetically distinct populations are rare or threatened, and another 106 populations have disappeared (Nehlsen et al. 1991). This decline is in large part due to habitat alteration, dam construction, and landscape-scale deforestation, with contributions from inappropriate hatchery management and poor harvest strategies. In contrast, Mid-Atlantic and North Atlantic fish stocks had the highest increase in biomass, although only 20% of the fish stocks status were known (Heinz Center 2002). Jackson et al. (2001) point out the important linkage of habitat loss and degradation coupled with overfishing that drive many coastal marine and estuarine ecosystems to collapse. For example, on a global level, destruction of oyster reefs is estimated at 91% (Jackson 2008), and oyster production in the Chesapeake Bay is only about 1% of what it was in the 1960s (Wesson et al. 1999). Clearly, conservation of aquatic resources requires management of fishing effort and the mosaic of habitats used by nekton that sustain fisheries production (Botsford et al. 1997; Peterson 2003).

Other aquatic organisms

The status of aquatic organisms other than fish is less clear because of the lack of long-term monitoring data. However, freshwater mussel species are declining throughout much of the United States. In the United States and Canada, 72% of native mussel taxa are considered endangered, threatened, or of special concern (Williams et al. 1993; Abell et al. 2000). Taylor et al. (2007) summarized the current status of crayfish and found that 47.4% of species in this group are at risk. Other key aquatic taxonomic groups with high proportions of species at risk include stoneflies (43%), amphibians (36%), and dragonflies/damselflies (18%) (Stein et al. 2000). The number and diversity of freshwater gastropods (over 650 different species) is the richest in the world; however, their rate of imperilment exceeds all other major animal groups in North America. Approximately 60 freshwater snail species (9%) are presumed extinct, 20 are on the federal endangered or threatened species list, and another 290 (48%) are of concern (Johnson 2003). The causes of declines in these species are presumed to be similar to those of freshwater fishes.

Coastal benthic invertebrates are also difficult to track due to the lack of long-term data. The limited data currently available suggests that about 3-45% of the benthic invertebrate communities are classified as degraded (depending on region), suggesting poor habitat quality in those areas (Heinz Center 2002, updated 2003, in press). Atlantic Coast estuaries had about 3-35% degraded benthic invertebrate communities (Heinz Center 2002, updated, in press), whereas the Pacific Coast had about 3% (Heinz Center updated, in press). Trends in the percentage of degraded estuaries remained relatively constant over the past 10 years, but will likely become more evident as more long-term data are collected. As with freshwater benthic invertebrates, this data gap is essential to determining the habitat quality of coastal environments (sensu Peterson 2003).

Aquatic habitats are threatened globally

The 2005 Millennium Ecosystem Assessment (World Health Organization 2005) indicated that over the past 50 to 100 years, rapid human population increases have resulted in large-scale habitat changes and pollution of inland water bodies and coastal areas around the world. Current trends indicate a continued, very rapid increase in human population effects on aquatic production and its supporting biodiversity in the future. The nation's rivers have been extensively modified by dredging, channelization, impoundment, and diking. Freshwater systems seem to be at higher risk than marine systems because of the larger scale of marine systems when compared to smaller freshwater systems. Already 84% of the fish on the International Union for the Conservation of Nature (IUCN) "Redlist" are freshwater species (Harvey 2001). Stressors on the world's aquatic habitats are a serious concern for aquatic life, and extinction rates in freshwater habitats are five times higher than their terrestrial counterparts (Sand-Jensen 2001; Ricciardi and Rasmussen 1999).

The diversity of freshwater species in the United States is unrivaled anywhere in the world, with over 800 freshwater fish species representing 10% of the world's freshwater fishes from very deep evolutionary lineages, as well as some of the most diverse and distinctive assemblages of mussels, gastropods, crayfishes, and amphibians (Abell et al. 2000; Stein et al. 2000).

Aquatic habitats of all types have been substantially reduced over the past 100 years (Johnston 1994; Vitousek et al. 1997; Kennish 2001). Wetlands in the United States have been severely impacted, and wetland acreage today is less than half what it was in Colonial times (Heinz Center 2002). The rate of loss has declined over the past 40 years, and the most recent study by the U.S. Fish and Wildlife Service concluded that the coterminous U.S. gained about 59,000 acres per year of wetlands between 1998 and 2004 (Dahl 2006). The quality of the wetlands gained or remaining is unknown, however. Focusing on maintaining and improving the health of the nation's aquatic habitats may curb the major biodiversity crisis facing the nation's freshwater ecosystems.

The coastal and estuarine areas of the United States provide vital services, such as sustaining commercial, subsistence, and recreational fisheries, supporting waterfowl populations, protecting coastal populations from the effects of storms and floods, and providing numerous recreational opportunities. The health of coastal and estuarine areas is declining, due in part to their enormous appeal as places to live and vacation. During the same time period that the coterminous United States as a whole experienced a net increase of wetlands, the coastal watersheds of the eastern United States (Atlantic and Gulf of Mexico coasts) saw a loss of approximately 385,000 acres of wetlands, the majority of it to coastal development (Stedman and Dahl 2008). The National Coastal Condition Report II (NCCR) (EPA 2004)—released by the U.S. Environmental Protection Agency, NOAA, U.S. Fish and Wildlife Service, and U.S. Geological Survey—reports that the nation's estuarine resources are diminishing and continue to be threatened, receiving a "fair" rating on a scale of good, fair, and poor. Evaluation of sediment quality, water quality, benthic community condition, and coastal habitat loss indices as part of the NCCR II indicates that 28% of estuarine waters are impaired for aquatic life use. According to this report, the overall national coastal habitat condition, based on long-term wetland loss rates, is poor.

Threats to healthy habitat

Since most of our nation's freshwater, estuarine and marine aquatic habitats have not been fully mapped to date, it is very difficult to precisely determine the extent of degraded aquatic habitat nationally. However, the causes of habitat degradation are generally well known from existing reports and information. Appendix 1 provides an overview of a number of national and regional habitat condition reports that frame many of the problems found to date from a broad range of approaches used to assess national or global habitat quality. We have grouped the various threats into five basic categories:

Direct habitat modification

Coastal watersheds represent 13% of the nation's land surface area but they are home to more than half of the human population, and the urban sprawl that covered 14% of America's coastal watersheds in 1997 is predicted to increase to 25% by 2015 (Beach 2002). Humans modify aquatic habitats in many different ways; for example, wetlands are filled in for urban and suburban development or drained for agricultural use. In marine areas, bulkhead construction, shoreline hardening for erosion control, and dredging for marinas (and the associated increase in boating) destroy shallow-water seagrass beds and other shallow-water coastal habitats. Similar effects to those in marine areas have been noted in inland lakes, impoundments, and reservoirs.

In the intensive commercial fisheries of California and New England, any given section of the sea bottom is scraped with trawls more than once per year (Auster et al. 1996; Friedlander et al. 1999). However, sensitive bottom-dwelling communities can take up to five years or more to recover from a single trawl pass and never fully recover from the trawling activity (Peterson and Estes 2001). Stone et al. (2005) reported that bottom trawling produced changes in seafloor fauna, in particular prey fauna for economically important ground fish.

Flow/Water volume alteration

The huge demand for water, particularly in arid areas of the United States, has created a crisis for aquatic organisms, and many historically perennial rivers no longer flow to the sea all year round due to excessive water diversion (National Research Council 1999). Dams play a huge role in this flow regulation, particularly in the Great Plains, Rocky Mountains, and arid Southwest, where water stored in large dams is up to 3.8 times the mean annual runoff (Graf 1999). The most rapid large dam-building phase occurred between the 1950s and late 1970s; however, since 1980 the increases in national dam storage capacity have been relatively minor because most of the prime locations have been developed. Even so, 75,000 large dams and 250,000 small dams remain on U.S. rivers (National Research Council 1992). These dams cumulatively fragment the rivers of the United States; alter downstream and upstream flow patterns and within reservoir lentic habitat; eliminate or alter seasonal flooding cycles, water quality, and temperature; reduce sediment supply to estuaries; and prohibit movement of migratory fishes. They replace riverine environments and biota that have adapted to swiftly flowing streams with lacustrine habitats and species (McAllister et al. 1997; Graf 1999; Abell et al. 2000; Harvey 2001).

In addition to dams, poor land practices have resulted in excess sedimentation, filling in of reservoirs, and degraded fish populations.. Consequently, entire native and naturalized fish communities are in danger. For example, every native fish species in the lower Colorado River is either in decline or has been extirpated (Moyle and Leidy 1992). In the Columbia River Basin, more than a third of original salmon habitat is blocked by dams (Levin and Schiewe 2001).

Changes in hydrologic routing that stem from landscape alterations are perhaps the chief environmental effects caused by development (Dunne and Leopold 1978). Increases in development threaten rivers and estuaries, as paved surfaces and canalized rivers alter natural flow regimes, reduce the lag time between storm event discharges and increase peak river flows. These changes in peak flow events have significant implications for sediment movement in watersheds and river channel shape. They also contribute to an increased risk of floods that affect people and property. Additional widespread river and stream habitat alterations on a national scale, such as extensive flow diversions for irrigation and for industrial and municipal water needs, can cause dewatering of habitat.

Pollution

Water is a universal solvent and is used to remove millions of gallons of human-generated waste each year through sewage systems, agricultural runoff associated with excessive use of fertilizers, or industrially produced animal waste. Animal feedlots produce about 500 million tons of manure each year, more than three times the amount of sanitary waste produced by the human population (EPA 2002). In assessed waters of the U.S., 47% of rivers/streams, 60% of lakes/reservoirs/ponds, 100% of open waters of the Great Lakes, and 61% of bays/estuaries are considered impaired (EPA 2008).

The primary pollution concern is nutrient enrichment, which has resulted in 78% of our nation's coastal rivers and estuaries having eutrophic conditions rated as moderate to high, and has contributed to the Gulf of Mexico's anoxic (dead) zone. The mid-Atlantic region is the worst, with over 50% of the estuaries having high levels of eutrophication. Bleak outlooks are predicted for our nation's estuaries, with overall eutrophication conditions predicted to worsen in 65% of the systems assessed (Bricker et al. 2007). The total amount of nitrogen released into coastal waters along the Atlantic seaboard and the Gulf of Mexico from anthropogenic sources has increased about fivefold since the preindustrial era and, if current practices continue, it will increase 30% by 2030 (Howarth et al. 2002).

Urban development has increased non-point source pollution; every year, 16.5 million gallons of oil runs off America's streets into our waterways (Pew Oceans Commission 2003). In addition, point source discharges of contaminants such as polychlorinated biphenyls (PCBs) and heavy metals have contributed to broad-scale impacts on fish populations and other aquatic populations (e.g., mink), and there is a growing concern about endocrine disruptors that can cause intersex in fish.

Invasive species

Since the arrival of the first Europeans in North America, the rate of introductions of known exotic aquatic species has increased exponentially. For example, in the San Francisco Bay, between 1961 and 1995, it is estimated that there was one new introduction every 14 weeks from ballast water releases (Cohen and Carlton 1998). These invasive species often compete indirectly with other plants and animals by changing the food webs and energy flow, or directly by modifying habitat in aquatic systems. An example of the former occurred in the Great Lakes, with the invasion by alewives and sea lamprey from the Atlantic Coast; however, direct modification of habitat has resulted from zebra and quagga mussel infestations across the country.

Climate change

In addition to these varied threats, climate change over the next century is expected to have profound effects on coastal and marine ecosystems. Global air temperature is expected to warm by 1.4 to 5.8^{o}C in the 21st century, affecting sea-surface temperatures and raising the global sea level by 9 to 88 cm (IPCC 2001; Twilley et al. 2001). This sea-level rise, in combination with subsidence on the East Coast, will gradually inundate highly productive coastal wetlands, estuaries, and mangrove forests (Pew Oceans Commission 2003). Higher water temperatures will result in bleaching of coral reefs and the gradual loss of structural complexity and biodiversity in these key biomes. It has been projected that a mean sea-surface temperature rise of just 1^{o}C could cause the global destruction of coral reef ecosystems (Goreau and Hayes 1994; Hoegh-Guldberg 1999).

In a warmer climate, cold-water species will be seriously affected and their ranges are expected to shift north. For example, a 2^{o}C increase in temperature will reduce freshwater salmon habitat by 35% (Keleher and Rahel 1996). Warmer temperatures will result in the drying of shallow lakes and a decrease in water depth of the deeper lakes (Meisner et al. 1987), while temperature and rainfall changes will alter migration cues and upset fish reproduction and rearing patterns. Significant shifts in rainfall patterns are expected with climate change, with much of the southern United States becoming drier overall with much more frequent intense storm events. These rainfall changes will increase the severity of floods and droughts that will affect both inland and coastal waters. Fish species that rely on specific and predictable flow patterns will have their overall productivity impaired.

Increases in atmospheric carbon dioxide is also causing ocean acidification (a lowering of pH), which is affecting coral reefs and other organisms. NOAA data collected in 2006 from ocean sampling in the Pacific Ocean from the southern to northern hemispheres confirms that the oceans are becoming more acidic. The field study collected data about the effects of ocean acidification on the water chemistry and marine organisms from Tahiti to Alaska, and found evidence that verifies earlier computer model projections and is consistent with data in other oceans. One result is that shell production in pteropods (free-swimming planktonic mollusks that form a calcium carbonate shell made of aragonite) is affected. They are an important food source for juvenile North Pacific salmon and also are eaten by mackerel, herring, and cod (Feely 2006). Reduction of pH also affects the growth rates and calcification process in coral reefs and could severely reduce the rate of reef formation (Jackson 2008).

Additionally, changes in ocean and atmospheric circulation resulting from climate change could adversely affect coastal upwelling and productivity, causing significant local, regional, and global changes in the distribution and abundance of living marine resources (Pew Oceans Commission 2003). For example, dead zones off the U.S. West Coast in recent years have been attributed to a shift in wind and current patterns that changed the location and intensity of coastal upwellings. The zones ranged at times from California to Washington State and resulted in massive mortalities of benthic organisms. The worst low-oxygen ocean conditions ever observed on the U.S. West Coast were documented off the Oregon coast in 2006. Dead crabs and other decomposing benthic organisms covered the sea floor and fish had apparently abandoned the area (ScienceDaily 2006).

Habitat Assessment as a Decision Support Tool

Key Points:

- The decision support tool would have the following characteristics and capabilities: measure and characterize the condition of fish habitat; assess the efficacy of conservation activities; portray habitat at multiple scales using GIS software; possess flexibility; and be web-based.
- All aquatic systems will be classified to allow for the vertical summarization of habitat condition and the horizontal comparison of similar systems.
- The habitat assessment will have a hierarchical framework.
- The inland and coastal classification and assessment must be integrated to show connectivity of habitats and processes and to fully assess habitat condition.

Overview of the assessment tool

Protection and rehabilitation of aquatic habitat is a critical need throughout much of the United States. Therefore, managers are faced with deciding where to focus their efforts in order to maximize benefits. To date, no standardized method has been developed that integrates all of the current habitat condition information into a decision support tool. National reports such as the National Coastal Condition Report II (NCCR II) (EPA 2004), the National Estuarine Eutrophication Assessment (NEEA) (Bricker et al. 1999), and the State of the Nation's Ecosystems (Heinz Center 2002) use coarse measurements from which it is difficult to develop useful management tools. Setting up a monitoring program that would allow the tracking of the condition compared to an ideal state is costly; therefore, regional reports are often the only sources of information about conditions.

A national fish habitat assessment is essential as a means to allow decision makers to take advantage of available habitat data and assessments and quickly prioritize habitat types and locations for protection, restoration, or habitat enhancement. The tool will aid in identifying: 1) areas in most need of conservation or protection to benefit the most species or the habitats that are in the highest peril in that region; and 2) areas that offer opportunities to make the largest gains in protection or rehabilitation. Using such an assessment as a decision support tool would also enable rapid and effective feedback on the success of project work, which is not available at this time. In addition, the assessment will allow users to examine potential outcomes of future conditions and predict the likely direction of system changes in response to developmental pressures. Finally, a national assessment would provide a meaningful context to compare information and knowledge between and among partners working on similar systems.

Several large-scale projects have demonstrated methods for developing and applying model tools that assist with estimation of aquatic species distributions. One such project is Aquatic Gap Analysis (AGA), which uses work done by TNC and other groups and was developed to better understand aquatic ecosystem patterns and the biological diversity of aquatic systems, and to identify gaps in their conservation. AGA focuses on aquatic habitats and uses models of associations between observed species occurrences and the landscape-scale features of habitat conditions to estimate species occurrences for all sampled and unsampled areas of an ecosystem. Pilot Aquatic Gap projects undertaken on a statewide (e.g., Missouri, Ohio, and South Dakota) or regional basis (e.g., Lower Colorado River Basin, Great Lakes Basin, Upper Missouri River Basin, and Puget Sound) have provided an improved understanding of the status of aquatic biological diversity and associations of aquatic organisms with particular habitat conditions for aquatic systems scattered across the nation. The model systems resulting from these projects provide spatial data management and species-specific mapping tools that allow examination of species distributions on any scale from the region (100s to 1,000s km) to metahabitat (~1–2 km). Classification systems are also being developed for these aquatic habitat focus areas.

