Fisheries Indicators, Freshwater

Freshwater fisheries exist among diverse ecosystems and fauna, provide societal benefits, and are influenced by human activities. Fisheries scientists assess the status and sustainability of fisheries by multiple approaches, including abundance and condition indices, population parameters, community indices, modeling, and surveys of habitat and human dimensions. The future sustainability of freshwater fisheries is limited not by available methods but by society's will.

Freshwater fisheries provide recreation, food, aesthetic values, and economic benefits to society. They are typically smaller in scale than marine fisheries but function through similar ecological processes and may thus serve as microcosms for larger fisheries. Activities and conditions on land, associated with the watershed and especially at the land-water interface (i.e., the riparian zone), strongly influence freshwater fisheries. Fisheries exist in a broad diversity of ecosystem types and corresponding fish fauna in freshwater environments, ranging from small streams to expansive lakes and the fishes supported in those systems. There is thus no single approach, method, technique, or tool best suited to assess freshwater fisheries. Fisheries scientists have developed over decades an extensive set of procedures to indicate the ecological state of freshwater fisheries.

Three primary, overlapping components constitute fisheries: (1) the fish or invertebrate organism, (2) the environment or the habitat for the resource, and (3) associated humans. Fishery assessment therefore often includes quantifying static or dynamic parameters of multiple fishery components. The associated methods, techniques, and indicators thereby may include aspects of biology, ecology, physiology, behavior, physical sciences, and socioeconomics. Thorough fishery assessment may require a multidisciplinary team.

There is no clear criterion for determining sustainability of freshwater fisheries. Freshwater fisheries worldwide receive varying levels of human management, usually by government agencies, nongovernmental organizations, or private landowners or consortiums. Scientists may consider even the most intensively managed fisheries (e.g., by fish culture, stocking, and harvest or habitat manipulations) sustainable as long as human intervention and resources are available. Some fisheries are self-sustaining, however (e.g., free-flowing rivers that are difficult to directly manipulate). Fisheries managers seek to achieve elements of self-sustainability in freshwater fisheries, but the nature of many fisheries (e.g., small ponds or urban community fisheries) may require continual intensive management to meet human resource demands.

A Rich History

Long ago, fisheries were considered abundantly endless food resources that could not be overexploited. With human population growth and modern interests in recreational fishing, it became clear that the productive capacity of freshwater ecosystems could not meet the demand for fisheries products in public waters. Scientists thus developed modern fisheries management and assessment over decades toward a goal to balance the supply and demand of fisheries. Modern conservation programs have further enhanced the movement. Achieving that supply–demand balance is an ongoing challenge, especially in densely populated areas of the world and in undeveloped countries, where food resources may be limited.

Many of the concepts and methods for fisheries assessment are rooted in ancient and historical fishing and early management efforts. Fish collection techniques have evolved over centuries with human desires to efficiently capture fish for food. Although many fisheries techniques existed in a rudimentary form earlier, North American and European fishery scientists developed fisheries techniques and analytical approaches during and since the latter half of the twentieth century, in what is considered the modern era of fisheries management.

Ecosystem and Faunal Diversity

Freshwater ecosystems and the aquatic fauna they support are tremendously diverse. Corresponding fisheries assessment approaches and techniques are thus similarly variable among ecosystems. Freshwater ecosystems generally divide between two categories based on geomorphology and hydrology. Lentic water bodies are standing or relatively still water and include lakes, reservoirs, ponds, and wetlands. Lotic waters are flowing streams, rivers, or springs.

The different physical and biotic properties and dynamic processes between lentic and lotic ecosystems warrant different conceptual and practical approaches to fisheries assessment. Overall, the spatial habitat patterns and dynamics of primary (plant photosynthesis) and secondary (animal tissue elaboration) production and associated fish population and community regulation mechanisms are rather distinct between the two types of water bodies. Density-dependent processes in both lentic and lotic systems regulate fish populations, for example, but density-independent factors (e.g., flooding, drought, temperature fluctuations) have a greater influence in the dynamic lotic environment. These ecological differences between system types have resulted in multiple approaches for fisheries assessment.

