METHODS FOR SAMPLING FISH COMMUNITIES AS A PART OF THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

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COVER PHOTOGRAPH: Backpack electrofishing on Woodland Creek, Ulster County, New York.

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By Michael R. Meador, Thomas F. Cuffney, and Martin E. Gurtz

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CONVERSION FACTORS

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
	Volume	
liter (L)	0.2642	gallon
milliliter (mL)	0.2642×10^{-3}	gallon
	Mass	
gram (g)	0.03527	ounce, avoirdupois

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ABSTRACT

Fish community structure is characterized in the U.S. Geological Survey's National Water-Quality Assessment Program as part of an integrated physical, chemical, and biological assessment of the Nation's water quality. The objective of the National Water-Quality Assessment characterization of fish community structure is to relate fish community characteristics to physical, chemical, and other biological factors to assess water-quality conditions. To accomplish this, fish community structure is described at sites representing selected environmental settings. In addition, spatial and temporal patterns in fish community structure are examined at local, regional, and national levels.

A representative sample of the fish community is collected by sampling a stream reach using two complementary methods. The primary collection method is electrofishing using backpack, towed, or boat-operated electrofishing gear; seining is a secondary technique. Other secondary techniques may be substituted after careful consideration of sampling efficiency and consultation with local fish ecologists. Before fish sampling is conducted, careful consideration must be given to collecting permits; protecting endangered, threatened, and special-concern species; and coordinating sampling efforts with other fish ecologists. After the sample is collected, individual fish are identified to species by ichthyologists. Length and weight measurements are taken, and the presence of external anomalies are recorded.

INTRODUCTION

Background

The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program is designed to assess status of and trends in the Nation's water quality and to develop an understanding of the major factors that affect observed water-quality conditions and trends (Hirsch and others, 1988; Leahy and others, 1990). This is accomplished by collecting physical, chemical, and biological data at sites that represent major natural and human factors (for example, ecoregion, land use, stream size, hydrology, and geology) that are thought to control water quality in the river basin. These data are used to provide an integrated assessment of water quality within selected environmental settings, assess trends in water quality, and investigate the influence of major natural and human factors on water quality.

The biological components of NAWQA consist of ecological surveys (characterizations of fish, benthic invertebrate, and algal communities) and tissue contaminant studies. Biological components are important to an integrated assessment of water quality because of factors such as (1) sensitivity to a wide variety of natural and human environmental influences (for example, chemical constituents, hydrologic modifications, sedimentation, and thermal enhancement); (2) increased analytical sensitivity due to bioconcentration of certain contaminants; (3) integration of exposure to environmental influences over multiple temporal and spatial scales (for example, algae integrate exposure over several millimeters and for periods of several weeks, whereas fish may integrate exposure over many kilometers and for a decade or more); and (4) a high degree of public interest and concern, particularly for endangered species.

Ecological surveys as part of NAWQA are designed to characterize fish, benthic invertebrate, and algal communities and associated instream and riparian habitats. Community analysis offers several advantages for large-scale water-quality assessments when compared with toxicity testing (American Society for Testing of Materials, 1988), biochemical characterization (Day and Scott, 1990; Hontela and others, 1991; Monod and Vindimian, 1991; Schoor and others, 1991), or direct measurement of ecological processes. For example, community surveys directly relate to actual ambient conditions, take into account a large range of species representing a variety of environmental exposure pathways, eliminate the need to culture and maintain test organisms, and incorporate secondary effects that arise from the interactions of populations through competitive and predator-prey interactions. Community surveys remain the only means of directly assessing the biological integrity of a site and the only approach that is sensitive to toxicological influences and habitat degradation resulting from changes in land use.

A fish community is a group of fishes belonging to a number of different species that occur in the same area and interact with each other. The structure of a fish community is determined by the species present, their relative abundances, life-stages and size distributions, and their distributions in space and time. Changes in fish community structure occur with natural or human changes in the physical and chemical characteristics of their environment. The ability to detect changes in fish community structure can be gained by developing an increased understanding of the factors that determine the distribution and abundance of fish species and identifying relations among patterns in fish community structure, physical habitat, and water chemistry conditions (Tonn and others, 1983).