The “first stage” decision support tool developed here will be largely based on current habitat conditions and theoretical potential for aquatic systems. Lack of sufficient biological data and the relatively short development time-frame prohibit extensive development of species-habitat models for the best projections. However, demonstrations should be developed in focus areas where data are available and such models are developed within the time and resources available to the partnerships, as they strengthen the relationships between fish populations and habitat condition.

Tool Capabilities

The decision support tool will have the following capabilities:

Measure and characterize condition

- Assess changes in habitat conditions over time and predict potential future conditions.
- Evaluate and compare conditions for similar systems in the United States based on geospatial measures of habitat (e.g., basin and channel characteristics).
- Assess how any particular factor (e.g., water quality, connectivity, etc.) influences the overall score of the habitat quality.

Assess efficacy

- Assess the efficacy of on-the-ground conservation activities.
- All systems will be scored within their classified group (i.e., Ecological Drainage Unit (EDU) or small headwater stream group) to establish a baseline and develop long-term habitat goals.
- Habitat scores calculated after management actions (i.e., protection, rehabilitation, and enhancement) can be compared to the baseline for signs of improvement (or maintaining high quality).

Depict habitat at multiple scales

- The system should be essentially “scale-less” to allow data entry and analysis at any scale.
- View habitat characteristics and biological projections at various desired scales from the finest resolution allowed by the data (e.g., stream segment (1–2 km) or ecological unit) to regional and national scales.
- Data gaps and limitations of the condition indices will be clearly documented.

Includes Flexibility

- Incorporate additional data and/or improved metrics and tools as they become available.
- Provide conversions or transfer functions to ensure older metrics can be evaluated in the terms of new metrics.
- Identify high-priority data gaps and then fill those gaps as necessary information becomes available.
- Test the metrics to determine how important a particular metric is in affecting aquatic habitat conditions (i.e., sensitivity analysis).

Is web-accessible and GIS-based

- Interface with any public user or partner entity, through an internet map server and appropriate tutorial tools, so that users can identify the particular ecological unit or aquatic habitat of interest.
- The information will be placed on a server within a federal agency or national organization, where information will be updated as new data become available.

System Classification

Habitat Assessment Framework

Replacement or rehabilitation of degraded aquatic habitats is very costly; so a prerequisite for such actions is a thorough knowledge of the "function" of the aquatic habitat of concern, although this is rarely fully known. For the NFHAP to be successful there must be a clear understanding of aquatic habitat components and processes, and a framework in which to begin addressing habitat problems. This section describes the framework that is used to develop the assessment methodology found later in the document.

The concept of hierarchy theory, where large-scale patterns and processes shape and constrain those at finer scales, has emerged in aquatic ecology as a framework to describe habitat in a hierarchy of abiotic patterns and processes that determine biotic patterns and processes (Allen and Starr 1982; Frissell et al. 1986; Klijn 1994). These hierarchies are geospatial, placing specific aquatic habitats within the zoogeographic, climatic, physiographic, and hydrologic environments that shape them. Frameworks have been defined and refined for a variety of aquatic ecosystem types, across a range of spatial and temporal scales. Hierarchical frameworks of aquatic habitat are not only important for understanding the cross-scale processes that constrain and maintain fine-scale habitat; they are also necessary to understand, quantify, and manage for human impacts to aquatic habitats and subsequent effects on biological structure and productivity. Conservation activities must address effects on driving dynamic and structural processes at the scales at which they originate and operate, in order to best manage for quantity, quality, and linkages of diverse aquatic habitats. This concept is critical to the success of NFHAP projects and partnerships. Table 2 gives examples of the uses of a hierarchical framework:

Table 2. Examples where a hierarchical framework is used.

Organization	Use
U.S. Geological Survey (USGS) NAQWA program (http://water.usgs.gov/nawqa/)	Sampling designs
USGS Aquatic GAP program (http://gapanalysis.nbii.gov/portal/community/GAP_Analysis_Program/Communities/GAP_Projects/Aquatic_Projects/)	Establishing zoogeographic and hydrologic regions in developing regional conservation plans
USGS National Hydrography Database-Plus program (http://nhd.usgs.gov/)	Assessment of hydrology and water quality
USDA Forest Service and NOAA-NMFS	Inform aquatic ecosystem management
The Nature Conservancy (http://www.nature.org/aboutus/howwework/cbd/science/art19226.html#)	Identification of regional conservation priorities

This multi-scale capability allows users to address questions requiring integration of information from local sources with information at regional and national scales. It is important to recognize the limitations of using the larger scale (e.g., landscape level) to assess habitat condition at smaller scales. In particular, it is very easy to accumulate habitat condition information at increasing scales. One must use caution in extrapolating data at a lower level than the scale at which it was collected. Therefore, assessing local habitat condition or improvements may be limited to landscape-level metrics.

Classification of fish habitat

We define aquatic habitat as a hierarchy of different attributes at several spatial and temporal scales corresponding to patterns of dominant ecological processes that affect fish distributions. For this national assessment and synthesis, it is critical that habitats are classified and represented as mapped units at several different spatial scales. They can then be assessed for their condition, and the type and severity of threats to them. These units need to be classified and mapped with relative consistency across the United States, given data limitations. By fulfilling these criteria, the units will then be the basis for regional and national assessment and synthesis.

Identifying the key attributes of each landscape unit will allow a nearly unlimited variety of analyses and comparisons between systems that may not seem to be related but are controlled by the same fundamental processes. For example, on a superficial basis, it may not seem that Rocky Mountain high gradient streams have much in common with Appalachian Mountain high gradient streams; however, they share similar geomorphology, stream powers, and rainfall amounts. This allows for broad exchange and review of rehabilitation strategies in similar systems across the United States to an extent not seen to date.

Coastal vs. Inland

For this classification, the first major delineation in habitat is between inland and coastal habitat. In the NFHAP, inland habitats are defined as waters above the head of tide for those directly linked to marine systems and, in the Great Lakes they are defined as waters above the elevation of backwater effects of the Great Lakes. Coastal systems are defined as those that include all tidal waters, and in the Great Lakes they are the waters below elevation of backwater effects from the Great Lakes. Anadromous and adfluvial waters include all connected waters to either marine or Great Lakes waters to the first natural barrier.

Inland Habitats

The classification scheme to be used in this decision support tool is described in detail in Higgins et al. (2005) and is summarized here. Freshwater inland habitats will be initially classified within national and regional contexts of zoogeography, climate, and physiography, down to the level of landscape ecosystems. Aquatic landscape ecosystems are interconnected streams, lakes, and wetlands that can be mapped as distinct hydrologic catchment units, and can also be easily depicted as an assemblage of characteristic component streams, lakes, and wetlands. Representing them as catchments is important for three reasons:

1) On a national or regional map, catchments can be represented more easily than all of the individual components.
2) Catchments are critical to assess hydrologic landscape patterns that constrain aquatic ecosystem characteristics.
3) Catchments are critical to assess hydrologic landscape patterns of threats and impacts to aquatic ecosystems.

The approach uses mapped landscape features at varying scales to attribute the dominant characteristics of freshwater habitats associated with each scale. This approach has grown out of a large body of work linking landscape features to freshwater habitat, and incorporates attributes of freshwater ecosystems such as size, drainage network position, and connectivity to characterize distinctions in interconnected lakes, streams, and wetland complexes (Maxwell et al. 1995; Seelbach et al. 1997; Higgins et al. 2005; Sowa et al. 2005, 2007).

Higgins et al. (2005), Sowa et al. (2005), and Seelbach et al. (1997) have implemented detailed approaches to classify freshwater landscape ecosystems down to the stream segment and individual lake level, incorporating attributes of stream and lake size, elevation, stream gradient, local connectivity and landscape network position, catchment and local geology, hydrologic regime, valley morphology, and lake shoreline complexity. The Nature Conservancy and several Aquatic GAP programs have implemented, or are currently implementing, this detailed approach for a majority of the United States.

A simplified, consistent framework for the NFHAP is needed to allow the ranking of classified units and the implementation of the assessment in a timely manner; thus we propose to start the national framework at the landscape ecosystem level. The more detailed macro/meso habitat classifications and additional field data can be further developed and refined, and used by Fish Habitat Partnerships (e.g., Southeast Aquatic Resource Partnership).

The recommended simplified approach is to initially use catchment size, average system gradient, and drainage network position of interconnecting streams, lakes, and wetlands. This differentiates true headwater stream and lake complexes from those that are small but are connected directly to large mainstem rivers. This will establish an initial national framework to characterize freshwater landscape ecosystems by size and stream power. Lake, impoundment, and reservoir classification should initially start with size (both surface acreage and volume) and turnover ratio. Further refinement of size categories and all of the other attributes should be conducted by Fish Habitat Partnerships to better reflect more meaningful ecological breaks. Shoreline habitats of the Great Lakes are being classified by Aquatic Gap using methods similar to those for marine shoreline classification.

Landscape ecosystems of different sizes will be nested within Ecological Drainage Units (EDUs) (Higgins et al. 2005; Sowa et al. 2005, 2007). EDUs are created using 8-digit USGS Hydrologic Unit Codes (HUCs), and 6-digit HUCs in Alaska, and are used to distinguish regional landscape and climate patterns that influence broad ecosystem characteristics such as lake and stream density, morphology, hydrology, temperature, and nutrient regimes. This provides ecological context for the HUCs, aggregating them into meaningful geospatial groups. EDUs have been mapped for the majority of the United States including 40% of Alaska and are nested within Freshwater Ecoregions, which are delineated based on distinct assemblages of aquatic biota, primarily freshwater fishes. Completion of the EDU classification and mapping is moving forward quickly by TNC and these data will be available in 2008 for the entire United States.

Coastal Habitat Classification

Overall Approach. To ensure that the linkages between coastal and inland systems are fully established, the classification and condition analysis process for both systems will be integrated. Coastal habitat classification will follow a similar approach to that of freshwater, using geomorphological, physical, and chemical data to describe and delineate patterns of habitat in a hierarchical approach. The Coastal and Marine Ecological Classification Standard (CMECS), developed by NOAA and NatureServe, will be used to classify habitats. CMECS is relevant to all U.S. coastal and marine environments and can be applied on local, regional, and continental scales. The classification provides a structure for synthesizing data so habitats can be characterized and reported in a standard way, and information can be aggregated and evaluated across the national landscape and seascape. Built on existing classification efforts and informed by a series of technical meetings and workshops, the CMECS standard integrates the current state of knowledge about ecological and habitat classification. The result is an ecosystem-oriented, science-based framework to allow effective identification, monitoring, protection, and restoration of unique biotic assemblages, protected species, critical habitat, and important ecosystem components (Madden et al. 2005, 2008).

CMECS Version III has three distinct components each describing a different aspect of the coastal and marine environment. Taken together, these components provide a structured way to organize information about coastal and marine habitats and a standard terminology for describing them. The Benthic Cover Component (BCC) is a hierarchical system that describes the geomorphologic, physico-chemical, and biological composition of the coastal and marine substrate. The Water Column Component (WCC) describes the structure, patterns, processes, and biology of the overlying water column. The Geoform Component (GFC) describes the major geomorphic or structural characteristics of the coast and seafloor at various scales. A fourth component for subbenthic habitats is currently being developed. The flexibility of the CMECS classification standard will support a variety of local and regional applications.

Specifically, the Benthic Cover Component (BCC) classifies geologic and biotic cover of the substrate at different spatial scales and places the associated biology in the context of the physical habitat. This component is organized into a branched hierarchy of six nested levels that correspond to both functional and ecological relationships at progressively smaller spatial scales. The BCC branches into five Systems (nearshore, neritic, oceanic, estuarine, and freshwater influenced) at the highest level based on salinity, depth, and enclosure and two Subsystems defined by tidal regime (i.e., intertidal or subtidal). Each Subsystem further divides into Classes (e.g., coral reef, aquatic bed) and then Subclasses (e.g., spur and groove reef, rooted vascular vegetation), largely adopting the values in the FGDC wetland classification standard (Cowardin et al. 1979). Groups are defined within the Subclasses based on factors that reflect the variance in biotic composition of the Biotopes. Biotopes represent broad biological associations identified by dominant or diagnostic species that are fixed to the substrate.

The Water Column Component (WCC) describes the structure, pattern, and processes of the water column. Although the water column is highly variable spatially and temporally, conceptually it is composed of repeating structures and processes that strongly influence the distribution and condition of the biota. This classification component employs multiple classifiers. The WCC classifiers can be used alone or in combination to describe the structure and composition of the water column—the classification of the water column is not strictly hierarchical. The first category, System, is the same as that of the BCC and should always be used to put the water column units into the same context as the BCC. Additional classifiers address features such as depth (vertical zonation), structure (upper and lower water column), hydroform (e.g., major ocean currents, large coastal fronts, waves), dominant lifeforms, and biotopes. Because of its dynamic and three-dimensional nature, the water column can be a challenge to map. The WCC is intended to be mapped independently of the other components of the classification standard to provide information on distinct water column ecological units as necessary. However, it can be overlain on the BCC and GFC components to help users understand the vertical component of the marine environment.

The Geoform Component (GFC) describes the structure of the coastline and sea floor at multiple scales. A Geoform is equivalent in concept to a terrestrial landform (e.g., mountain, butte, moraine, etc.) and likewise varies in scale from very large (e.g., seamount, embayment) to very small (e.g., tidepool, sand ripple). Geoforms shape the large-scale seascape in repeatable and predictable ways by providing structure, channeling energy flows, regulating bioenergetics, and controlling transfer rates of energy, material, and organisms. The morphology of these features controls such processes as water exchange rates and water turnover times, hydrologic transport, energy and nutrient cycling, shelter and exposure, and migration and spawning patterns. The framework for the GFC is based largely on the structure described by Greene et al. (2007), but expands it and re-organizes some options to encompass a larger number of coastal and nearshore features. As with the WCC, the GFC is intended to be mapped as a separate layer from the BCC. When overlain on the BCC, the GFC layer can provide additional insight into how benthic patterns vary with the structure of the substrate. GFC types may also be used independently when information on structure is required to meet the objectives of a given project.

In addition to the components of CMECS, a list of standard attributes—a consistent set of variables that provide the basis for classification and description of the CMECS units—is provided. When required to define a unit, these standard attributes are called “classifiers” as described under the WCC discussion above. When used to further describe a unit, these standard attributes are called “modifiers.” Standard attributes provide a consistent standard for data collection and application.

Linkage with Inland Systems. CMECS will be applied within the geographic confinements of NOAA’s Coastal Assessment Framework (CAF, http://coastalgeospatial.noaa.gov/). The CAF characterizes coastal watersheds within a nested hierarchy of spatial units for small- and large-scale coastal resource data analyses. For CMECS application, the CAF units of Estuarine Drainage Areas (EDA) and Coastal Drainage Areas (CDA) will be utilized and provide the hydrologic linkage with inland systems. An EDA is that component of an estuary's entire watershed that empties directly into the estuary and is affected by tides and may be composed of all or part of a single or several USGS hydrologic units. A CDA is defined as that component of an entire watershed that meets the following three criteria: 1) it is not part of any EDA; 2) it drains directly into an ocean, an estuary, or the Great Lakes; and 3) it is composed only of the downstream-most HUC in which the head-of-tide is found. The CMECS can be applied independently of the geographical framework provided by the CAF, but for purposes of this assessment—particularly the need to link the coastal assessment to the inland assessment—application of CMECS will occur within the EDAs and CDAs defined by CAF.

System Condition and the Assessment of the Nation's Habitats

Key Points:

- The methodology for scoring habitat condition will consist of the following steps: 1) assign habitat variables; 2) analyze variables; 3) standardize metrics and formulate the degradation index; 4) analyze index properties; 5) conduct a sensitivity analysis of indices; and 6) calculate an overall habitat condition score.
- The key processes upon which habitat variables are based are: connectivity, hydrology/circulation, bottom form complexity, material recruitment, water quality, food webs, and energy flow in communities.
- The overarching assumption is that changes in the large-scale control variables that directly influence local habitat conditions will directly influence the productivity and composition of the fish and aquatic community.