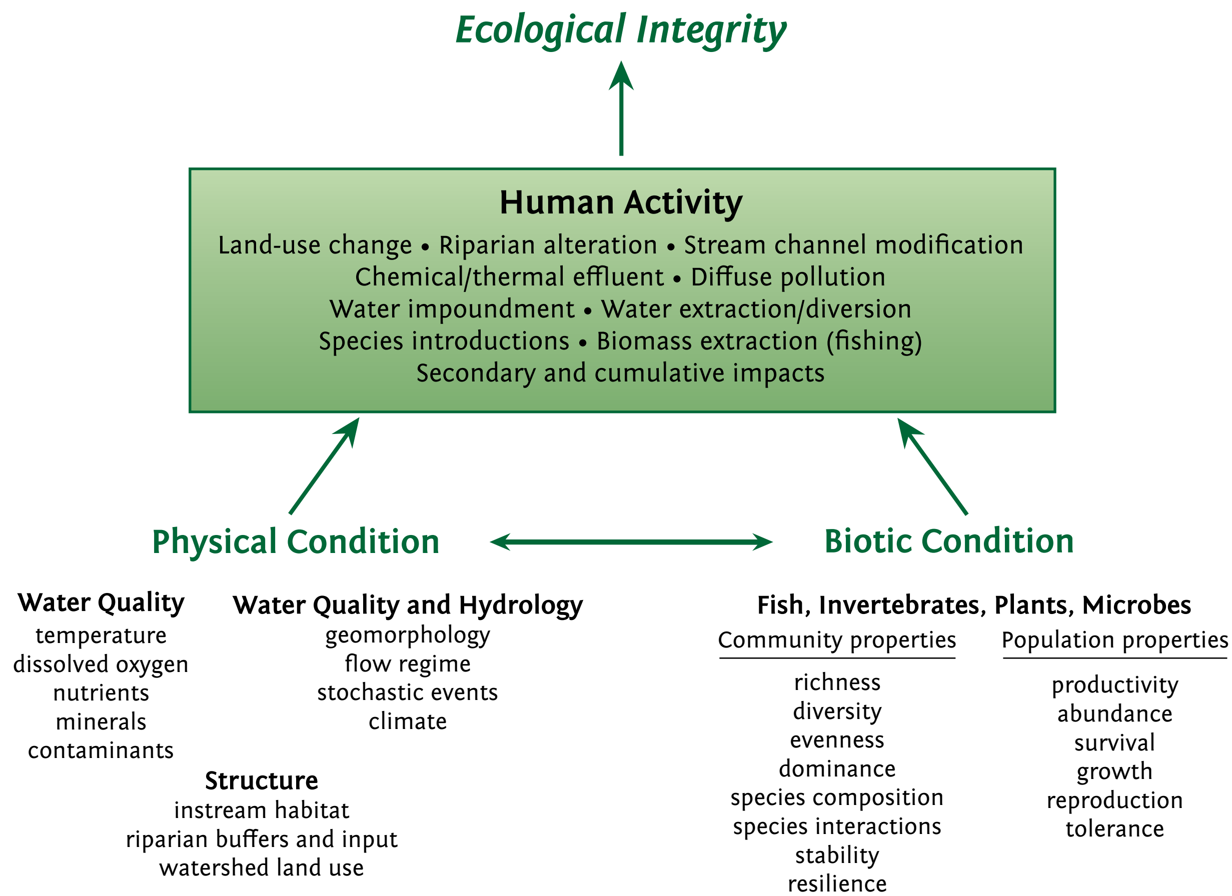
Within and among freshwater habitats, fishes have adopted a wide variety of morphological, life history, and behavioral patterns and adaptations to survive in specific aquatic habitats and changing environments, and to effectively utilize resources for ecological success. They have evolved a multitude of strategies and modes of feeding, reproduction, predator avoidance, habitat occupancy, and migration. This diversity in form, function, ecology, and behavior further complicates sampling and assessment of fish and fisheries.

Physical and Biotic Influences

A number of interacting natural and anthropogenic factors influence freshwater fish production, population dynamics, and sustainable exploitation rates. The physical setting of a freshwater ecosystem sets the framework in which biotic interactions occur to form the aquatic community. The latitude, climate, geology, geomorphology, water quantity and quality, and riparian and watershed attributes all interact at multiple scales to form the aquatic environment in which fish production occurs. Most of these factors are subject to human influences that can dramatically alter the aquatic environment and biotic community.