The study of fish communities is an essential component of many water-quality assessment programs (Hendricks and others, 1980; Karr and others, 1986; Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989) because fish are particularly sensitive indicators of water-quality conditions (Smith, 1971; Fausch and others, 1990). Human influences, such as changes in water chemistry or physical habitat modifications, can alter fish communities by disrupting their structures. Changes in fish community structure can be detected through changes in size components of the community, functional groups, species diversity, and relative abundance (Wootton, 1990).

The objective of the NAWQA characterization of fish community structure is to relate fish community characteristics to physical, chemical, and other biological factors as part of an integrated assessment of the Nation's water-quality conditions. To accomplish this, fish community structure is described at sites representing selected environmental settings. In addition, spatial and temporal patterns in fish community structure are examined at local, regional, and national levels. An integrated assessment of water quality will provide information to address questions, such as:

1. What are the relations among fish community structure, benthic invertebrate community structure, algal community structure, physical habitat complexity, and water chemistry under varying environmental settings?
2. How do local natural and human factors influence these relations--for example, what is the influence of local agricultural practices on the relations of fish community structure, benthic invertebrate community structure, algal community structure, physical habitat complexity, and water chemistry?
3. What is the influence of regional characteristics on these relations?
4. What patterns exist in the relations among temporal changes in fish community structure, physical habitat complexity, and water chemistry?

An integrated database will also provide information to generate additional hypotheses and address specific questions at local, regional, and national levels.

Purpose and Scope

This document provides detailed procedures for use by trained biologists in evaluating stream fish communities as part of the U.S. Geological Survey's (USGS) NAWQA Program. These procedures allow standardization of collection methods and descriptions of fish communities to facilitate unbiased evaluations of relations among physical, chemical, and biological components of water-quality conditions. The methods presented in this document have been established as standard procedures for characterizing fish communities in streams ranging from headwaters to large rivers (Bagenal, 1978; Nielsen and Johnson, 1983; Bryan, 1984; Ohio Environmental Protection Agency, 1987; Britton and Greeson, 1988; and Plafkin and others, 1989).

This document describes the sampling approach to be used in characterizing fish communities. This approach considers availability of existing data, the selection of sampling sites, the sampling reach, and the sampling season.

Sampling procedures focus mainly on electrofishing and seining techniques, but other sampling methods are discussed. Sampling-related issues include collection of permits, concerns about endangered species, and coordination of activities with other ecologists.

The processing of samples covers taxonomic identification, physical measurements, examination of fish for external anomalies, and the preservation of specimens. Forms for recording these data are presented.

NATIONAL WATER-QUALITY ASSESSMENT SAMPLING DESIGN

The NAWQA sampling design emphasizes a multidisciplinary approach using physical, chemical, and biological tools to provide multiple lines of evidence with which to evaluate water-quality conditions. For surface waters (streams and rivers) NAWQA focuses on a broad spectrum of attributes and sampling approaches to collect data on (1) hydrology; (2) inorganic constituents (major ions, trace elements, nutrients), physical measurements (suspended sediment, conductance, temperature), radionuclides, and organic contaminants in water; (3) trace elements and organic contaminants in bed material and aquatic biota; (4) ecological information (fish, benthic invertebrate, and algal communities); and stream habitat evaluation.

The program is organized into 60 study units on the basis of hydrologic systems (major river basins and large parts of aquifers). Each study unit conducts water-quality investigations for 4 to 5 years, followed by 5 years of low-level monitoring, with the cycle repeated perennially (Leahy and others, 1990). Study-unit investigations consist of four main components: (1) retrospective analysis and reconnaissance; (2) occurrence and distribution assessment; (3) assessment of long-term trends and changes; and (4) source, transport, fate, and effects studies.

Retrospective Analysis and Reconnaissance

Retrospective analysis and reconnaissance efforts provide information to aid in the focus of NAWQA issues and in the design of NAWQA studies. The retrospective analysis is designed to provide a historical perspective on water-quality conditions and biota within a study unit and to assist in the identification of major natural and human factors within that study unit. Analysis of retrospective information on water-quality conditions, biota, and natural and human influences within the study unit also provides baseline information to assist in identification of candidate sampling locations. However, sampling locations are not chosen until a reconnaissance is conducted or an exploration and evaluation of candidate sampling locations are completed.