International agreements, national legislation, and reports (e.g., the Great Lakes Water Quality Agreement, the Clean Water Act of 1972, The Heinz Center Report on the Nation's Ecosystems, and the Pew Oceans Report) have all identified the need to restore and maintain physical, chemical, and biological aspects of ecological integrity in our nation's aquatic ecosystems. However, effective measures of integrity have only recently been developed and continue to evolve. This is due partly to lack of availability of data and inadequate technology, and partly to non-standardized definitions.

Karr and Dudley (1981) defined biological integrity as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition and functional organization comparable to that of natural habitat of the region." The Index of Biotic Integrity (IBI), Habitat Suitability Index (HSI), Hilsenhoff's Index, and other indices have been developed to summarize ecosystem integrity using biological attributes to provide a means of computing values that can be compared. Leonard and Orth (1986) stated that "The IBI is based on the assumption that selected fish community attributes change in a consistent and characteristic fashion with increasing stream degradation." This assumption will be used in this effort.

It would be preferable to use biologically based indices such as fish, which are excellent indicators of habitat quality (e.g., Karr and Dudley 1981). However, this is not possible because fish abundance and community composition data, and statistically significant relationships between these factors and habitat quality, are exceedingly rare and patchy at the present time. This is attributable to the wide annual fluctuation of fish and aquatic community abundance and the difficulty of adequately sampling these communities. Thus, our initial indices will focus on habitat conditions that are definable and measurable, and have clear linkages to fish populations. We recommend that work continue to focus on the long-term development of fish-habitat relationships so they can be used in the future.

Due to the difficulty of scaling process-oriented variables (e.g., trophic interactions), percentage-based (standardized) indices will be used that are easier to define in any given scale. Given a classification of habitat types into potential ecological units, and values of variables that characterize habitat quality, ranked scores can be assigned to indicate level of degradation caused by each factor. Selecting the appropriate process-level condition variables (from within each major category) that are most important, within a given ecological unit, requires knowledge of each system's ecological structure and function, and its unique environmental threats. We expect and recommend that specific knowledge from local and regional partnerships be used to refine proposed indices, or that surrogate indices be used. If other indices are selected, it is critical that the rationale for their selection be fully documented and that they be compatible with the overall process-oriented approach.

Habitat Condition Scoring Methodology

Minns et al. (1994) used a five-step procedure for their development and application of an Index of Biotic Integrity (IBI) for Great Lakes littoral zone fish assemblages. Their approach provides some important standardization for index development. That general procedure was applied here, with modifications, to develop our Habitat Condition Indices for each classified unit. Those steps are as follows:

1) Habitat variables
2) Analysis of variables
3) Standardization of metrics and formulation of the degradation index
4) Analysis of index properties
5) Sensitivity analysis of indices
6) Overall habitat condition score

The following sections describe these steps.

Habitat Variables

Habitat variables thought to have significant influence on fish abundance, diversity, and/or distributions as identified by the Science and Data Committee were selected and classified into broad categories of effect by key system processes. The Science and Data Committee will develop a conceptual model that describes the interrelatedness of the variables. The highest levels of organization are the key processes and features, which include connectivity, hydrology and circulation, material recruitment, bottom form complexity, water quality, and food webs and energy flow in the aquatic systems. Many of these processes have been identified as the key controlling variables for inland aquatic habitats, with the most recent descriptions by Annear (2004). Similar processes are used for coastal and marine areas, and are identified and used in, e.g., NCCR report (2002), the Heinz reports, and the NOAA National Status and Trends Program reports (e.g., Bricker et al. 2007). These variables are listed in matrix form in Appendices 4 (Inland) and 6 (Coastal). Below are descriptions of the key processes and features.

1) Connectivity – A wealth of literature points to the importance of having unfragmented reaches of habitat that allow fish and other aquatic organisms to fully exploit all potential habitats to complete their life histories and to maximize their production. Many marine and adfluvial species (e.g. salmon, striped bass, and American eel) require connected riverine and estuary habitat to complete their life cycle. The primary reasons (impairments) for fragmentation are barrier culverts and dams without adequate fish passage, enclosed streams that behaviorally exclude fish passage, rivers and streams in concrete channels without the needed bottom roughness (complexity) or depth to allow fish passage, and causeways that constrict embayments and rivers into small areas that increase water velocities beyond the range that any life stages of fish can pass. Chemical and thermal barriers (e.g., polluted harbors separating marine species from important estuarine habitat, or acidic lakes blocking freshwater fish migration pathways, etc.) also impair connectivity, although they are sometimes overlooked as constituting barriers. In coastal systems, connectivity issues surround the proximity and size of important habitat features (e.g., sea grass beds, oyster reefs, coral reefs) and the connectivity between coastal and inland ecosystems (e.g., flood control structures).

2) Hydrology – Riverine (lotic), lake/reservoir (lentic), and coastal systems in most instances require dynamic flow regimes to transport sediment and woody debris, maintain riparian corridors, maintain channel valley integrity, sufficient water volume and stage variability. All of these components comprise the physical makeup of habitat in our rivers, streams, and lakes. Most aquatic species have specific requirements for depths and flows and are adapted to natural system flow regimes. Changes in flow will cascade into large-scale changes in habitat with resulting effects on fish and aquatic community composition and production. The annual, seasonal, and daily hydrology of a watershed can be altered by human activities through land use change and development. The key reasons (impairments) for hydrologic alteration include changes in stormwater runoff, storage reservoir operation, water withdrawal and diversion, wetland losses and land use that reduce natural system water storage, and hydropower projects that operate in a peaking power mode without any re-regulation.

3) Circulation – In coastal systems, vertical circulation of the water column generally distributes bottom nutrients and sediments throughout the water column, influencing growth of phytoplankton and benthic vegetation. Excessive nutrients may result in Harmful Algal Blooms, i.e., undesirable phytoplankton species or phytoplankton crops in such large numbers that their eventual death and decomposition may lead to degraded habitat conditions such as hypoxia. Tidal influence and large Great Lakes circulation cells also play a significant role in the redistribution of sediments and nutrients, and the energy level associated with tides and currents can influence habitat types significantly. For example, high-energy coastlines are more likely to have less fine sediments such as sand and mud, whereas low-energy coastlines may be dominated by these finer sediments. The substrate texture and grain size is a strong driver of a species' ability to inhabit a particular area. Finally, ocean currents and other types of mass water movements (e.g., gyres and Great Lakes circulation cells) play a crucial role in distribution of many larval species. Alterations of natural circulation patterns can have considerable impacts on coastal habitats and their related biological assemblages.

4) Bottom Form Complexity – The physical heterogeneity of aquatic habitat—such as the pool-riffle ratios in rivers and streams, river channel type, lakebed shape, estuary morphology, and channel shape—provide key patterns and potential limitations to the productivity of aquatic species. The alteration of the hydraulic characteristics of channel and bottom form includes any human-caused activity that has physically changed the contours, shoreline, or shape of our upland waters. Most of our nation's rivers, streams, lakes, estuaries, and nearshore habitats have been physically altered some time in the past 300 years without any regard to the effects on our fish and aquatic resources. The main ways our systems have been altered are by the direct channelization and straightening of our rivers with a resulting direct loss of aquatic habitat; the de-snagging of our rivers and lakes with a large loss in woody debris and associated reduction in three-dimensional complexity; the alteration of bottom contours of our lakes, reservoirs, rivers and estuaries through dredging or filling; sedimentation inputs, and the direct loss of river and stream habitat by impoundment. The key reasons (impairments) for hydraulic alteration include channelization and hardening of rivers, streams, lakes, and coastal shorelines; the de-snagging and removal of woody debris; the alteration of riparian and coastal forests and vegetation that reduces (or eliminates) woody debris recruitment to our rivers, streams, lakes, and coastal marine habitats; dredging, filling, and engineering of the bottoms of our waters (frequently in response to excessive sedimentation from upland areas); and dams that directly impound streams and rivers along with their natural processes that link to and support aquatic systems.

   The physical characteristics of coastal aquatic habitat—such as the channel configuration, bottom type and shape, and overall bottom orientation—influence tidal flow velocities and directions. In addition, wind and waves and other water movement impose key limitations on productivity and distribution of coastal species. The primary ways our coastal systems have been altered are by the direct channelization of tributaries and harbors, filling and hardening of coastal shoreline, resulting in direct loss of coastal habitat; construction of artificial breakwalls, thus altering sediment transport and nearshore energy environments; de-snagging of our coastal systems, causing a large loss in woody debris and habitat; and the alteration of the bottom contours of coastal areas through dredging or filling. Construction of impoundments, or diking of coastal wetland areas, also contributes to losses of marsh habitats and functions.

5) Material Recruitment – Nearly all of the materials (sediment, particulate organic matter, and woody debris) that rivers and streams transport come from the riparian zone. These materials control the habitat matrix in adjacent lakes and coastal areas along with structuring habitat in rivers and streams. The key reasons (impairments) for riparian zone alteration are engineered shorelines, hardened banks, and the loss of woody debris and living riparian buffer zone communities adjacent to lakes, rivers, and coastal marine shorelines.

6) Water Quality – The existence of intact, fully functional aquatic habitats must be accompanied by appropriate water and sediment chemistry to provide appropriate conditions for the production of fish and other aquatic life. Degradation of water quality can be direct (such as low or zero dissolved oxygen concentrations in the Mississippi River) or indirect through the eutrophication of coastal water bodies (e.g., in the Gulf of Mexico) from upland agricultural or urban runoff. There can also be direct human health effects from the consumption of contaminated fish and shellfish from systems with poor water or sediment quality. Water quality is also directly related to maintanence of water volumes, not simply controlling effluent discharges. The areas to examine are those impaired by mining, point (National Pollution Discharge Elimination Permits (NPDES) and non-point pollution where natural filters have been removed. Other areas to examine include those with fish and shellfish consumption advisories.

   The key reasons (impairments) for water quality alteration include in-stream and lake bottom mining (e.g., gravel and gold dredging operations), mine drainage and contamination, and stream and lake relocation. Water withdrawals by mining operations; excessive nutrient, sediment, and toxic inputs from non-point and point sources; low dissolved oxygen; and water temperatures that do not meet standards also impair water quality. Loss of wetlands and their natural filtering functions affects water quality, as well as many of the key factors influencing habitat integrity and species diversity.

7) Food Webs and Biological Energy Flow in Aquatic Communities – While the above abiotic factors will explain most of the habitat conditions of our systems, they can not directly determine the key biological functions governing trophic levels in aquatic communities. Efficient utilization of energy is critical to aquatic systems and can be disrupted by several means. For example, the introduction of Aquatic Nuisance or Invasive Species (ANS and AIS respectively) can interfere with energy transfer in food webs, and overexploitation of key species, or changes in habitat, can affect primary production in systems. Additionally, many efforts to control ANS and AIS create habitat impairments for other species (e.g., the installation of sea lamprey barriers on sea lamprey spawning streams that fragment systems).

   The key indicators or variables we propose to examine are: changes in overall species composition, the occurrence and diversity of native or naturalized fish and mussel communities that are sensitive indicators of habitat conditions, the existence of a complete food web that supports maximum production of the aquatic community, and balance throughout all production levels. We will also assess the occurrence of ANS or AIS that are able to capitalize on impaired aquatic habitat conditions and, in turn, cause problems with fish production. The main variables to assess for biotic alterations are threatened populations and species extirpation or extinction, the rate and number of lost species, reduced diversity and food web simplification, and the number and diversity of ANS.

The matrices shown in Appendices 4 and 6 use overall system information, such as the total river miles or estuarine or lake acreages, as the initial starting point in the analysis. These values are then converted to percentages for each condition variable by dividing the amount of habitat described by condition variables by the overall system variable. For example, the percentage of anadromous river miles connected to a coastal system would be expressed as the current anadromous river miles divided by the total length of river up to the first natural barrier.

$$\text{Connectivity} = \frac{\text{Current miles of anadromous or adfluvial river to man-made barrier (mi.)}}{\text{Miles of anadromous or adfluvial river to first natural barrier (mi.)}}$$

The scores of the variables, sub-components, and components will be averaged to provide an overall score. This system will allow for analysis and summarization of condition at any level or scale.

We evaluated and considered which underlying agents are reflected in local habitat conditions. These are very large scale variables that directly control the physics and chemical characteristics or drive the biological responses in a classified unit. Initial variable selection was based on "expert" knowledge of aquatic systems throughout the United States. That list was classified into a hierarchy of general effects. Then, as described above, those variables were examined system-by-system for redundancy and reduced to the set of variables to which aquatic communities within the system respond most strongly.

It should be noted that the example matrices provided in Appendices 4 and 6 are long-term target matrices that would be preferred if all of the data were available; but we acknowledge that the data are not available at this time to generate values for each of the condition variables. We also expect that not all of these variables will exactly fit every system, and encourage partnerships to develop their own condition measures as long as the output is consistent with those of other partnerships. However, all variables that are used should have available data, and surrogates should be used to fill in the gaps of knowledge. If surrogates are to be used initially until better data become available, it is important that transfer functions be developed to allow for conversion of information and condition analyses to the new information standards.

It is important that information and condition variables be standardized by systems. We have recommended that condition variables be scaled and scored against the expected range of values for such a system. For example, the authors do not expect a high mountain heavily forested river system to ever have the same productivity as a low elevation agriculture-based river system, and they should not be directly compared with respect to nutrients. However, the systems should be within 25% of the natural variation of a condition variable to be considered healthy, and this scaling can be used regardless of the type of system or its location. A number of tools and models are available to estimate the natural variation in many of the proposed condition variables, and we encourage their use unless empirical data are available, which should be used whenever possible. These include regional water temperature models (Wehrly et al. 2006), universal soil loss models (Foster et al. 2000, 2001), and hydrological analysis tools such as the Index of Hydrologic Alteration (Richter et al. 1996, 1997, 1998).

Two levels of analysis are suggested: 1) at the largest scale; and 2) if detailed data are available, at the lowest possible level of watershed, waterbody, or reach scale. Both of these systems will provide equivalent data at the highest levels and may use slightly different datasets because of the differences in scale for some variables. Appropriately developed transfer functions will allow information to be moved between these scales and properly summed.

We recommend use of all levels for analysis of all major habitat types: large lakes, montane freshwaters, xeric freshwaters and endorheic basins, temperate coastal rivers, temperate upland rivers, and temperate floodplain rivers and wetland complexes (definitions of these major habitat types are found in Appendix 3). The proposed variables would be examined to determine the best fit of indices to a given system. The proposed index set should be used as a long-range goal and, as stated above, we fully expect that many surrogate variables will be used initially, as the data do not exist for some of these variables. We encourage the addition of components and variables at all levels, provided the appropriate documentation is included. By using at least the top two tiers of variables, we expect to see improved consistency between scoring systems used by our partners for project development and evaluation of their individual systems.

We expect that a range of estimates, from professional judgment to exact measurement, are likely to be available for any given component or its elements. It is appropriate to use all available information, as long as the source and reliability of the data for a given variable or index are clearly documented.

Current Availability of Condition Data

Inland. Many of the variables used to calculate the condition of each ecological classification unit are not available nationwide for consistent scales of analysis. Development of many condition variables will need to rely on existing datasets to calculate indices on agreed upon scales, and surrogate variables will need to be used until improved data are available. For example, calculation of the percentage of unfragmented river miles in a system or length of unfragmented reaches in the each classification unit can likely be conducted at the 1:100,000 scale by using the National Hydrography Dataset (NHD) (http://nhd.usgs.gov/index.html) maintained by the USGS and EPA, and the National Inventory of Dams (http://crunch.tec.army.mil/nid/webpages/nid.cfm) maintained by the U.S. Army Corps of Engineers. However, to perform this calculation at smaller scales will require integration of many smaller databases systems and should be a priority for individual partnerships.

Databases containing the proper scale condition indices for use in determining the status of each classification unit, at a consistent national scale, are available for some condition variables. For example, NPDES permit data are widely available within the EPA, as are non-indigenous aquatic species data from the USGS and USFWS. These databases should be incorporated fairly easily into the proposed classification system data and used to determine the condition of each classification unit.

In some instances, no existing databases are available for the calculation of condition indices. Indices such as the location of natural stream channels or the structure of food webs would need further definition and development of tools before they could be incorporated into a database and integrated into an information system. If these variables prove to be critical in determining the status of fish habitat, then additional data acquisition and further development will be needed, and partnerships are encouraged to develop them. Another approach is to use surrogate variables that indirectly measure the same process or impairment and, when the data are available to fully parameterize the variable, use transfer functions to convert the older data.

Finally, model results may be used to fill in data gaps until empirical data become available. To ensure consistency across the country, it is critical that the use of any modeled output be fully documented and that the Science and Data Committee be consulted on its use.