Ecological integrity of an ecosystem is the ability of its chemical, physical, and biological environments to exist and function similarly to that of a region's natural habitat. An ecosystem that human activities minimally influence has high ecological integrity, requires minimal direct management (other than protective measures), and is generally self-sustaining with regard to fisheries. Human global effects have both gradual and catastrophic impacts on biodiversity and ecosystem function at the local level of environments that support aquatic life, fish, and fisheries. Aquatic fauna thus are declining at a rapid rate globally and locally. Proximate effects of human activity on ecological integrity of aquatic systems include changes in land use in the watershed, stream channel modifications, point and diffuse chemical and thermal pollution, water impoundment and extraction, species introductions, fishing, and landscape development. (See figure 1 on page 132.) These activities act at multiple scales to transform the physical and biological components of aquatic systems from their original condition to altered states with reduced biological diversity and ecological function.

Figure 1. Physical and Biotic Factors Affecting the Ecological Integrity of Aquatic Systems and How Human Activity Alters Them



Source: Hubert and Quist (2010).

Fishery Assessment and Indicators

Fish abundance, age and size composition, and length and weight relationships are the primary parameters scientists require to describe the status of a fish population. In addition to static parameters (i.e., those at a single point in time), dynamic parameters that quantify rates of population processes, such as survival, growth, reproduction, and mortality, provide greater insight into a fish population's ecological state. Many management or policy objectives require assessment at the fish assemblage (or community) level, and parameters that describe fish assemblage composition can relate important ecosystem attributes. Exact measurement of most of these parameters is difficult, cumbersome, or impractical to conduct. Fishery scientists thus have developed methods to estimate these parameters without complete data, or have developed indices that describe attributes assumed to correlate with true parameters. An additional useful approach to understand population status or dynamics is quantitative modeling to estimate parameters statically or over time. Physical surroundings and human interactions greatly influence the status of a fish stock or population. Managers thus find assessments of habitat and human dimensions associated with fisheries informative.

Sampling Considerations

Many different sampling gears (equipment and instruments) and techniques can sample freshwater fish. Electrofishing, angling, netting, seining (fishing with a net that hangs vertically in the water), and trawling have specific properties and biases for capturing fish that vary among fish species, sizes, and environments. Fish sampling gears are designed for, and most effective in, appropriate environments for target species and sizes. No single sampling technique can effectively sample the entire fish assemblage of an ecosystem; multiple gears are usually deployed for a more complete sample. Fish populations and assemblages vary over time and among sites within ecosystems. The spatial, temporal, and organizational scales of the sampling environment therefore are critical considerations in fishery assessment and monitoring. There is no standard procedure for sampling fish assemblages, but fisheries scientists have recognized the need to standardize sampling protocols and quantitative procedures for interpreting sampling results. Recent compendiums of standard methods for sampling freshwater fishes and analyses and interpretation of resulting data, published by the American Fisheries Society (Guy and Brown 2007; Bonar, Hubert, and Willis 2009), represent important advances toward common methods for freshwater fisheries.

Abundance and Condition Indices

Fish sampling is never complete (i.e., managers cannot sample all fish present), so scientists use actual catch or indices of catch to indicate relative population sizes to assess fish populations. Actual catch can be an indicative measure of fish population size, but it is highly variable and fluctuates with the amount of sampling effort expended. Scientists therefore most commonly apply catch per unit effort as an index that they assume to be proportional to population size. Catch is expressed as the number or total weight (i.e., biomass) of fish caught. Managers quantify effort as a standard time, space, or activity unit, depending on the gear and habitat fished. Sampling may be by a passive gear (e.g., trap or entanglement gear) or an active gear (e.g., seine net or electrofisher). Units of effort may include the time that a gear is set or actively fished, the linear distance, area, or volume of water sampled, or a standard sampling activity, such as a seine haul. Managers can also generate catch per effort data by conducting angler or commercial fisher surveys to estimate their catch and effort expended. Scientists may consider catch per effort indices a minimum estimate of, or proportional to, the true population abundance for assessment, but they are more useful as relative indices to compare over time or among sites or populations.

Fisheries science commonly uses the relationship of length and weight in individual fish within a population to indicate the condition (or plumpness) of individual fish as an index of their well-being. The condition of fish in a population may be estimated by graphing the curvilinear relationship of length–weight data and deriving the resulting mathematical equation. Scientists find indices of condition easier to interpret and routinely apply two common indices. Fulton-type condition indices are a scaled value of the quotient of a fish's weight and its length cubed. Relative weight is the ratio of a fish's actual weight to the expected weight of a fish that length. The expected weight is termed standard weight; scientists develop standard weight equations for all sizes of a fish species to express the condition of a fish in good condition (often the 75th percentile of a large data set). Condition indices vary among species and are most useful for comparing populations or detecting length-related patterns or patterns over time within a population.