A reconnaissance consists of a rapid site assessment that includes evaluations of such factors as stream access, stream habitat conditions, proximity of major natural or human stream influences, and methods and equipment appropriate for conducting various types of sampling at that location. A reconnaissance is conducted to familiarize project personnel with watershed features of the study unit and to evaluate candidate locations for subsequent sampling of biological, chemical, and physical characteristics of streams. This subsequent, integrated sampling effort is known as an occurrence and distribution assessment.

Occurrence and Distribution Assessment

The occurrence and distribution assessment is conducted to characterize geographic and seasonal distributions of water-quality conditions in relation to major natural and human features. This assessment is designed to fill crucial gaps in existing data for each study unit. The design of water-quality investigations conducted during the occurrence and distribution assessment represents a balance between maximum flexibility of study units to

target issues of local importance, and national consistency in constituents measured, sampling approaches, and spatial and temporal resolution to allow for comparisons among study units. The occurrence and distribution assessment serves as a basis for designing field activities to evaluate long-term changes in water-quality conditions and studies of source, transport, fate, and effects.

Assessment of Long-term Trends and Changes

Assessments of long-term trends and changes in selected water-quality characteristics will be designed based on the results of the retrospective analyses, reconnaissance, occurrence and distribution assessment, and the concurrent development of information on the environmental framework. Temporal (for example, decadal) changes in the relations among physical, chemical, and biological factors will be interpreted in the context of changes in landscape features and human activities.

Source, Transport, Fate, and Effects Studies

Source, transport, fate, and effects studies are conducted to test hypotheses and examine specific issues about characteristics and causes of water-quality degradation. These studies are targeted for high-priority water-quality issues for individual study units and the Nation. The accumulation of results from these studies among study units enables the linking of broad assessments of status and trends to specific causes and processes by example and inference. Source, transport, fate, and effects studies are designed by individual study units and conducted at a wide range of spatial and temporal scales.

FISH COMMUNITY SAMPLING DESIGN

The fish community sampling design incorporates existing information with estimates of the fish community at sites representing selected environmental settings. Collection of data on the presence and relative abundance of fish species is closely coupled with data collected on physical habitat, water chemistry, and benthic invertebrate and algal communities. The fish community sampling design is structured with respect to the analysis of retrospective data, type of sample collected, sampling reach, selection of sampling sites, and sampling season.

Retrospective Data

Retrospective data concerning fish species are especially important because of the abundance of existing information available concerning fish distributions. Collections of fish specimens and descriptions of their occurrence and distribution across North America have continued for more than 200 years (Heins and Matthews, 1987). Many specimens are available for examination in collections housed in more than 100 university and government museums throughout the United States and Canada (Collette and Lachner, 1976). Detailed descriptions of fish species distributions have been compiled and summarized for the North American continent (Lee and others, 1980; Hocutt and Wiley, 1986) and many individual States (see references in Lee and others, 1980). Analysis of fish retrospective data allows project personnel to compile species lists, develop maps of species distributions, and identify areas within study units where little data are available.

Type of Sample

The type of sample collected to describe fish community structure for NAWQA is a representative sample (Hocutt and others, 1974; Hocutt, 1981). A representative sample provides information on the presence and relative abundance of species. The purpose of a representative sample is to provide a realistic sample of the fish community that represents the fish community inhabiting the sampled stream. The suitability of this type of sample for water-quality assessments has been documented, and a representative sample of fish is the type of sample recommended for assessing water quality (Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989).

Collection of a representative sample requires that the geomorphic channel units (pools, riffles, and runs) of the sampled stream section are representative of the geomorphology of the stream and that multiple sampling methods are used. Of the numerous methods for sampling fish (Nielsen and Johnson, 1983), each has limitations in a particular environment (Backiel and Welcomme, 1980). Nearly all methods designed to collect fish are selective for some component of the fish community and vary in their sampling efficiency. Thus, the combined methods used in collecting a representative sample complement each other, taking advantage of differences in selectivity and efficiency among methods to achieve a more precise representation of the fish community structure. Such a multigear approach has been strongly recommended for collecting a sample of the fish community (Lundberg and McDade, 1990).