Coastal. When calculating the coastal habitat condition for each classified habitat unit, we recommend using as many of the indices developed for the EPA National Coastal Condition Index Reports (http://www.epa.gov/owow/oceans/nccr/) as possible and working directly with EPA to integrate the data systems into the NFHAP data architecture. Again, we recommend as many of the variables as possible be used in the condition analysis and, as was discussed above for inland systems, fully expect surrogates to be used to fill data gaps.

In many instances the data needed for calculation of the condition indices for marine systems will rely on the same data sources as for inland systems. In these cases, we will simply use one integrated data structure that allows the necessary variables to link inland and coastal systems. For further discussion of these data sources, please see the inland condition data sources paragraphs.

The Heinz Center published an extensive discussion of possible indicators of the condition and uses of freshwater, coastal, and ocean habitats (Heinz Center 2002, updated, in press). Although our goals for reporting the status of fish habitat within ecological classifications are slightly different, the Heinz Center report provides an excellent overview of the types of data that may be available for further analysis and use by the partnerships.

As for inland systems, model results may be used to fill in data gaps until empirical data becomes available. To ensure consistency across the country, it is critical that the use of any modeled output be fully documented, and that the Science and Data Committee be consulted on its use.

Analysis of variables

This stage identifies redundancy among variables to reduce the effective variable set to a more manageable suite. This must be done on a system-by-system basis. For example, if there is a strong negative relationship between the percent urban area in a watershed and the percent agriculture, only one of those variables will be used, and the decision process must be documented.

Standardization of metrics and formulation of the degradation index

This step fulfills two important functions: 1) to remove the influence of different measurement units and widely different value ranges for metric values; and 2) to provide a continuous variable that avoids range gaps that arise when using integer scores. There may be some variables that do not lend themselves to being scored on a continuous basis. All scored variables should be standardized and then can be combined in such a way that they are comparable and will yield overall index values of degradation for each spatial unit examined. Each metric is a percentage with values ranging from 0 to 100. Individual metrics can then be summed, and the overall index adjusted for the number of variables used, such that final index values range from 0 to 100. Portions of this range can then be assigned qualitative labels for reporting purposes (e.g., 1–20 = Very Poor, 41–60 = Fair, 81–100 = Excellent, etc.).

Analysis of index properties

In the above form, the index assigns equal contributions from each metric (thus ensuring a range from 0 to 100). However, the sensitivity of the index to values of any particular metric can be evaluated at this stage. If the influences of any metric conflict and tend to cancel out their effects, they can be replaced by more suitable metrics. In future implementations of this decision support model, unequal weights may be applied to each metric if there are objective indications that it is necessary. To ensure consistency across the country, it is critical that any partnership decisions on weighing variables be fully documented, and that the Science and Data Committee be consulted before they are used

Sensitivity analysis of indices

Sensitivity analyses should be conducted to determine the amount of change required of any particular variable to have a significant effect on habitat condition. The importance of each individual metric to the overall index value can be evaluated and used to help identify the most influential factors affecting habitat condition.

Overall habitat condition score

Initially, an overall habitat condition score will be determined using the average of all of the individual higher-level metrics. Averages are sensitive to the extremes and system processes and aquatic community structure often respond to the extremes, either high or low in measurement. After sufficient scoring has been completed, additional statistical analysis is recommended to ensure that this is the appropriate metric.

Habitat quality will be scored by comparing each classified unit's total condition index with the best currently possible and to the theoretically best possible within the classified unit. This will provide all partners with potential targets (scores) for which to strive.

The best possible habitat conditions will be identified by setting the total rank score of each index to its highest quality value, which might include values beyond the range of any system that can be observed today. There are virtually no aquatic systems that do not show signs of human influence, even in the remote regions of Alaska. The likely potential conditions will be established by adjusting scores to the highest possible quality, given the limitations of anthropogenic influences that cannot, for all practical purposes, be eliminated and the climatic and geological conditions in the classified unit. Present conditions will be based on best available observed data.

To assist in the development of habitat priorities, we propose to use a joint index for each classified unit. The joint index will use habitat scores and a socioeconomic-political index, which is discussed in detail in a later section but is summarized here. The habitat assessment process described above will be used to identify the system process impairments and will be combined with socioeconomic and political variables that account for the “human importance” (i.e., the level of interest) of protecting, restoring, or enhancing a system. This may include, but is not limited to, factors like proximity to human population centers, costs of protection or modification, and likelihood of successful restoration or enhancement. When combined with the habitat assessment index, this should help to classify aquatic systems into those of high or low priority for attention. Thus, an index of *suggested* priorities can be attained using both the system process information and socioeconomic data.

Assumptions

The primary assumption of the habitat index development process is that habitat quality, habitat quantity, and desirable fish community characteristics are linked, and that improvement of habitat (or at least prevention of degradation) can improve or maintain those biotic conditions that are desirable. The overarching assumption is that changes in the large-scale control variables that directly influence local habitat conditions will directly influence the productivity and composition of the fish and aquatic community. We also assume there is a cascading hierarchical organization of habitat conditions that start at the lowest end with a specific impairment that has the ability to change a specific habitat variable, and that the specific impairment will, in turn, have cumulative effects on an entire class of habitat characteristics. The lowest level of our hierarchy is one that stakeholders can design projects that will directly affect the levels above, and ultimately improve, the classified unit’s habitat condition.

As with all assessment and restoration attempts, uncertainties may limit the extent to which predictions can be made. For example, at this time there are insufficient data about relationships between invertebrates and forage fish and vegetation type or water depth, to make accurate predictions regarding benefits (USACE and SFWMD 2004). We strongly recommend that partnerships and other funding agencies focus attention on the development of these habitat-fish relationships to help improve the assessment process.

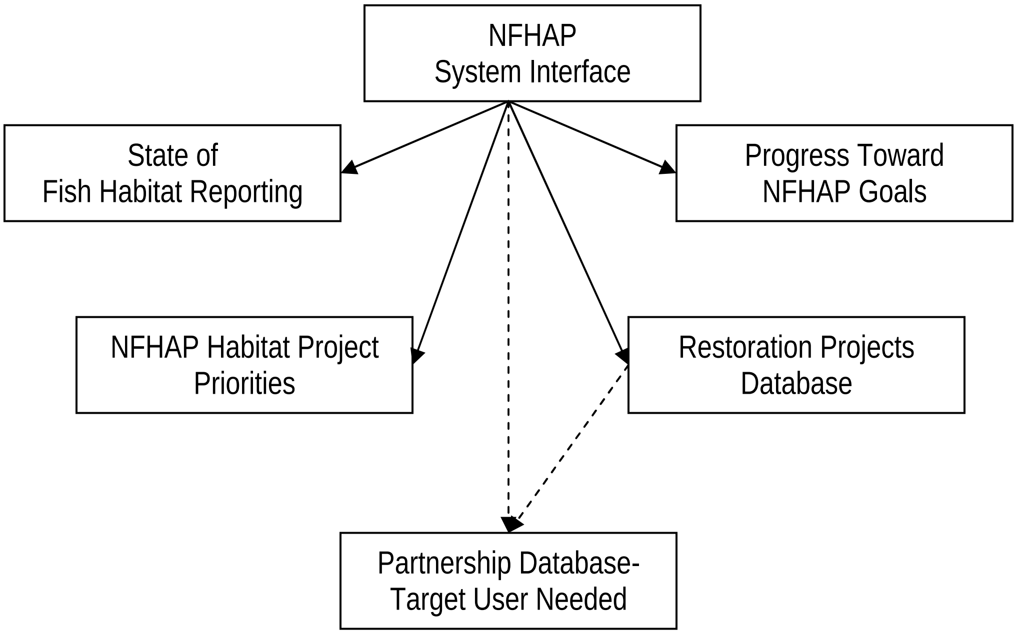
The Data and Information Technology to Make the Action Plan Work

Key Points:

- The NFHAP Decision Support System will consist of four subsystems:
  a. State of Fish Habitat Reporting System
  b. Progress toward NFHAP Goals Tracking System
  c. NFHAP Habitat Projects Priorities Data System
  d. NFHAP Restoration Projects Data System.
- Data to complete the initial development of this system will come from ongoing data projects, primarily those with a national or extensive regional dataset.
- To make this tool useful for aquatic resources managers, a national web-based GIS database will be developed to store conservation and habitat priorities. Conservation priorities would be developed from the individual regional, local, and state-based priorities, as well as from the NFH Board.

The NFHAP data management system will consist of four major information systems (State of Fish Habitat Reporting, Progress toward NFHAP goals, NFHAP Habitat Project Priorities, and Restoration Projects Database) that are accessed through a single ArcIMS© or other open-source GIS geographic interface (Figure 1). Each individual subsystem would serve different needs of the NFHAP and will be developed separately to meet these individual needs. The entire system will not have a single data warehouse, but would be distributed among integrated systems with data that can be combined to meet different needs. Development of such a system will be contingent on the development of partner applications, such as the Multistate Aquatic Resources Information System (MARIS), Streamnet, and other consortia.

Figure 1. Basic Conceptual Model of the NFHAP Data System.



Proposed Approach for State of Fish Habitat Reporting and Progress Toward NFHAP Goals Tracking Systems

Data for assessing the status of fish habitat units within ecoregional classification units and for monitoring progress toward NFHAP goals will come from the same general data sources. Therefore, these systems will be developed using similar approaches and similar data sources. To complete these systems, we will rely on a number of projects that have been funded or will be funded by the USGS National Biological Information Infrastructure (USGS/NBII) program, AFWA Multi-State Conservation Grants program, and other entities that, if properly coordinated, would form the basis of an integrated NFHAP data reporting and progress tracking system. Many of these projects have started collating/collecting data for specific purposes, but by themselves will not be able to address the broad information needs of the NFHAP. Integrating data resulting from at least some of these efforts will result in a better information network that could be used to guide and demonstrate the impact of the NFHAP.

Classification Data - System Architecture

The ecological classification used for freshwater and marine ecoregions form the basic reporting unit for reporting status and tracking progress toward NFHAP goals. These data form the basic backbone of the system and, as such, the national-level ecological classification units are the only dataset that should reside centrally on the NFHAP server. These data will be fixed and delivered through a standard ArcIMS© interface. However, integration of regional and local classification units will be done through web services interactions with local or regional servers.

This approach ensures that the basic national classification units are standard, but allow for smaller scale regional classification units to be integrated into the system.

Inland Waters Condition Data System Architecture

Data to complete the initial development of this system will come from ongoing data projects that reside in three fairly broad groups (note these lists are not inclusive; please see Appendix 5 for list of data sources for each condition variable):

1. **Species-specific or system-specific projects that use indicator species or habitat health as a measure of aquatic ecosystem health**. These projects generally occur at a national or regional scale, and the data collected generally focus on biological parameters. Examples of projects include:
   - Development of an integrated Sturgeon Information System, funded by the USGS/NBII and conducted through Michigan State University.
   - The Eastern Brook Trout Joint Venture, funded through the Multi-State Conservation Grants program, USGS/NBII, and U.S. Fish and Wildlife Service.
   - Numerous smaller scale efforts such as Colorado River Cutthroat Trout project, funded by USGS/NBII.

2. **Watershed-based projects that collect information on a number of different categories, including physical habitat, biological parameters, water quality and quantity, and watershed characteristics**. However, no single regional watershed project will have all the data available to meet the needs of the NFHAP benchmarks of success. We fully expect that groups of variables will be applicable from these sources and increase in utility when combined with external data sources. These projects include:
   - A number of projects funded under the USGS Aquatic GAP program, such as in the Lower Missouri River, Lower Colorado River, Puget Sound, and Great Lakes Drainages. The emphases within these projects are on species presence data, watershed characteristics, and physical habitat. In addition, USGS/NBII is funding projects to collate biological parameter data in the Rio Grande and Delaware River Basins.
   - The Multi-State Aquatic Resources Information System (MARIS) project, funded by numerous agencies and the AFWA Multi-State Conservation Grants program. This provides a system through which quantitative biological and water quality data are shared among several Great Lakes, midwest, and mountain states, and relies on state maintenance and ownership of their data.

3. **National projects that bring together information on status and trends of fish populations and habitats**. Federal fisheries agencies have developed national databases to gauge the total need for restoration or management activities, to prioritize their activities, and to track performance. These databases may focus only on resources where there is a federal role, but they do provide a national-scale indicator of fisheries and aquatic habitat health. Additionally, other very broad based data systems such as FishBase (http://www.fishbase.org/), the NOAA National Status and Trends Program

(www.ccma.nos.noaa.gov), and those held by NatureServe will also provide key datasets for the decision support system.

- FWS has developed a Populations Module in its Fisheries Information System (FIS) to record status and trends, management plans, assessment status, and location for species of federal management concern. In 2005, FWS transformed the FIS to a web-based system with public access of data through the FWS Environmental Conservation Online System (http://ecos.fws.gov).
- The Fish Passage Decision Support System (FPDSS) is an internet-based, geographically referenced comprehensive database of barriers preventing fish movement that is complemented by mapping and modeling analytical tools. The database includes barrier information such as location, type, size, owner, etc., as well as information on associated fish species and local habitat information (http://fpdss.fws.gov). The FPDSS can also be used to locate and manage reservoirs with high fisheries potential.
- The U.S. Army Corps of Engineers has identified and included over 79,000 dams in the National Inventory of Dams (NID) at http://crunch.tec.army.mil/nidpublic/webpages/nid.cfm. Patrick (2005) used the NID database to map all terminal dams for the Atlantic, Pacific, and Gulf coasts, and developed an evaluation tool to assist in the recovery and rebuilding of diadromous fish populations. This database has georeferenced locations for many dams in the coastal system.
- The NOAA Fisheries Toolbox (NFT) at http://nft.nefsc.noaa.gov/ is a suite of biological modeling software programs that can be used in fisheries stock assessments.

The NFHAP decision support tool will facilitate the integration of these projects via web services in into an ArcIMS© information system that should be used for assessments of the success of the plan across large watersheds at the regional and national scales. Note that the current focus of most of these efforts is to provide data accessibility and decision support, not to conduct detailed biological assessments. Although some of these efforts contain the components necessary to conduct basic evaluations of aquatic habitat, additional resources will be needed to build improved tools to evaluate relationships between habitat parameters and fish populations.

Coastal Condition Data System Architecture

Data for performing coastal condition analyses will follow a similar approach as the inland freshwater condition analysis. The marine condition data system architecture will be developed to integrate with existing systems such as the Integrated Ocean Observing System (IOOS) and associated datastreams such as the Global Ocean Observing System (GOOS). In the United States, a national office was established to coordinate development of IOOS, "a system of systems that routinely and continuously provides quality controlled data and information on current and future states of the oceans and Great Lakes from the global scale of ocean basins to local scales of coastal ecosystems" (http://www.ocean.us/what_is_ioos). IOOS is the U.S. contribution to GOOS, "a permanent global system for observations, modeling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions of the sea for as far ahead as possible, and the basis for forecasts of climate change" (http://www.ioc-goos.org/). Each region of the United States has a regional association to oversee and promote IOOS coordination. The Southeast Coastal Ocean Observing Regional Association (SECOORA), among others, is a good example and a source for the process of creating a distributed system via government, academic, and private entities. Other data sources such as NOAA's Regional Ecosystem Data Management portal will be valuable assets in the development of the coastal data system architecture.

Action Plan Habitat Projects Priorities Database

A variety of national, regional, state, and other scales of priority setting have been conducted for aquatic habitat conservation (protection, restoration, and enhancement) from such sources as the State Wildlife Action Plans, State Fish and Wildlife Agency Fisheries/River/Watershed Planning Documents, The Nature Conservancy Ecoregional Conservation Plans, Trout Unlimited Planning Documents, USFWS Endangered Species Recovery and Wildlife Refuge Plans, NOAA-NMFS Coastal Rehabilitation Plans, and USFS Forest Plans, to name a few. These priorities, along with the supporting documentation, evidence, and decision processes, provide extremely valuable information for aquatic habitat planning work. Together they have far-reaching consequences and could increase the efficiency of our partners in protecting and rehabilitating aquatic habitat. It is important that the NFHAP capitalize on these existing planning investments and use them to speed up the delivery of critical habitat protection and rehabilitation on priorities agreed upon by multiple assessments. Unfortunately, little of this information is available to our partners because it is fragmented and often inaccessible. Rolling these disparate priorities and approaches into a consistent national coverage online will greatly improve partnerships' abilities to rapidly provide improvements to our aquatic habitat. Priorities identified by this work may serve as initial starting points from which partners may determine their own priorities and develop active projects.