The size structure of a fish population is an important component of assessing population status. Length-frequency distributions are a simple but informative description of fish population dynamics. They are usually displayed as a histogram (bar graph) of fish numbers among size groups and incorporate information about reproduction, growth, and mortality. Imbalances in length-frequency histograms can indicate problems associated with reproductive failure, juvenile mortality, slow growth, or excessive exploitation or natural mortality. Stock density indices make further use of length-frequency distributions by expressing the proportion of catchable fish in a population (stock size) that are of a quality size or other specified length (e.g., preferred or trophy size). Deviations of stock density indices from expected ranges may indicate reproductive problems, overexploitation, or other causes for imbalance in the population size structure. The combination of relative weight indices and stock density indices can be extremely informative for assessing and managing exploited fish populations.

Population Parameter Estimates

In some situations, managers may require estimates of the true population density and biomass to guide management or policy decisions. Such procedures require additional cost and effort, compared to catch per effort indices. Scientists estimate the true abundance of freshwater fish populations using mark-recapture, removal, or surplus-production methods. Mark-recapture methods involve multiple sampling events where managers mark the fish and then resample them to detect the ratio of marked and unmarked fish to estimate the total population. Removal methods use repeated sampling without return to the population (temporarily or permanently) to detect the decrease in catch among samples to estimate the original population size. Scientists apply surplus-production methods to exploited fisheries to estimate population biomass from the pattern of yield (i.e., fish biomass harvested) and fishing effort over time.

Fish population abundance estimates are especially useful in freshwater fisheries to compare with rates of harvest to assess the sustainability of fishing. They also allow the estimation of population rate parameters. Population rate parameters, including reproduction, survival, and growth, are extremely helpful in understanding fish population dynamics toward effective management. Integrating these parameters also allows estimation of the annual rate of fish production or the total biomass of fish tissue produced by a population during a year. This integration is the ultimate parameter for assessing if a population is sustainably exploited.

Community Indices

In modern fisheries management, target game fish species are not managed in isolation of other fishes and aquatic organisms in their environment. Managers sample and consider the entire fish assemblage of an ecosystem in fishery assessments. Assemblage assessment may require additional effort, but assemblage attributes, such as species richness, are generally less variable than abundance estimates for individual species. Assemblage assessments thus usually require smaller sample sizes to obtain precise estimates and can ultimately be more cost-effective than single species approaches.

Ecologists have developed two primary approaches to quantify community structure and applied them to fish assemblages. They are the use of (1) community structural indices based directly on field samples and (2) biotic indices based on the relative abundance of indicator organisms. Both approaches are applicable to describing fish assemblage characteristics and may be related to environmental quality, but biotic indices are especially suited to quantifying ecological integrity. The relative abundance of species, other taxa (scientific classification), or other categorical attributes within an assemblage may be combined into a single measure to describe the status of the community. The most common of these measures is species diversity, which incorporates the number of species in an assemblage (species richness), as well as the relative abundance of those species (evenness). Scientists may develop fish biotic indices using indicator species or guilds (a group of species that use the same resources), which they may then incorporate into a single index. The most common fish biotic index is the Index of Biological Integrity, also known as the Index of Biotic Integrity. James R. Karr, a US ecologist and expert in fisheries, and his colleagues initially developed the index for warm-water stream ecosystems, but others have widely modified it and applied it in other systems. Scientists designed this fish community index to indicate biological integrity of aquatic ecosystems by integrating attributes of the fish assemblage, population, and individuals using relative abundance of species and condition of individuals. Developing an Index of Biological Integrity for fish within a region requires substantial effort, but scientists may use individual metrics of the index or related assemblage structural indices (e.g., richness, diversity, evenness) singly or in aggregate as quantitative characteristics for comparison and assessment.

Monitoring

Single static measurements of a fish population or assemblage are of limited value in fishery assessment, and monitoring the trend over time or spatial variation is more informative. Therefore, an optimal approach is to develop carefully designed monitoring programs to fully understand the dynamic processes and variation in an ecosystem and fishery. It is also beneficial to include standardized sampling over time and among sites and to consider multiple quantitative indicators in interpreting resulting data. Most fisheries resource agencies have adopted broad scale approaches to inform management decisions, and monitoring programs may include surveys of other fauna (e.g., aquatic macroinvertebrates), habitat conditions, and anglers and the nonfishing public.