Sampling Reach

The sampling reach is a section of stream designated as the sampling unit for describing fish community structure. The length of the sampling reach is determined by a combination of factors, including stream geomorphology, meander wavelength, and a minimum-maximum length criterion. The primary determinant of sampling reach length is geomorphology. The sampling reach should include at least two examples each of two different types of geomorphic channel units. However, where this is not possible (for example, a stream that is a continuous run), the length of the sampling reach should include one meander wavelength, based on 20 times the distance of the channel width (Leopold and others, 1964). These criteria have been recommended for determining the length of sampling reach for sampling fish community structure (Lyons, 1992) because fish species richness is a function of the number of geomorphic channel units sampled (Gorman and Karr, 1978; Angermeier and Schlosser, 1989), and the size and spacing of these units are functions of stream size (Leopold and others, 1964). In addition, a minimum-maximum length criterion is used to provide a minimum sampling reach length necessary to ensure the collection of a representative sample of the fish community and limit sampling reach length to a distance that prevents unnecessary sampling and minimizes crew fatigue (and associated reduction of sampling efficiency).

There is little information concerning the minimum sampling reach length required to obtain a representative sample of the fish community. Studies that examined the relation between the length of stream sampled and fish species richness revealed that the number of species captured increased rapidly over the initial sampling distance (Angermeier and Karr,

1986; Angermeier and Schlosser, 1989; Lyons, 1992). The general relation between sampling distance and number of fish species collected indicates that as sampling distance increases, fewer species are collected until an asymptote is achieved where increasing sampling reach length causes little or no increase in the cumulative number of fish species collected (fig. 1). A sampling reach length that is equal to or exceeds this asymptotic sampling distance is more likely to produce a representative sample of the fish community than a shorter sampling reach length. Therefore, the asymptotic sampling distance represents the ideal minimum sampling reach length required for collecting a representative sample of fish.