We recommend that a National GIS Database be established that captures all existing and future conservation and habitat priorities into an easily accessible web-based system. This database should geo-reference all priorities and use the same classification system as discussed in this report to allow for rapid reporting, summarization, and evaluation. The system should provide for a simple web-based data entry method to allow for rapid updates as new planning processes and devices develop additional priorities. The database should be public and provide all associated information and documents for each priority. In the future, information on fine-scale habitat classification, maps, and comprehensive suites of aquatic biodiversity—along with information on condition, threats, current efforts, and links to the NFHAP Project Assessment—should be incorporated into the database.

Habitat Prioritization

We recognize that selecting a small set from the large number of existing priorities, and those identified from the National or Regional Assessments, is a significant challenge. We suggest a two-pronged approach. First, it is our opinion that providing all of the possible and available aquatic conservation and habitat rehabilitation priorities is important as guiding information for our NFHAP projects. This will inform any regional or local partnership interested in identifying a focal project and gathering information to generate support for their work. It is clear that a national listing is also needed that would be accomplished by merging all of the data and defining a suite of 100 national priorities for congressional funding focus.

We propose that national roll-up of information on these priorities proceed by:

1) Aggregating existing priorities and classified unit habitat scores linked to spatial coverages into one centralized database.

2) Obtaining the top 10 geo-referenced conservation/habitat priorities from all of the Nation's Fisheries Agency Chiefs for state and territorial managed waters that are based on state and territory watershed or waterbody planning documents. This step was added to help reduce the potentially thousands of individual state and territorial fisheries and aquatic habitat priorities into a smaller set and to ensure that the public trust responsibilities are properly represented.

3) Obtaining the top 10 geo-referenced conservation/habitat priorities from the Exclusive Economic Zone (EEZ), each tribal reservation, and the Alaska subsistence areas from the appropriate federal agencies and tribal authorities.

4) All priorities should be moved into the NFHAP habitat classification system to create a consistent spatial-unit map of priorities.

5) Two ranking processes should be used: one based on individual key priorities and one based on classified units (e.g., those units having the most priorities). The index for each individual priority would include scores for the number of times it has been identified as a priority, the likely investment return of the priority, the number of groups identifying them as priorities, and whether the state fisheries agency has ranked it as a priority. The index for each classified unit would include scores for the number of priorities in the unit, number of groups involved in identifying them as priorities, the likely total investment return of all priorities, and the number of state fisheries agency priorities in the classified unit.

6) The index would identify the top 100 national priorities by individual conservation/habitat priority and would provide information on which classified units have the most needs. Additional and similar analyses should be conducted to provide priorities by state, region, and ecoregion to assist regional and local partners' project planning.

The use of these existing data and investments will provide our NFHAP partners with many potential habitat project options. There are likely many more projects than there will be available funding, all of which would be considered worthy choices; however, some may not be feasible, and others may be more desirable and cost-effective. To improve the probability of success, we strongly recommend that a final modifier be included that scores projects: 1) higher scores for protecting fully functioning systems and lower scores for re-engineering highly modified systems; and 2) the likely feasibility of project. This last filter will provide some guidance as to which of the options will provide the best return for our aquatic resources, be the most cost-effective, and provide the highest likelihood for success.

Currently, there is no data system that houses conservation priorities. Conservation priorities need to be developed from the individual regional, local, and state-based priorities. This system will integrate data from the State Wildlife Action Plans, joint venture conservation priorities, and other conservation priorities into a centralized data system that will need to be maintained, updated, and housed by a single entity. The habitat projects priorities database will consist of a data entry system (both with batch loading and single entry capabilities) and data reporting interface. Access to projects will initially come through the NFHAP ArcIMS© geographic interface.

Action Plan Habitat Projects Database

One of the efforts of the NFHAP Data Team was to assess fish habitat restoration, rehabilitation, enhancement, and protection efforts across the United States. The state fish and wildlife agencies were surveyed to collect information on fish habitat projects they identified as successful. The data submitted provides project information including factors such as resource issues addressed, methodology, protocols, project plans, and project partners, as well as metrics used to indicate project success. The information will be used to implement the NFHAP by delineating locations of fish habitat restoration projects and highlighting their project objectives and measures of success. Additionally, it provides a test bed to develop the project assessment database that will be critical to future NFHAP efforts. Similar databases already exist (e.g., NOAA's National Estuaries Restoration Inventory and the Mississippi-Alabama Sea Grant Restoration databases) that can be used as models for creating the NFHAP projects database.

The Aquatic Habitat Restoration Information Survey and Database was designed to collect data from state agencies with established databases of project information (see Appendix 7). A submission form was created and distributed to assist other states in submitting project information in a systematic format. The database structure is the foundation from which a web-based searchable interface will be developed. The interface will provide management agencies a reference for information on fish habitat restoration projects, including contacts and links to individual projects. The restoration projects are geo-referenced to enable integration with the ArcIMS© web tool being developed to display the nation's fish habitat assessment and priorities.

Action Plan Data System Functionality

Once complete, the NFHAP decision support and information system would provide the following functionality:

1. **Continued updating and reporting on the state of fish habitat throughout the United States.** Functionality would consist of queries, integration, and data that could be developed to produce the state of the fish habitat report at multiple scales. A query-based interface into the NFHAP ArcIMS© system will allow for ease of access to data and preformatted reports for users. An expert system with more flexibility and functionality

will also be available for those users who have an intimate working knowledge of ArcIMS systems.

Examples of websites created to assist resource managers and researchers query existing research projects are: the Eastern Brook Trout Joint Venture mapping application (http://sain.nbii.org/EBTJV); Calfish information system (http://www.calfish.org/DesktopDefault.aspx); Florida Seagrass Conservation Information system (http://research.myfwc.com/features/category_sub.asp?id=4978); Big Cypress Basin–Estero Bay Regional Research Database (http://ocean.floridamarine.org/bcb/); and the National Estuaries Restoration Inventory Database (NERI) (http://neri.noaa.gov). These are examples of various query tools that allow users to search by agency, region, and subject for conservation efforts.

2. **Continual evaluation of progress toward NFHAP goals.** Progress toward NFHAP goals will rely on the same set of classification and condition data that will be used to report the status of fish habitat. Queries into this system would call on independent data (indicators) that evaluate progress toward these goals.

3. **Viewing NFHAP Habitat Project Priorities**. Conservation priorities will come from multiple sources including a stakeholder survey that could result in three tiered results: 1) national priorities, 2) regional priorities, and 3) local priorities. Data will be accessed and presented from regional priorities developed from national and regional input. Additional prioritization tools and reports will be developed using the methods discussed elsewhere in this report. All of this data will be created through NFHAP efforts and supplied through a searchable website and reports. Clicking on the region type map would then allow analysis to the highest resolution available.

4. **Habitat Projects Database**. As results become available from NFHAP projects, a database will be developed to capture all aspects of the project from funding to administration to evaluation results. Currently, there is a similar project funded by USGS that could be used a template, as well as the previously mentioned NERI and Mississippi-Alabama Sea Grant Restoration databases Initially the database will be a single centralized data system, but eventually it is recommended to use a distributed, integrated approach.

Action Plan System Standards and Integration Issues

The decision support system interface will address the following questions and meet the following conditions:

1. What is the appropriate scale at which the data should be available (and is the system built such that multiple scale data can be observed?)

   The decision support tool should be as flexible as possible without excluding any information. The degree of flexibility depends on time and funding. The shell should be multi-scalable, but leave missing data where data are not available. The first phase should work at one state (at current classification) resolution and the second phase would have multiple scale items.

Providing information at the highest resolution will be required to fully implement the decision support tool. Scaling up to a consistent level should be avoided in the design. It is likely that different regions may have different levels of scale, but care will have to be taken to avoid losing resolution at the national level. The State of Fish Habitat Report can focus at lower resolutions, but the website database should attempt to include data to the highest resolution available within the limits of available storage.

2. What are the necessary data standards that need to be used to get the core data (conditions and classification) integrated?

   Successful implementation of the NFHAP information system will depend on information transfer standards. We can strongly encourage individual partners to incorporate standards into existing data systems, but we recognize that not all key data partners will have the flexibility to change reporting standards. At a minimum we recommend the use of the Integrated Taxonomic Information Systems (ITIS) for taxonomic naming and the use of Federal Geographic Data Committee (FGDC) standards for geospatial identification of data. In addition, the ArcIMS© interface will be built using the standard 1:100,000 National Hydrography Dataset (NHD+).

   However, a number of reporting standards—including descriptions of habitat, water quality, and other key variables—will need to be agreed upon before the transfer tool can be developed. The National Fish Habitat Board should develop such standards in collaboration with the Science and Data Committee and in consultation with the regional partnerships. Once standards are developed, it will be possible to develop a number of web services transfer tools that will mine distributed databases for data that meet users' needs. This transfer tool will be provided in a recommended user format that can be sent out to each data partner.

3. Is it easier to build interfaces between existing species, watershed, and national approaches, or should we start new?

   To find the most efficient way to build the decision support system, we will need to determine the easiest way to access existing information systems and databases. Discussions about how to integrate existing data will require involvement of GIS and database programmers. It is critical to have programmers involved in these recommendations, while being mindful that their input may restrict the effort by tailoring the products to the strengths and experiences of these staff members.

The decision support system will need to identify and list the appropriate web services and GIS tools that will be necessary to properly integrate data from distributed systems. FGDC compliant metadata will be the first necessary step to integrate data from existing sources. The system must be developed to meet not only the needs of the NFHAP, but also the needs of local, regional, and other NFHAP-related activities.

Recommendations

1. The NFHAP Decision Support System should consist of four subsystems:
    a. State of Fish Habitat Reporting System
    b. Progress toward NFHAP Goals Tracking System
    c. NFHAP Habitat Projects Priorities Data System
    d. NFHAP Restoration Projects Data System.

2. A single central query-based geographic interface into the decision support system should be built that will access data/information within each subsystem.

3. A single entity should operate and maintain control over the national interface of the NFHAP system.

4. The ecoregion classification data should be housed and centrally maintained to allow for the national scale reporting and integration of local and regional scale classification data from distributed servers.

5. Data to populate the Decision Support System should come from a number of existing online data systems and providers. Initial system development will depend on willing providers and NFHAP grantees.

6. A standing data subteam should be developed as part of the Board's Science and Data Committee, consisting of representatives from each data provider (see list of condition data for providers) and regional partnerships. Members of the data subteam should have expertise in data structures and user needs.

7. Additionally, professional GIS, web services, and database experts should be assigned to the data subteam in order to fully develop the user requirements and NFHAP system architecture.

8. Key milestones that need to be addressed to allow the system to be fully developed include identifying:

    a. Key data transfer standards
    b. Key web services for integration
    c. Plan for working with distributed providers of data
    d. Scaling issues for initial development
    e. Mechanisms to integrate regional joint partnership information systems

9. A centralized conservation priorities database will need to be developed to provide user access to these data via the geographic Decision Support System interface or through tabular means.

10. Similarly, the habitat projects database will need to be developed to provide user access to project data via the geographic Decision Support System interface, or through tabular means. This data system should be housed and maintained by a single entity.

Prioritization of National Fish Habitat Action Plan Projects

Key points:

- A system to help score priorities for classified units, waters, and projects is needed.
- The prioritization system should use data from the National Fish Habitat Assessment scores, information on the type of intervention, existing priorities, and socioeconomic information.

We recognize that selecting systems and projects from the vast number of existing priorities, and those identified from the National or Partnership Fish Habitat Assessments, is a significant challenge. There are likely many more projects than there will be available funding, all of which would be considered worthy choices; however, some may not feasible, and others may be more desirable and cost effective. We suggest an approach that includes the system/water/project condition scoring, weighting systems/waters/projects by the type of intervention (protection, rehabilitation, or improvement), available priority consideration, and weighting by a set of socioeconomic factors. A scoring matrix using the steps below should provide the needed decision support tool for Board and Partnership prioritization.

We propose that national roll-up of information on these priorities proceed by:

1) Incorporating the National and Partnership Fish Habitat Assessment scores into the prioritization efforts and aggregating available aquatic conservation and fisheries habitat priorities and classified unit habitat assessment scores linked to spatial coverage into one centralized geo-referenced database. There should be a determination of whether the project will focus on the protection of intact systems/waters, rehabilitation of degraded systems/waters, or the improvement of engineered systems/water, with the scoring of projects in that order.

2) Obtaining the top 10 geo-referenced conservation/habitat priorities from all of the nation’s fisheries agency chiefs for state and territorial managed waters that are based on state and territory watershed or waterbody planning documents (i.e., State Wildlife Action Plans). This step will reduce the potentially thousands of individual state and territorial fisheries and aquatic habitat priorities into a smaller set and ensure that the public trust responsibilities are properly represented. A system or water with a large number of listed priorities and interested parties should be given higher priority than one with few listed priorities or partners.

3) Obtaining the top 10 geo-referenced conservation/habitat priorities from the Exclusive Economic Zone (EEZ), each tribal reservation, and the Alaska subsistence areas from the appropriate federal agencies and tribal authorities. This information, along with information from Step 2 above, will inform any regional or local partnerships interested in identifying focal projects and focusing opportunities to generate support for the needed work.

4) Given the differences in scale, two socioeconomic measures should be developed: one based on individual waters, and one based on classified units (e.g., those units that have the most priorities). The index for each individual water or project should include scores for the number of times it has been identified as a priority, the likely investment return of the priority, the number of groups identifying them as priorities, proximity to population centers, and whether it is a top-ranked priority. The index for each classified unit should include scores for the number of priorities in the unit, number of groups involved in identifying them as priorities, the likely total investment return of all priorities, an estimate of the cost-benefit ratio of work on a system or on an individual project, proximity to population centers, the number of top-ranked priorities in the classified unit, and other key factors that may be unique to that system/water.

We envision a potential prioritization scoring system as follows:

> Prioritization Score = (NFH Assessment Score) x (Type of Intervention) x (Classified Unit or Water or Project Priority Score/Total Number of Priorities) x (Socioeconomic Index)

where the type of intervention is scored in a simple linear scale with a score of 3 given to protection efforts, a score of 2 given to efforts to rehabilitate systems or waters, and 1 to efforts to improve engineered systems; and the socioeconomic index uses the following equation:

> Socioeconomic Index = (Probability of success) x (Estimated cost:benefit ratio) x (Distance to population centers score) x (Other key factors)

The use of these existing data and investments will provide our NFHAP partners with many potential habitat project options. To further narrow these options for decision-makers, we recommend developing a list of the top 100 priorities by classified units, individual waters, and, ultimately, projects for both the nation and for each partnership. Additional and similar analyses should be conducted to provide priorities by state, region, congressional district, federal lands, and ecoregions to assist regional and local partners' project planning.

The Evaluation of National Fish Habitat Action Plan Projects

Key Points:

- Many agencies and organizations have put significant financial resources toward conservation activities, but very little monitoring has occurred to measure the long-term success of individual projects or the collective conservation success on a regional or national scale.
- The Science and Data Committee will develop a fish habitat condition report for the nation every five years, to measure progress toward NFHAP goals.
- The NFHAP activities should be evaluated at three scales: 1) the local project level; 2) the regional Fish Habitat Partnership level; and 3) the National Fish Habitat Board level.
- Conducting these evaluations provides the opportunity for adaptive management on multiple scales.

There are many river "improvement" projects in the United States that have collectively straightened, dredged, re-routed, landscaped, and covered hundreds of miles of river bank in synthetic products, very often under the banner of river restoration (Leopold 1994). But more often than not, these physical alterations conflict with natural geomorphologic processes and are at best temporary cosmetic changes to rivers; at worst, they do more harm than good (Leopold 1994).

Unfortunately, many restoration projects have failed to produce sufficient evidence that they have restored "normal function" of the lost aquatic habitat. Since 1990, it is conservatively estimated that $14 to $15 billion has been spent on restoration of streams and rivers in the United States, with an average cost of over $1 billion per year (Bernhardt et al. 2005). Evaluating the cumulative effect of this spending has been nearly impossible, as only 10% of project records indicated that any form of assessment or monitoring occurred (Bernhardt et al. 2005). Learning from these programs, it is essential to ensure that existing high-quality habitats do not become further degraded, and careful evaluation mechanisms need to be in place for future habitat restoration activities.

Defining Success

Truly successful fish habitat projects should not focus on individual rock-log and riprap projects. They should tackle problems from a system and process perspective and incorporate landscape and policy-level approaches to conservation and rehabilitation. For example, if lack of woody debris is identified as a limiting factor in a stream, rather than throwing individual bundles of wood into the river to be washed away during the next high-flow period, an action should be identified to provide a long-term solution—such as restoration and protection of riparian forests, which produce woody debris, higher up in the catchment. Appendix 7 is a table drawn up from the analysis of 138 state river-restoration projects and shows a variety of completed activities. Each activity is ranked in its importance to sustainable, landscape-level fish-habitat, with 1 being the most important and 3 being the least important. More than half of the activities undertaken were ranked 3. This analysis illustrates a difficult lesson that must be learned and shared widely. We simply cannot afford to continue pouring limited resources into activities that will not have long-term, large-scale, and self-sustaining biologically meaningful results for the nation's aquatic life. Moving forward with the NFHAP will require stringent quality-control checks by panels of regional experts working at a systems and process scale with clear criteria to reduce the likelihood of funding projects that will not meet these criteria.