Modeling Approaches

Fish population models estimate summary population characteristics by incorporating dynamic processes. These approaches are especially suitable to determine, forecast, and understand the exploitation and sustainability of fisheries, as they may include various ecological stressors and the projected population response. There are many modeling frameworks that may or may not include field data. A primary advantage of modeling approaches is that they can incorporate physical, biotic, natural, and anthropogenic factors and integrate their combined effects on a population or assemblage. Precise population prediction is not always the objective of modeling assessment; rather, scientists are primarily interested in the trends, relative sensitivity of influential factors, and the dynamic processes in understanding the ecology and sustainability of fisheries.

Habitat

Fish habitat includes all the physical, chemical, and biological attributes of the aquatic environment required to sustain a population. Natural and anthropogenic habitat alterations change the suitability of habitat for fish and other biota. Habitat monitoring is thus most informative in comparisons over time and among locations. Habitat monitoring is particularly important for quantifying gradual degradation over time or to assess restoration or other habitat management actions. Managers can measure individual parameters describing water quality, stream characteristics, or lake attributes by relatively standard procedures, and they may calculate and compare indices. Habitat assessment procedures generally are designed to describe the bank, riparian zone, and watershed characteristics of streams and rivers and the morphometrics, water quality, hydrodynamics, and trophic state of lakes and reservoirs. Geographic information systems and associated data sets allow approaches for habitat assessment at broad spatial scales. Scientists describe habitat at reach, segment, and basin scales and quantify riparian and watershed attributes from existing data layers. Many aquatic habitat processes act at broad scales and may be cumulative in nature; the ability to quantify watershed or riparian land cover and associated landscape parameters thus is an important advance.

The Human Factor

Humans manage fisheries because we exploit them for food or recreation. Our activities in the water and on land alter their environment. There are three primary reasons that humans exploit fisheries: subsistence fishers harvest fish to eat themselves, commercial fishers sell their catch, and recreational users fish for personal enjoyment. Along with the varied goals of these groups, their fishing techniques, habits, and attitudes differ as well. Managers frequently practice regulating or influencing people's behavior to indirectly manage the fishery resource. They thus need information about fishery constituents for effective management toward a sustainable harvest. Knowledge of fishery constituents and other human stakeholders of freshwater systems and their role in decision making is critical to allocating fishery resources, habitat management, policy and regulation development, and seeking stakeholder satisfaction with the fishery and their experiences.

Conservation and management decisions may require sociological, economic, legal, and political information. Scientists gather this information through document review; individual and group interviews; mail, telephone, and Internet surveys; and direct observation. Managers can then implement knowledge of the human factor into the management process to influence decisions on the exploitation and conservation of fishery resources.

Conflicting Goals

Management of aquatic systems for both fisheries and ecological integrity may be common goals in some systems but may also present a conflict. Fisheries management incorporates not only information about the biology and ecology of the resource, but also considers economics, aesthetics, human attitudes, and the interests of users and the general public. The values of direct fishery users (e.g., catch, harvest, fish quality) may conflict with those of indirect users or nonusers (e.g., aesthetics, existence value, ecological services), however. Fishery management goals, such as enhancing or maximizing fish abundance, population structure, catch, or harvest, therefore may be contrary to those to maintain robust communities and natural self-sustaining habitat. As fishery managers seek to include multiple stakeholders and uses in management, they face a primary challenge to incorporate concepts and values of users and nonusers, as well as consumptive and nonconsumptive users, and to consider ecological services, function, and integrity as they manage the physical and biotic environments of fishes.

An Uncertain Future

Society has a growing interest in, concern for, and demand for the conservation and sustainable management of freshwater fisheries and ecosystems. Fisheries agencies are responding with action in many regions, but political and other societal pressures may limit their efforts. Progressive agencies are incorporating broad and holistic ecological and socioeconomic approaches into management. Integrating approaches, such as adaptive management and structured decision making, leads to improvement in the management process, results, and public support. The scientific tools and methods managers require for fishery assessment to guide conservation and management exist and are available to agencies worldwide, but the political will to employ them and consider the science in management and policy decisions is highly variable. The future sustainability of freshwater fisheries and ecosystems is uncertain and limited not by available methods or science but by the will of society.

Thomas J. KWAK
United States Geological Survey

See also Biological Indicators (*several articles*); Ecolabels; Ecosystem Health Indicators; Fisheries Indicators, Marine; Index of Biological Integrity (IBI); Ocean Acidification—Measurement; Organic and Consumer Labels; Remote Sensing; Species Barcoding

Further Reading

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