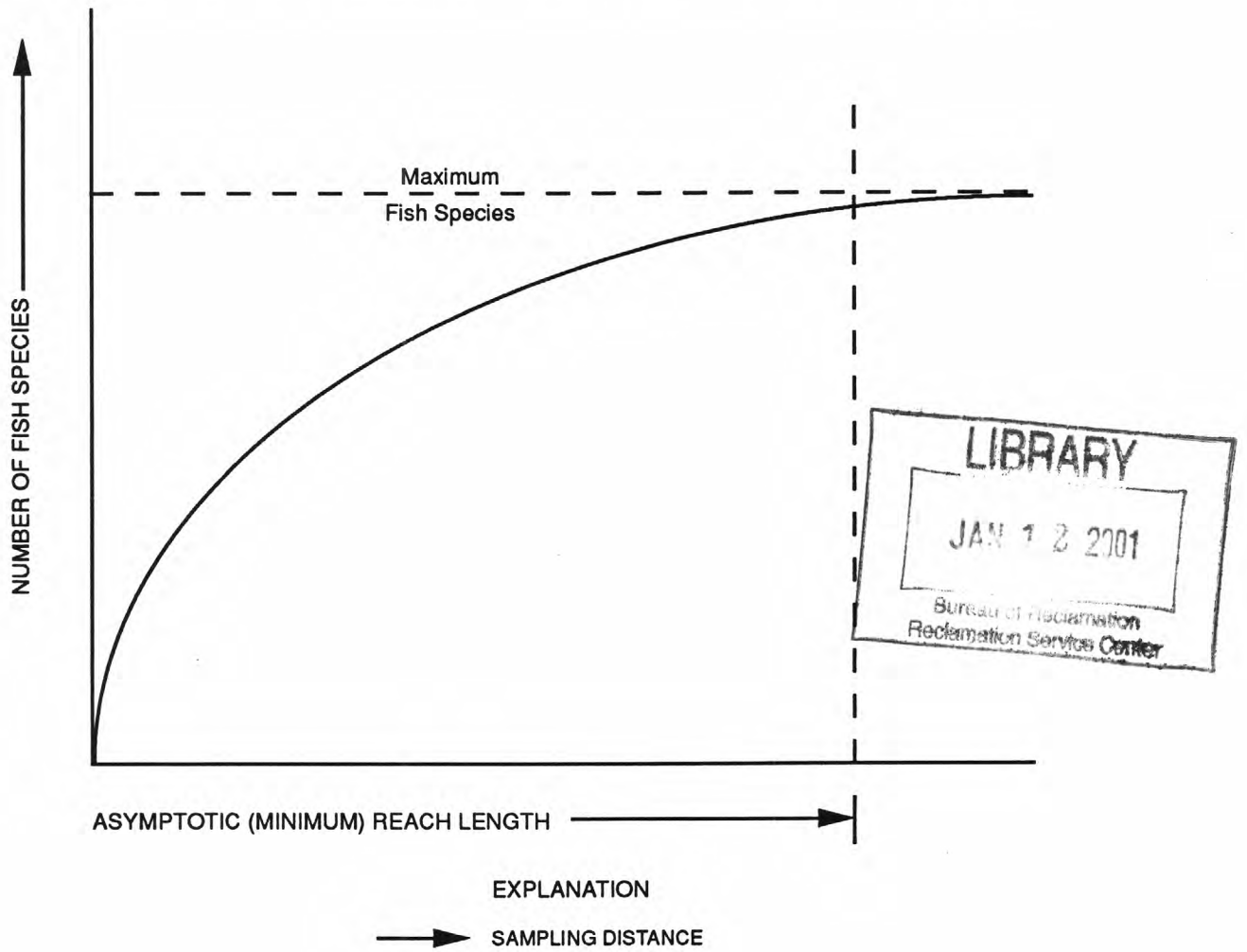

Figure 1.--Representation of the relation between sampling distance and the number of fish species collected.

The asymptotic sampling distance or minimum sampling reach length necessary for sampling fish communities is generally stream dependent. Differences in the rate at which the number of fish species collected increases with increasing sampling reach length vary within and among streams (Lyons, 1992). One approach to determining the minimum sampling reach length required at each site would be to initiate an iterative sampling procedure whereby the number of fish species collected over the distance sampled is

determined as sampling is conducted. Sampling would be discontinued when little or no increase in the cumulative number of species is observed. The minimum sampling reach length would then be calculated at every sampling reach as a result of sampling. However, such a procedure is likely to be more time consuming and difficult than sampling a specified distance. It would also require that fish sampling always be conducted prior to other NAWQA sampling efforts, and this may not be feasible.

Fish community sampling as part of NAWQA is based on a minimum sampling reach length established prior to fish sampling and not as a result of fish sampling. Matthews (1990) recommended a minimum sampling reach length of greater than 100 m for sampling fish communities in wadeable (less than or equal to about 1 m deep) warm-water midwestern streams. Lyons (1992), in a study of Wisconsin warmwater streams, calculated a median asymptotic sampling distance of 222 m. However, the author noted that at several sites, substantially shorter sampling distances yielded similar estimates of fish species richness. Based on these studies, a minimum sampling reach length can be estimated at more than 100 m but less than about 200 m. Therefore, the minimum sampling reach length for NAWQA fish sampling in wadeable streams is designated as 150 m, which is the same as that recommended by the Ohio Environmental Protection Agency (1987).

Criteria for determining minimum-maximum sampling reach lengths for nonwadeable streams (those requiring a boat to sample) are less clear than those for wadeable streams. Lyons (1992) suggested that a positive correlation is likely to exist between asymptotic sampling distance and stream size (width), and that larger streams may require greater sampling distances than do small streams. This suggestion is supported by other water-quality monitoring protocols that describe procedures for collecting fish samples to characterize fish community structure in nonwadeable streams (Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989). These sources suggest that a minimum sampling reach length of 500 m is necessary to collect a representative sample of fish in nonwadeable streams. Therefore, the minimum sampling reach length for NAWQA fish community assessment at nonwadeable sites is designated as 500 m.