Measuring Success

Many reactive spending programs in the United States have funneled financial resources toward important aquatic problems, but when it comes to analyzing our progress little work has been done to measure the collective conservation impact beyond the scale of individual projects. Since 1990, we have poured $14 to $15 billion into river restoration projects in the United States, but there is only piecemeal information available on the performance of these projects, making a comprehensive assessment of progress at a national or even regional level virtually impossible (Bernhardt 2005). In a database of 3,700 river restoration projects, only 10% indicated that any form of assessment or monitoring took place (Bernhardt 2005). In a separate analysis of 138 fish-habitat projects undertaken by various state agencies, 44% had defined success standards prior to implementation and 34% attained those standards as shown in Appendix 7.

One of the key activities of the NFHAP will be to establish a system of evaluation that measures conservation success at regional and national scales. One suggested approach has been to emulate the National Waterfowl Management Plan, which defined specific species and habitat targets in relation to clearly defined baselines (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2004). However, fish populations cannot be assessed in the same way as waterfowl because most are r-selected[*] organisms and their populations fluctuate greatly from year to year, making fish abundance a less meaningful indicator than bird numbers. In order to define a clear baseline against which to measure change, the Science and Data Committee recommends using the National Fish Habitat Assessment for the nation, which will be an invaluable tool to measure progress at any scale and an important product of the NFHAP.

If changes in fish habitat condition are clearly measurable over the next 10 years, this will be reflected in the State of the Nation's Fish Habitat Assessment report, but it will be difficult to specifically identify which changes occurring at a national level were directly attributable to the National Fish Habitat Action Plan and which were caused by other large-scale efforts. Thus, a second more specific analysis of individual projects will be required. This meta-analysis should assess: 1) the effectiveness of individual projects in relation to clearly defined goals; 2) the cumulative effects of individual projects at various scales, including partnership and national levels; and 3) the lessons learned and how they were used to inform conservation actions elsewhere.

Evaluation Measures

Many different, but broadly similar, evaluation approaches are taken by different conservation groups (Stem et al. 2005). The basic principles of evaluation are described below. The details of the particular prescriptive framework will be determined by the Science and Data Committee.

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[*] Typically have many small offspring, fast rates of population growth, and relatively short generations (e.g., bacteria, some insects, and plants, e.g., dandelions) (Raven and Johnson 1992).

1) Effectiveness – The key to measuring effectiveness is to set clearly defined and measurable goals before starting any activities. This may seem obvious to most people, but it is a step that has been omitted in about half of all state-run fish habitat projects examined by Ostroff (USGS unpublished data). If goals are clearly and quantifiably established in advance, then the actual performance can be qualitatively assessed and scored based on how effective the actions were at achieving the original goals (e.g., 1 = unsatisfactory, 2 = less than satisfactory, 3 = satisfactory, 4 = more than satisfactory, 5 = exceeded expectations). All projects under the NFHAP should be evaluated on this kind of scale. This is a consistent performance measure of the "bang for the conservation buck" that could be scaled up to a national level across a diverse range of project types, assuming that project activities lead to meaningful positive biological responses or to important lessons learned.

Another possible approach is to generate actual cost/benefit estimates of monetary improvements in fisheries accruing from the investments in fish habitat, but currently this approach is unlikely to have sufficient data. If this approach is taken, a similar scale could be developed as discussed in the previous paragraph.

2) Cumulative Effects – The sheer scope of different activities and indicators that could potentially fall under the banner of the NFHAP is overwhelming, and the types of conservation interventions will vary widely from place to place. Thus, identifying a limited set of universal biological indicators that should be measured at the national level is a particularly challenging task. This is further compounded by the fact that many projects measure their success using goals or indicators that are biologically meaningless (e.g., number of volunteers assisting with a culvert removal, amount of money invested in a particular activity). Nonetheless, it will be important for the NFHAP to quantitatively assess its progress toward the national goal. Thus, a limited set of indicators could be selected, using the input of the regional experts and, upon completion, each project should report progress towards these goals (if any) so the information can be incorporated into a national meta-analysis.

The first set of indicators relate to the first three goals of the NFHAP. The first indicator should quantify the amount of habitat protected or restored and should always be expressed as a percentage of the National total to give an indication of the scale. The second set of indicators should be the percent change in the overall National Fish Habitat condition scores that results from the actions taken. This change can be documented at any relevant scale. The third set of indicators should be species-focused and related to the final two goals of the NFHAP. Individual project managers would identify individual fish species targeted for conservation actions, and express the population(s) they are working with as an approximate percentage of its natural range. The projects should identify simple, directional population changes (increasing/stable/decreasing) in relation to a predefined baseline.

3) Lessons Learned – A wealth of high-quality, peer-reviewed information has been published on the costs and benefits of various conservation activities. It is critical that all decisions and actions undertaken by the NFHAP are informed by the best available information, and that lessons learned are widely disseminated. This can be done by encouraging the publication of results in peer-reviewed journals, facilitating seminars and conferences, and commissioning meta-analyses of multiple small-scale projects to shed light on best practices.

There is also a need to identify what is known and not known regarding the successes and failures of various conservation activities, as well as their uncertainties. This will allow well-informed decisions regarding possible restoration and/or monitoring projects, and avoid repeating mistakes.

Scaling Issues

The NFHAP Core Workgroup has been mindful that fish habitats in the United States are extremely heterogeneous, ranging from the xeric springs and rivers of the Sonoran Desert to the salt marsh ecosystems on the East Coast and the Arctic islands, representing the most northerly extent of freshwater in North America (Abell et al. 2000). Recognizing that each distinctive geographical area has its own unique set of threats and the need for a comprehensive national approach to the issue, a set of broad National Goals were established in the NFHAP that should guide partnerships. Partnerships are geographically or species-focused groups involving many stakeholders, and are the equivalent of "Joint Ventures" of the National Waterfowl Management Plan. They conduct threats analyses, develop regional measurement protocols in consultation with the National Board, and establish local priorities in consultation with a wide array of stakeholders that fit broadly into the overall goals of the NFHAP. A pilot example of a partnership is currently being implemented and is known as the South East Aquatic Resources Partnership (SARP) http://www.sarpaquatic.org/. Thus the system has three distinct scales around which priorities and strategies are developed: projects, partnerships, and the National Fish Habitat Board. The system is flexible enough to allow for other scales, ranging from each classified unit of water to congressional or political boundaries that may be of interest to specific partners within a partnership; however, the three-level scale should be required for evaluation.

Evaluation Implementation

The NFHAP should be implemented at three distinct scales: 1) the Project level that conducts the actual habitat activities, 2) the Partnership level that establishes regional-scale priorities; and 3) the National level that establishes national priorities. We strongly recommend that each of these organizations have clear roles and responsibilities within the monitoring and evaluation framework, as follows:

1) *Project Level*
    a. Define project goals within the framework of regional partnerships and the NFHAP after conducting specific threats analyses.
    b. Identify appropriate, quantifiable indicators that link activities to meaningful biological and fish habitat responses (short-term and long-term) that can be related to Fish Habitat Assessment scoring.
    c. Measure baseline information to gauge biological responses.
    d. Monitor progress towards goal and adaptive management to ensure that goals are achieved.
    e. Conduct post-project evaluation to assess success in relation to original goals, determining changes in Fish Habitat Assessment scores, and feeding data and reports up to the partnership level.

2) *Partnership Level*
    a. Establish priorities and goals after conducting threats, situational, and viability analyses.
    b. Maintain database for tracking projects and goals in relation to the regional or partnership plan.
    c. Ensure peer-review of individual project proposals and provide quality control to include a recommendation letter to funding agencies.
    d. Provide quality control with final evaluation that assesses the grantees self-assessment of progress to initial goals.
    e. Ensure the availability of post-project evaluation information and deliver such data to the National Board.
    f. Ensure all data can be assimilated into the National Fish Habitat Assessment.
    g. Compile evaluation, lessons learned, and best practices; conduct a regional meta-analysis of the project portfolio; and deliver results up to the National Board.

3) *National Board Level*
    a. Establish national goals, scope, and targets.
    b. Broadly oversee grant-making from appropriations.
    c. Issue guidelines for the establishment and formalization of regional partnerships.
    d. Ensure development and implementation of national database and tracking system.
    e. Coordinate regional partnerships and ensure compatibility of project tracking databases, terminology, and evaluation metrics among all partnerships.
    f. Coordinate and synthesize evaluation at a national level.
    g. Disseminate lessons learned and best practices and commission third-party evaluations of activities when required.
    h. Produce an independent State of the Nation's Fish Habitat report to verify and track progress toward national goals.
    i. Learn from results and respond appropriately to improve operations.

Evaluation – A tool to improvement

Many resource mangers are struggling to determine the best methods to achieve improvements in fish habitat and to measure conservation success in order to justify the investment of hundreds of millions of dollars in conservation funds around the world. But the ability to measure conservation impact has not greatly improved (Parrish et al. 2003). A wide range of approaches with different mechanisms achieve the basic principles outlined here, and a number of useful online resources are available to provide guidance to a wide range of audiences. Regardless of the method ultimately employed, the systematic implementation of monitoring and evaluation is a tool that can help focus actions to directly mitigate threats, increase the efficiency and value of investments, and assess progress at large scales. Application of monitoring and evaluation at multiple levels will provide us with an unprecedented glimpse of the collective effects of our conservation actions, and is a crucial learning opportunity to refine and improve our understanding of how to effectively measure conservation success at many different scales.

We strongly recommend that the National Fish Habitat Assessment classification system be used to compare systems that are similar to each other and learn from the lessons of others as the information becomes available. The classification system recommended in this document may be analyzed in almost unlimited ways. Initially, we recommend some simple horizontal classifications for comparisons be set up to allow for lessons learned to be transferred based on water size. For example, streams and rivers can be classified as follows:

- Headwaters: $\leq 10\ km^2$
- Creeks: $10 \sim 100\ km^2$
- Small Rivers: $100 \sim 1,000\ km^2$
- Medium Rivers: $1,000 \sim 10,000\ km^2$
- Large Rivers: $10,000 \sim 25,000\ km^2$
- Great Rivers: $> 25,000\ km^2$

Size and location in the watershed are important characteristics that control the available physical energy of the systems. Similar initial systems should be developed for lakes and coastal systems. As stated above, the potential number of horizontal comparison classifications is huge, and will depend on the question of interest. But size is a good starting place. The overall intent of this effort is to allow for knowledge transfer among all partnerships participating in the NFHAP.

Initiative Science Schedule

To fully implement the National Fish Habitat Assessment and NFHAP supporting databases, a phased approach should be taken to ensure sufficient development and testing of each module of the system. The following schedule should be considered for the NFHAP:

1. October 2008
    a. Deliverable
        i. Prototype system to include classification system and base condition factor database
    b. Systems
        i. Rivers and streams – Continental US

2. December 2008
    a. Deliverable
        i. Complete testing of prototype system
        ii. Include all possible condition factors into database
    b. Systems
        i. Rivers and streams – Continental US

3. September 2009
    a. Deliverable
        i. Incorporation of additional systems and geographic areas into assessment
    b. Systems
        i. Rivers and Streams – Alaska and Hawaii
        ii. Lakes – Continental US
        iii. Inshore coastal waters – Continental US

4. March 2010
    a. Deliverable
        i. Extent system to all possible habitats
    b. Systems
        i. Lakes – Alaska
        ii. Inshore coastal waters – Alaska and Hawaii

5. July 2010
    a. Deliverable
        i. Prototype National Fish Habitat Assessment

6. October 2010
    a. Deliverable
        i. First National Fish Habitat Assessment

7. September 2015
    a. Deliverable
        i. Second National Fish Habitat Assessment

The National Fish Habitat Priorities and Project Database should consider the following schedule:

1. June 2009
    a. Deliverable
        i. Database design completed

2. September 2009
    b. Deliverable
        i. Prototype database completed
        ii. Begin database testing

3. February 2010
    c. Deliverable
        i. Complete testing
        ii. Implement web-based system for partner use

3. October 2010
    a. Deliverable
        i. NFHAP Project Report

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Appendices

Appendix 1 - How much is affected based on current information?

Regional Coastal Comparison using the National Coastal Condition Report II and the National Estuarine Eutrophication Assessment

A number of national and regional assessments were reviewed to determine the condition of fisheries habitat in the United States. Where information was available to define the condition in reference to a desired state, percentage scores were calculated (with 100% representing the desired condition) in order to summarize and compare between broad-scale regions identified by such reports as the National Coastal Condition Report II (NCCR II; U.S. EPA 2004), the National Estuarine Eutrophication Assessment (NEEA; Bricker et al 1999), and the State of the Nation's Ecosystems (Heinz Center 2002). In reviewing a variety of reports, there were many instances where there were conditions without an indicator of the ideal state, and these values were not included in the analysis. Overall percentage scores were compared to the NCCR II and the NEEA values since they represented the most comprehensive, scored assessment available (Table 1). In the assessments analyzed, only two regions (West Coast and Northeast U.S.) were found to have a significant number of indicators to compare with the NCCR II assessment – these were the West Coast and the Northeast United States.

Table 1. Summary and Comparison of Habitat Condition Assessments by Region (all applicable scores from each report have been converted to a 100-point scale for comparibility)

Region of U.S.	NCCR II Condition Scores	NEEA Condition Scores	Mean of Other Reported Condition Scores	Variance of Other Reported Conditions Scores	Number of Sample Indicators Evaluated by Other Reports
Northeast	36	65	45	4	151
Southeast	76	45	53	(too few samples)	6
Puerto Rico	34	-	10	(too few samples)	1
Gulf of Mexico	48	84	42	(too few samples)	3
West Coast	40	68	63	8	84
Great Lakes	44	-	40	(too few samples)	2
Alaska/Hawai'i	-	-	50	(too few samples)	2
National	46	33	51	6	26

While the Heinz Center (2002) report (hereafter referred to as the Heinz report) has suites of indicators, they are often "snapshot" views of the current condition of the system and the report generally does not try to assess the condition in terms of a desired state. Additionally, the Heinz report describes conditions based on ecosystem types as opposed to regions. There were a few inland indicators that the Heinz report possessed, which are discussed below, while the NCCR II focused on the coastal ecosystems.

Wetland and Other Physical Habitats Losses/Open Water Gain -

According to the Heinz report and the U.S. Fish and Wildlife Service's Wetland Status and Trends program, wetlands in the lower 48 states declined from approximately 210 million acres in 1780 to approximately 108 million acres in 2004. Conversely, pond, lake (excluding the Great Lakes), and reservoir acreage has increased from17 to 21 million acres between the1950s and the mid 1990s. The following summary findings are from "Status and Trends of Wetlands in the Conterminous United States 1998 – 2004" (Dahl 2006) and a new study summarized in "Coastal Wetlands of the Eastern United States: Status and Trends from 1998 to 2004" (Stedman and Dahl, 2008).

- In 2004, there were an estimated 107.7 million acres of wetlands in the conterminous United States. Of this total, 95 percent were freshwater wetlands and five percent were saltwater wetlands. Approximately 38 percent were in the coastal watersheds of the Atlantic Ocean, Gulf of Mexico, and Great Lakes.

- Between 1998 and 2004, wetland acreage increased by an annual average of 32,000 acres nationally. In contrast, the coastal watersheds of the eastern U.S. lost approximately 60,000 acres annually during that same time period.

- Freshwater vegetated wetlands continued to decline, while freshwater ponds continued to increase by nearly 13% in the last decade. Trends indicate that the acreage of ponds is now about equal to that of all estuarine wetlands.

- Estuarine emergent wetlands continued to decline, losing almost 65,000 acres between 1998 and 2004. Most of these wetlands were lost to deepwater habitats through erosion, inundation, or other processes. The loss was greatest in the mid-Atlantic region.

- The analysis during this study period attributed causes of wetland losses nationally to: Urban Development (30%), Agriculture (26%), Silviculture (23%), and Rural Development (21%). For the coastal watersheds of the eastern U.S. the causes were more heavily weighted toward development (71 %) and loss to deepwater habitats (25%). Only 3% of the loss was due to agriculture.

Recent loss in wetlands is concentrated in coastal areas, where development is affecting the freshwater wetlands in the upper parts of the coastal watersheds. For the Gulf Coast, it was estimated that the loss of mangroves were 5-10% from 1957-2004, which was attributed to commercial and residential development (NOAA 2005). From this same report and over the same entire historic time period investigated (1937-57 to 2004), aquatic beds lost 5-10%, and oyster reefs in the Mid Atlantic lost up to 5% of their area due to heavy port and harbor development. Over the last 10 to 15 years, it was postulated that increased regulatory oversight in these open-water areas has lead to an overall reduction in loss for these habitats, but the results of the 1998-2004 study (Stedman and Dahl, 2008) show that wetland loss in coastal areas is still occurring at an alarming rate.

As detailed in the Heinz report, EPA performed an analysis integrating the National Hydrologic Dataset and their own National Land Cover Dataset to determine that 77% of the riparian areas (defined as 100 feet from river/stream edge) in the lower 48 states was in an "unaltered" state. This state is more accurately defined as non-agricultural and non-urban riparian areas, since it is likely that some alteration of the shoreline may have taken place in the past. In a NOAA (2005) report looking at the *coastal* shoreline, it was estimated that there had been a 3-8% loss of natural (non-armored) shorelines. There was an estimated loss of 7-32% of natural shorelines between 1938 and 2004, with the Pacific Coast dramatically losing an estimated 22-60%, most likely due to increased waterfront development.

In addition, the Heinz report outlined some benthic community indicators from the EPA's Environmental Monitoring and Assessment Program for estuaries occurring in the Mid Atlantic, South Atlantic, and Gulf of Mexico. From these regions, the percent of estuarine bottom area that was un-degraded was roughly 65, 70, and 47 respectively. For sediment contamination combined over these three regions, only 40% of these estuary areas had no exceedances of any sediment contaminant guideline.

Assumptions and Problems with Working with These Reports -

There is a great deal of difficulty in attempting to summarize aquatic habitat condition based on the available reports. Regional reports are often snapshots of conditions, due to the time and cost of setting up a monitoring program that would allow the tracking of condition compared to an ideal state. Values are collected on what parameters are a regional priority or generally attainable. A great deal of water quality data are available, and these data are the suite of parameters that are most commonly compared between regions or assessed nationally. However, water quality data do not consistently correlate to the overall habitat quality. Additionally, most habitat parameters will vary greatly within a region, such that the better and worse areas cancel each others' effects when assessed over larger geographic scales. Determining the effective habitat condition may require a focus on temporally important windows in critical habitats that have the greatest impact on populations. While many national condition assessments may be ecosystem based, in some cases, there may have to be species-specific assessments of condition (e.g. species that are flow and/or temperature sensitive).

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Appendix 2 – Ecoregions and Nested Zoogeographic Units

General Ecoregion Definition: There are many definitions of ecoregions. However, they all combine patterns of climate, landforms and biota to delineate and organize them at multiple scales. For this report, we are defining an ecoregion as a large area of land or water containing a distinct assemblage of natural communities and species, whose boundaries approximate the original extent of natural communities before major land use change. These communities share most of their species, dynamics and environmental conditions and function together effectively as a conservation unit (Dinerstein et al. 1995).

More specifically, freshwater ecoregions are part of a hierarchy of aquatic zoogeographic units (in some parts of the world this hierarchical classification is further developed than others). The highest level of organization is the biogeographical realm (ie, Neotropical, Nearctic, Afrotropical, Palearctic, Indo-Malay, Austral-Asia, Oceania, and Antarctic), defined as *continental or subcontinental-sized areas* having unifying features of geography and fauna/flora/vegetation (Udvardy 1975).

The Coastal and Marine Ecological Classification Standard (CMECS) also utilizes ecoregions to define large areas of the coasts and oceans that are relatively homogeneous with regard to physical and biological variables and reflect ecological boundaries determined by climate (temperate, tropical, polar), physical structure, such as major currents or ocean basins, and the characteristics of the biological associations, such as isolation or endemism. Spalding et al. (2007) recently published an article defining marine ecoregions for the world based on extensive literature review and workshops. CMECS will adopt these ecoregions.

The next level in the hierarchy is the subzone. Subzones are subcontinental zoogeographic strata with unique aquatic communities, created in large part by plate tectonics and mountain building. Subzones typically cover *millions of square kilometers*. Broad patterns of fish communities and unique aquatic communities define subzones (e.g., the Pacific, Arctic-Atlantic, and Mexican Transition subzones cover North America) (Maxwell et al. 1995).

Bioregions are the next level of organization and portray refinements of fish distributions resulting from changes in routes of dispersal and isolation within subzones caused by geoclimatic factors. Barriers to dispersal caused by glaciers, or changes in flow patterns caused by uplift after and subsidiary to that separating subzones, are the major agents for this delineation. Bioregions typically cover *hundreds of thousands of square kilometers*. Patterns of unique communities, endemism, and dispersal within fish families define bioregions (there are 11 of these in Africa and 10 in North America) (Abell et al. 2000; Maxwell et al. 1995; Thieme et al. 2005).

Historic mixing and isolation of stream faunas within bioregions have created the patterns that define freshwater ecoregions, which occupy the next level of organization. Freshwater ecoregions comprise the drainage basins containing shared species assemblages. The freshwater fish fauna within each ecoregion shows some common ancestry to other ecoregions within the same bioregion, and ecoregions within a bioregion will normally share some species.

Ecoregions typically, though not always, maintain hydrographic integrity (i.e., follow drainage divides) and cover *tens of thousands to hundreds of thousands of square kilometers*. Basins may be split between two or more ecoregions where distinct biogeographic breaks occur. Systems that harbor paleoendemics (basal clades) rather than neoendemics (recent derivatives) are distinguished as separate ecoregions.

Although ecoregions are intended to represent broad biogeographic patterns rather than localized endemism, they provide the potential for several levels of subdivision to capture finer patterns (Higgins et al. 2005). Biodiversity hot-spots, such as small lakes with numerous endemic species, may be highlighted at lower levels of organization than ecoregions.

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Appendix 3. Major Habitat Types (MHTs) of Freshwater Ecoregions

Following are the descriptions of the MHTs that occur in the United States:

1. Large Lakes are freshwater ecoregions that are dominated and defined by large lentic systems. Freshwater ecosystems in these ecoregions may include in-flowing and out-flowing rivers and various peripheral wetlands in addition to the lakes themselves. This MHT includes large tropical, temperate, and polar lakes. In the United States, the Laurentian Great Lakes are components of this MHT.

2.. *Montane Freshwaters* are freshwater ecoregions comprising small streams, rivers, lakes or wetlands at higher elevations, regardless of latitude. These ecoregions include either high gradient, relatively shallow, fast-flowing streams, with rapids or complexes of high-altitude wetlands and lakes, and montane climatic conditions.

3. Xeric Freshwaters and Endorheic (Closed) Basins are freshwater ecoregions dominated by endorheic aquatic systems or freshwaters that are found in arid, semi-arid, or dry sub-humid environments. These ecosystems tend to have specific fauna adapted to ephemeral and intermittent flooding regimes or lower waters levels during certain times of the year. An example in the US is the Death Valley ecoregion.

4. Temperate Coastal Rivers are freshwater ecoregions dominated by several small to medium coastal basins in mid-latitudes (temperate). These ecoregions are characterized by riverine ecosystems, but may also contain small lakes, coastal lagoons, and other wetlands. Migratory species that spend part of their life cycles within marine environments may inhabit these ecoregions. Although floodplains may occur along rivers within this MHT, the dominant features are numerous, small to medium-sized basins that drain to the ocean, instead of one large river predominating with an extensive fringing floodplain. This MHT also encompasses island ecoregions with these characteristics. Examples in the US include the North Pacific Coastal and South Atlantic ecoregions.

5. Temperate Upland Rivers are freshwater ecoregions that are dominated and defined by mid-latitude non-floodplain rivers, including headwater drainages and tributaries of large river systems. These rivers are characterized by moderate gradients and the absence of a cyclically flooded, fringing floodplain. Examples in the US include the Ozark Highlands and Ouachita Highlands.

6. Temperate Floodplain Rivers and Wetland Complexes are freshwater ecoregions that are dominated by a single mid-latitude large river system, including the main stem river drainage and associated sub-basins, which are either currently or were historically characterized by a cyclically flooded, fringing floodplain. These ecoregions may also contain wetland complexes composed of internal deltas, marshes, and/or swamps, associated with the main river system. Examples include the Mississippi and Middle Missouri Rivers.

7. Polar Freshwaters are freshwater ecoregions comprising entire drainages; from the headwaters to mouth, and found in high latitudes. Examples in the US include theYukon in Alaska.

Appendix 4 – Inland Condition Variable Matrix

See separate file attachment.

Appendix 5 – Data Sources for Inland Condition Variables

Process	Data Need	Data Source	Scale	Easy of Use	Data Location
Connectivity	Fragmentation	National Hydrography Data	National, 1-100K National Water Layer	Both variables could be calculated from existing datasets with relative ease at the 1-100K scale. Smaller scale calculations would rely on numerous regional databases and would take significant time to implement	http://nhd.usgs.gov/data.html
Connectivity	Fragmentation	Fish Passage Decision Support System	National, but not all areas		crunch.tec.army.mil/nid/webpages/nid.cfm
Connectivity	Fragmentation	National Inventory of Dams	National, but higher level scale		http://fpdss.fws.gov/index.jsp
Connectivity	Fragmentation	CA Passage Assessment Database (PAD)	California		http://www.calfish.org/downloads/PAD_Metadata.htm
Connectivity	Fragmentation	Interagency Restoration Database	Pacific Northwest		http://www.reo.gov/restoration/
Connectivity	Fragmentation	National River Restoration Science Synthesis	National, but not all areas		http://nrrss.nbii.gov/
Hydrology	Daily Hydrograph	USGS Gauging Station Data	National, but localized	Hydrograph variables would be hard to calculate consistently across a similar scale. Although the data is avaiable nationally, it is come from highly localized gauging stations and would be hard to scale properly. Analysis would need to be developed using TNC Index of Hydrologic Alteration	http://waterdata.usgs.gov/nwis

Hydrology	Annual Hydrograph	USGS Gauging Station Data	National, but localized	Hydrograph variables would be hard to calculate consistently across a similar scale. Although the data is avaiable nationally, it is come from highly localized gauging stations and would be hard to scale properly. Analysis would need to be developed using TNC Index of Hydrologic Alteration and many watershed will be analysed as part of TNC national analysis.	http://waterdata.usgs.gov/nwis
Channel and Bottom Form	Channel Modification			Generally not available within any databases, could be calculated (possibly) from NHD data if a proper algorithm could be developed. Lakes and many river systems have bottom contour data available.	
Channel and Bottom Form and Material Recruitment	Woody Debris	USGS GAP	National	No national database for these variables exists. It may be possible to calculate these indices from existing sources, however it would be time consuming and likely not be possible nationwide.	http://www.gap.uidaho.edu/
Channel and Bottom Form	Wetlands	National Wetlands Inventory	National		http://www.fws.gov/nwi/
Channel and Bottom Form	Channel Configuration	USGS EROS Data Center	National		http://edc.usgs.gov/geodata/
Water Quality	Mining	USGS Mineral Resources Spatial Data	National, where USGS regulates	The location of mines in the United States actively monitored by USGS is readily available online. This could be easily used as an indicator, however determing impairment length would be more difficult and would be dependend on flow models and the NHD.	http://mrdata.usgs.gov/

Water Quality and Material Recruitment	Non-Point Source Pollution	EPA 303(d) List	National	Data for designation of EPA 303(d) lists are readily available and use the NHD for river reach identification. Would be easy to integrate data into system.	http://www.epa.gov/waters/data/downloads.html
Water Quality	NPDES Sources	EPA NPDES regulated facilities	National	Location of active NPDES permits managed by EPA is readily available through an enviromapper interface. NPDES permit data appears to be mapped to the 1-100K Hydro layer. Determing the effect of these discharges does not appear to be readily available, but could be calculated from flow models and the NHD.	http://www.epa.gov/enviro/index_java.html
Water Quality	Fish Consumption Advisories	EPA National Listing of Fish Advisories	National	Data is available nationally for fish consumption warnings, based on state and federal consumption data.	http://epa.gov/waterscience/fish/advisories/
Energy Flow	Native Fish and Mussel Communities			Numerous data systems with locations and distribution of fish and mussel across multiple scales exist for possible use. However, they are not integrated into one usuable format for completion of national level analyses. Preliminary analyses would have to occur around regions in which data sharing consortium have completed. It would take some effort to integrate the numerous regional and national databases to generate coherent ecoregional scale fish and mussel distributions.	
Energy Flow	Native Fish and Mussel	NatureServe	National		http://www.natureserve.org/explorer/

	Communities				
Energy Flow	Native Fish Communites	US Fish Explorer	National by 8 digit HUCS		http://far.nbii.gov/
Energy Flow	Native Fish and Mussel Communities	MARIS	Upper Midwest States & Wyoming		http://www.gis.uiuc.edu/maris/
Energy Flow	Native Fish Communites	StreamNet	Pacific Northwest States		http://www.streamnet.org/
Energy Flow	Native Fish and Mussel Communities	CalFish	California		http://www.calfish.org/DesktopDefault.aspx
Energy Flow	Energy Web			Fish trophic structure could be potentially calculated from the type of databases mentioned above, however it would be dependent on definitions of the energy web.	
Energy Flow	Aquatic Nuisance Species	USGS Nonindigenous Aquatic Species	National	Non-indigneous aquatic species locations are available at a variety of different scales and can be easily integrated into a system.	http://nas.er.usgs.gov/

Appendix 6 – Coastal Condition Variable Matrix and Data Sources

Appendix 6 proposes a set of twenty indicator variables which may be useful in assessing coastal (estuarine and marine) fish habitat on a National scale. This list is based on several preceding efforts, and narrowed further by applying selective criteria. As a starting point, we used a set of common regional indicator variables developed by NOAA's Ecosystem Goal Team (NOAA/EGT 2006), taking into account pre-existing efforts by EPA's National Coastal Condition Reports (EPA 2001, 2004, 2006) and the Heinz Center (2002, 2008). Additional indicator variables were considered from other synoptic sources (CSO 2007, Bricker et al. 2007, Kimbrough et al. 2008, Waddell and Clarke 2008). Four additional criteria were applied to narrow the field of indicator variables:

1. Is the parameter clearly relevant to fish populations?
2. Can it help to distinguish “good” versus “bad” habitat quality for fish?
3. Can it demonstrate the effects of habitat conservation activities?
4. Are there data available to support it on a National scale?

The twenty proposed indicators are arranged into five categories: Living Marine Resources, Biotic Habitats, Water Quality, Environmental Contamination, and Hydrology. For each indicator, possible measurement units are suggested, mostly based on methods in previous assessments. Potential data sources and earlier efforts where the indicator has been used are cited in the table, and identified in the reference list below. Although many of the measurement units and data sources are regional in scope, these indicators are intended to provide a common understanding of ecosystem status both within and among regions.

Prerequisite to the completion of a National coastal fish habitat assessment is the development of a spatial framework to organize and display the scores and rankings at an appropriate scale. NOAA's Coastal Asessment Framework (NOAA/NOS 2007) provides an excellent starting point, with spatial resolution approximately to the level of an individual estuarine waterbody. The Coastal Assessment Framework is based on USGS' hydrologic units (8-digit HUCs), and therefore should be compatible with the inland freshwater fish habitat assessment framework which uses the same watershed units (Seaber et al. 1987, USGS 2008a). However, the Coastal Assessment Framework (CAF) does not provide useful units in marine waters, so a spatial scheme will need to be developed considering biogeographic regions and jurisdictional boundaries offshore (NOAA 2004, Burgess et al. 2005, NOAA/CSC 2008a, Spalding et al. 2007). One of the challenges in completing a National-scale assessment is ensuring that the indicator variables and their spatial framework are compatible.

Appendix 6, continued. Coastal Condition Variable Matrix and Data Sources

Category and ID	Indicator	Measurement Units	Precedents and Data Sources
Living Marine Resources			
1	Status of Fishery Species	Status of fishery stocks with habitat identified as a factor for decline, or with a habitat component of recovery plan.	NOAA/EGT 2006; Heinz Center 2002, 2008; CSO 2007; NOAA/NMFS 1999, 2008a; ASMFC 2008 ; NEFMC 1998, 2007; SAFMC 1998, 2007; PFMC 2005; PaCOOS 2008.
2	Status of Indicator Species	Status of individual key species (indicator, protected, sentinel, concern, keystone).	NOAA/EGT 2006; Heinz Center 2002, 2008; CSO 2007; NOAA/NMFS 2008b; Nelson and Monaco 2000.
3	Non-indigenous and Invasive Species	Number or dominance of non-indiginous species (all taxa), measured separately for invasive species.	NOAA/EGT 2006; Heinz Center 2002, 2008; CSO 2007; NISC 2008; USDA 2008; USGS 2008b.
Biotic Habitats			
4	Status of Coastal Wetlands	Instantaneous rate of loss ("Z") of coastal wetlands (regional), total loss of coastal wetlands (regional or per estuary).	NOAA/EGT 2006; Heinz Center 2002, 2008; CSO 2007; EPA 2001,2004; Dahl 2005; UNEP 2001; Stedman and Dahl 2008; CCAP 2008; USFWS 2008; USACE 2008.
5	Status of Submerged Aquatic Vegetation (SAV)	Instantaneous rate of loss ("Z") of seagrass, kelp, or other regional SAV.	NOAA/EGT 2006; Heinz Center 2002, 2008; CSO 2007; NOAA/CSC 2008b.
6	Status of Hard Bottom Habitats	Reef rugosity, coral bleaching (degree heating weeks), percent live coral cover, status of live oysters on mapped oyster reefs.	NOAA/EGT 2006; Waddell 2005; Waddell and Clarke 2008; Lumsden et al. 2007; Coen et al. 2007; UNEP 2001; BRT 2007; CORIS 2008.
7	Benthic Invertebrate Index	Benthic Index Score = good-fair-poor	NOAA/EGT 2006; EPA 2001, 2004; NBI 2008.
Water Quality			
8	Eutrophication - Nutrient levels	Eutrophication Index (low to high), dissolved inorganic nitrogen (DIN); dissolved inorganic phosphorus (DIP).	NOAA/EGT 2006; Bricker et al. 2007; Heinz Center 2002, 2008; EPA 2001, 2004, 2006, 2008; UNEP 2001; CSO 2007.
9	Eutrophication - Chlorophyll a	Eutrophication Index (low to high) - chlorophyll-a	NOAA/EGT 2006; Bricker et al. 2007; Heinz Center 2002, 2008; EPA 2001, 2004, 2006, 2008; UNEP 2001; CSO 2007.
10	Eutrophication - Water clarity	Eutrophication Index (low to high) - water clarity.	NOAA/EGT 2006; Bricker et al. 2007; Heinz Center 2002,2008; EPA 2001, 2004, 2006, 2008; UNEP 2001; CSO 2007.
11	Eutrophication - Dissolved oxygen	Occurrence of hypoxia and anoxia - historic, real-time, and forecast.	NOAA/EGT 2006; Bricker et al. 2007; Heinz Center 2002, 2008; EPA 2001, 2004, 2006, 2008; CSO 2007; UNEP 2001; NOAA/NCDDC 2008.
12	Harmful Algal Blooms (HABs)	Occurrence of HAB events - historic, real-time, and forecast.	NOAA/EGT 2006; Heinz Center 2002, 2008; FWRI 2008; WHOI 2008; UNEP 2001; NOAA/CSCOR 2008.

Appendix 6, continued. Coastal Condition Variable Matrix and Data Sources

Category and ID	Indicator	Measurement Units	Precedents and Data Sources
Environmental Contamination			
13	Chemical contamination of sediments	Contamination status ranked low to high - trend increasing, decreasing, or stable.	NOAA/EGT 2006; Kimbrough et al. 2008; Heinz Center 2002, 2008; UNEP 2001; CSO 2007; EPA 2001, 2004, 2006, 2008.
14	Chemical contamination in fish and mollusks	Metal and organic contamination status ranked low to high - trend increasing, decreasing, or stable.	NOAA/EGT 2006; Kimbrough et al. 2008; Heinz Center 2002,2008; EPA 2001,2004; UNEP 2001; CSO 2007; EPA 2001, 2004, 2006, 2008.
Hydrology			
15	Degree of alteration of freshwater inflow	Freshwater withdrawals and hydrologic alterations	NOAA/NOS 2007; USACE 2008; USGS 2008c; Orlando et al. 1993, 1994; USGS 2008d.
16	Degree of alteration of tidal flow	Hydrologic alteration of tidal flow	NOAA/NOS 2007; USACE 2008; Orlando et al. 1993, 1994; USGS 2008c.
17	Degree of estuarine channelization	Degree of channelization and dredging in estuaries.	NOAA/NOS 2007; USACE 2008; USGS 2008c.
18	Extent of shoreline armoring	Miles of shoreline armored or percent of total length of shoreline armored (regional)	NOAA/EGT 2006; Heinz Center 2002,2008; Surfrider Foundation 2008; NOAA/NOS 2008.
19	Fish-accessible stream miles	Number of barriers to fish passage from coast into tributary rivers.	NOAA/EGT 2006; USACE 2008; USFWS 2008b.
20	Percent change in impervious surfaces in watershed	Percent of watershed land area covered by impervious surfaces, or total land area of impervious surfaces, or rate of land conversion	CCAP 2008; NBII 2008.

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Appendix 7 – Rehabilitation Project Database

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Overall Objective	Objective	Activity	Activity outcome	Biological Response	Indicators
Overall Habitat Protection	Land Acquisition	Purchase of land or easements	Protect threatened and endangered species Allow easement for restoration activities Allow public access Ability to alter land use regulations	Allow for ecological repair	Number of acres protected Number of stream miles protected
Instream Habitat Improvement	Bank Stabilization		Prevent failure at toe of streambank	Reduce sedimentation and erosion	Longitudinal profile Channel cross-sections Aerial photography interpretation Photo point comparison Vegetation plot monitoring Life/integrity of structures Stream profile - pools, riffles Pebble counts
		Brush bundles added	Stream flow energy dissipated	Reduce sedimentation and erosion	
		Channel reconfiguration activities	Redirect streamflow energy	Reduce sedimentation and erosion	
		Coir or coconut fiber logs/matting	Traps sediment	Reduce sedimentation and erosion	
		Flow modification activities	Stream flow energy dissipated	Reduce sedimentation and erosion	
		Grade control	Reduces bank heights	Improves bank stability	
		Install sediment-trap dam	Traps sediment	Reduce sedimentation and erosion	
		J-hook installed	Stream flow energy dissipated away from banks	Reduce sedimentation and erosion	
		Large woody debris added	Stream flow energy dissipated away from banks	Reduce sedimentation and erosion	
		Livestock exclusion	Reduce bank destruction	Reduce sedimentation and erosion	
		Lunkers/skyhooks installed	Stabilize undercut banks	Reduce sedimentation and erosion	
		Planting	Secure riparian soils	Reduce sedimentation and erosion	
		Reslope streambank	Obtain stable slope	Enhances conditions for plant establishment	
		Rip rap installed	Secure near-vertical streambanks	Reduce sedimentation and erosion	
		Road drainage system improvements	Reduce runoff	Reduce sedimentation and erosion	
		Road obliteration	Reduce runoff	Reduce sedimentation and erosion	
		Road upgrade/maintenance	Reduce runoff	Reduce sedimentation and erosion	
		Rock gabions installed	Stream flow energy dissipated away from banks	Reduce sedimentation and erosion	
		Rock/log vanes installed	Stream flow energy dissipated	Reduce sedimentation and erosion	

			away from banks		
		Rock/log weirs installed	Control streambed erosion	Reduce sedimentation and erosion	Large woody debris counts/unit length
		Root wad revetments	Reduce erosion	Scour pools, create cover	
		Stream pool construction	Stream flow energy dissipated	Reduce sedimentation and erosion	
		Terracing	Allow for soil absorption of rainfall runoff	Reduce sedimentation and erosion	
	Channel Reconfiguration	Channel realignment	Reconnection to main channel	Allow connectivity for habitat utilization	Water flow/velocity Channel cross-sections Aerial photography interpretation Stream profile - pools, riffles
		Channel relocation	Avoid development disturbance	Ensure connectivity for habitat utilization	
		Construct aggraded braided channel	Restore channel complexity	Allow juvenile fish species to utilize rearing habitat	
		Dechannelization	Stream flow energy dissipated	Reduce sedimentation and erosion	
			Restore pools and riffles	Spawning and rearing habitat created	
		Flow modification activities	Redirect streamflow energy	Regain natural water flow	
		Grade control	Reduce headcutting	Reduce streambank erosion	
	Fish Passage	Baffles on culvert installed	Allow fish passage	Allow connectivity to spawning habitat	Egg and larval fish sampling Video monitoring of fish passage Species diversity indices
		Channel reconfiguration activities	Allow upstream migration	Allow connectivity to spawning habitat	
		Culvert removal	Remove blockage of main channel	Allow connectivity to spawning habitat	
		Culvert modification	Remove blockage of main channel	Allow connectivity to spawning habitat	
		Dam removal	Remove blockage of main channel	Allow connectivity to spawning habitat	
		Deflectors/barbs	Scour pools	Spawning habitat created	
		Remove or modify tidegates	Allow fish passage to estuarine channels	Allow adjustment to salinity for anadromous or catadromous fishes	
		Fish exclusion screens installed	Prevent entrapment mortality of juvenile fish species	Improve survivability of spawning fish	
Instream Habitat Improvement continued	Fish Passage continued	Fish ladder improvement	Allow upstream migration	Allow connectivity for spawning and habitat utilization	
		Fish ladder installed	Allow upstream migration	Allow connectivity for spawning and habitat utilization	
		Install span-type structure for stream crossing	Allow upstream migration	Allow connectivity for spawning and habitat utilization	
			Allow downstream sediment transfer	Nutrient transport	

		Instream habitat creation activities	Reduce shelter deficit	Provide feeding and resting areas for spawning fish	
		Large woody debris removed	Remove blockage to main channel	Allow connectivity for spawning and habitat utilization	
		Large woody debris added	Reduce shelter deficit	Spawning habitat created	
		Provide suitable migration flows in regulated streams	Facilitate and expedite upstream or downstream migration	Allow connectivity for spawning and habitat utilization	Streamflow gage records
		Stream pool construction	Stream flow energy dissipated Create areas of reduced velocity	Allow connectivity for spawning and habitat utilization	
	Instream / Lake Habitat Creation	Artificial structures installed	Create habitat for fluctuating impoundment	Provide cover for warmwater species	Fish population estimates
		Boulder clusters	Create areas of reduced velocity Reduce pool deficit	Provide feeding and resting areas for fish Spawning and rearing habitat created	Pool habitats stable Rapid bioassessment protocols
		Brush bundles added	Reduce shelter deficit Provide shading	Encourage food web dynamics Spawning and rearing habitat created	Embeddedness of riffle rock Egg and larval fish sampling
		Deflectors/barbs	Scour pools	Spawning and rearing habitat created	
		Half-log installed	Reduce shelter deficit	Provide feeding and resting areas for fish	
		Island creation	Provide shoreline habitat	Encourage food web dynamics	Egg ribbon counts
		J-hook installed	Create pool habitat	Provide feeding and resting areas for fish	
		Large woody debris added	Reduce shelter deficit	Spawning and rearing habitat created	Young-of-year presence
		Lunkers/skyhooks installed	Create overhead bank cover	Provide feeding and resting areas for fish	Age class distribution
		Riffles created	Provide unavailable gravel for spawning substrate	Spawning and rearing habitat created	Fish abundance
		Rock/log weirs installed	Create pool habitat	Provide feeding and resting areas for fish	Fish growth data
		Root wad revetments	Promote formation of pool habitat Provide overhead cover	Spawning and rearing habitat created	Life/integrity of structures Aquatic invertebrate IBI
		Sediment trap dam	Maintenance of pool habitat	Spawning and rearing habitat maintained	
		Spawning gravel placement	Provide spawning substrate	Spawning and rearing habitat created	

		Streampool construction	Reduce shelter deficit	Spawning and rearing habitat created	
	Flow Modification	Boulder clusters	Create areas of reduced velocity	Provide feeding and resting areas for fish	Water flow/velocity/gage data Channel cross-sections
		Berm/dike modification	Stop overland sheetwater from floods	Reduce colonization of invasive species	
		Culvert removal/modification	Allow water flow	Restore natural water levels	
		Dam modification/removal	Reduce water supply deficit	Restore natural water levels	
		Modify flow releases from dam	Mimic natural hydrograph	Restore natural riparian vegetation and behavioral stimuli	
		Dechannelization	Stream flow energy dissipated	Reduce sedimentation and erosion	
		Deflectors/barbs	Constrict channel, accelerate streamflow	Provide water depth diversity	
		Grade control structures	Reduce upstream energy slope	Prevent streambed scouring	
		Irrigation practice improvement	Reduce water supply deficit	Restore natural water levels	
		Large woody debris removed - very special case	Remove blockage of main channel	Allow connectivity for habitat utilization	
		Large woody debris added	Stream flow energy dissipated	Spawning and rearing habitat created	
		Off-stream storage pond construction	Improve late summer surface flows	Enhance anadromous salmonid habitat and availability	
		Road obliteration	Reduce runoff	Restore natural water levels	
		Stream pool construction	Stream flow energy dissipated	Restore width/depth ratio	
Faunal Species Management	Fish Reintroduction	Fish exclusion screens installed	Prevent entrapment mortality of juvenile fish species	Improve survivability of reintroduced fish	Young-of-year presence Fish growth data
		Fish passage activities	Remove blockages	Allow connectivity to spawning habitat	
		Fish trapped for rearing	Collect brood stock	Allow for rearing of fish for population establishment	
		Instream habitat creation activities	Create suitable habitat for fish population establishment	Improve survivability of reintroduced fish	
	Faunal Removal	Invasive faunal removal	Remove competition for native fish species	Native fish populations establish/stabilize	Fish species composition Native fish species condition
Riparian Habitat Improvement	Riparian Management	Bank stabilization activities	Reduce erosion	Reduce sedimentation	Percent plant survival
		Off-channel habitat wetland creation	Provide low-flow areas with warmer temperatures	Increase suitable overwintering habitat	Vegetation plot monitoring
		Off-channel ponds created	Provide no-flow pools with	Increase suitable overwintering	Aerial photography

			warmer temperatures	habitat	interpretation
		Road drainage system improvements Mimic natural hydrograph	Reduce sedimentation Restore riparian community recruitment	Reduce non-point pollution levels Restore LWD input source and control sediment input & transport	Water transparency Dissolved oxygen levels Water levels/flow
	Floral Species Management	Planting	Reduce shelter deficit Bank stabilization	Improve water quality Reduce erosion	Water transparency Longitudinal cross-sections
		Invasive vegetation removal	Allow native vegetation species to dominate	Regain local ecological balance	Aerial photgraph comparisons
		Livestock exclusion	Allow establishment of floral species	Reduce sedimentation and erosion	Vegetation plot monitoring
	Land Use Regulations	Boating restrictions	Reduce erosion from wake disturbance	Reduce sedimentation	Water transparency
		Conservation grazing management	Protect existing high quality habitat	Maintain local ecological balance	Nutrient levels - nitrogen
		Livestock exclusion	Reduce erosion Reduce establishment of invasive plants	Repair riparian dysfunction Improve water quality	Vegetation plot monitoring
		Livestock water access area development	Prevents need for livestock to enter habitat	Improve water quality	
Water Quality Improvement	Water Quality Management	Bank stabilization activities	Reduce erosion	Reduce sedimentation	Water transparency
		Dredging	Reduce sediment levels Reduce non-point pollution build-up	Reduce vegetation growth Stabilizes nutrient and oxygen levels	Dissolved oxygen levels Overwintering fish surveys
		Invasive faunal removal	Allow native species to dominate	Increase water clarity	Lake volume-bathymetry monitoring
		Invasive vegetation removal	Reduce eutrophication	Increase oxygen levels	Aquatic vegetation density
		Lake shoreline deepening	Reduce siltation	Decrease eutrophication	Nutrient levels - phosphorus, nitrogen
		Livestock exclusion	Eliminate livestock use of habitat	Reduce nutrient loading and sedimentation	Conductivity
		Livestock water access area development	Prevents need for livestock to enter habitat	Reduce nutrient loading and sedimentation	Sediment loading rates
		Off-channel wetland habitat creation	Provide low-flow areas with warmer temperatures	Increase suitable overwintering habitat	Fish age/growth
		Sediment trap dam installed	Reduce sedimentation	Decrease eutrophication	Fish condition

		Stormwater/runoff control	Reduce sedimentation	Stabilize nutrient levels	Fish species composition
		Upland erosion control	Reduce non-point pollution	Stabilize nutrient levels	Fish species abundance
Recreational Opportunity Improvement	Aesthetics/ Recreation	Faunal species management activities	Improve fish habitat	Increase fish populations	Tourism/visitor/use hours/days
		Instream habitat improvement activities	Improve fish habitat	Increase fish populations	Angler success/CPUE
		Riparian habitat Improvement activities	Improve fish habitat	Increase fish populations	Angler satisfaction
		Water quality improvement activities	Improve fish habitat	Increase fish populations	
		Fishing jetties installed	Provide angler access	Increase angler satisfaction	