A maximum sampling reach length criterion is required to prevent unnecessary sampling and minimize any reduction of sampling efficiency as a result of crew fatigue. In some cases, determination of the sampling reach length based on geomorphic channel units or meander wavelength results in a sampling reach length that exceeds the minimum length required to collect a representative sample of fish. For example, some streams are relatively wide (greater than 30 m), yet too shallow to accommodate a boat. Sampling of such streams could result in sampling reach lengths greater than 600 m, a sampling distance that greatly exceeds the distance required to obtain a representative sample and one that could result in reduced sampling efficiency as a result of crew fatigue.

No published studies have addressed maximum sampling reach length with respect to fish sampling. A maximum sampling reach length, as with a minimum sampling reach length, is stream dependent. However, for reasons discussed in determining a minimum sampling reach length, an estimated maximum sampling reach length must be established prior to sampling. The Ohio Environmental Protection Agency (1987) and Plafkin and others

(1989) suggested that 200 m represents a maximum sampling reach length for wadeable streams. However, Lyons (1992) reported that although about 200 m represented a median asymptotic distance, in some cases sampling distances as great as 500 m were required to achieve a representative sample of fish species. Therefore, a sampling reach length of 300 m for wadeable streams is estimated as the maximum length of sampling reach necessary to ensure the collection of a representative sample of fish as part of NAWQA, yet minimize unnecessary sampling and reduced sampling efficiency as a result of crew fatigue. However, in relatively wide (greater than about 30 m) wadeable streams, a maximum reach length of 500 m should be considered. The maximum sampling reach length for fish community sampling in nonwadeable streams as part of the NAWQA Program is designated as 1,000 m, which is the same as that recommended by the Ohio Environmental Protection Agency (1987) and Plafkin and others (1989).

Selection of Sampling Sites

Sampling sites are generally chosen to represent the set of environmental conditions deemed important for controlling water quality in the study unit. Sites should represent combinations of natural and human factors thought to collectively influence the physical, chemical, and biological characteristics of water quality in the study unit and to be of local, regional, or national importance. Two distinct types of sampling sites are established as part of NAWQA--fixed sites and synoptic sites.

Fixed sites are typically located at or near USGS gaging stations where continuous discharge measurements are available. At these sites, broad suites of physical and chemical characteristics are measured along with characterizations of fish, benthic invertebrate, and algal communities. Three sampling reaches are established to represent environmental conditions associated with each fixed site. Three sampling reaches are the minimum necessary to establish a meaningful estimate of variability among sampling reaches. Major discontinuities in riparian or instream characteristics within or among sampling reaches should be avoided. The reaches should also include only those habitat features that truly represent the physical conditions of the stream. For example, if a stream is composed predominantly of a sequence of riffles and runs with one large pool, the pool should not be included in a sampling reach. Inclusion of the pool would incorrectly emphasize pool-dwelling species, thereby providing an estimate of the local fish community rather than an estimate of the fish community that is representative of the stream.

The distance between sampling reaches at fixed sites should be equal to the minimum sampling reach length (150 m for wadeable streams and 500 m for nonwadeable streams), to ensure the establishment of distinct sampling units. At a subset of fixed sites, multiple sampling reaches (minimum of three) are sampled in one year to assess the magnitude of sampling reach-to-reach variability. One sampling reach is sampled in each of three successive years to estimate short-term temporal variability.

Synoptic sites are typically nongaged sites where one-time samples of a limited number of physical and chemical characteristics are measured with the objective of answering questions regarding source, occurrence, or spatial distribution. When fish

samples are collected at synoptic sites, only one sampling reach is required. Retrospective data can provide information concerning questions addressed by synoptic sites.

Sampling Season

The sampling season should occur during low- and stable-flow periods (usually mid-June to early October). Sampling during low- and stable-flow conditions minimizes problems that occur with reduced stream access during higher flows, and maximizes the suitability of wadeable stream sampling methods, which facilitates comparability of data among sites. Choosing a sampling season in which flow variability is low increases the likelihood that samples throughout the study unit can be collected under similar flow conditions and reduces the chance that an unusually high flow would interfere with sampling.

Life history characteristics also must be considered in relation to the sampling season. Many fish species make extensive seasonal migrations. However, studies have shown that fish populations and individual fish tend to remain in the same area during summer low-flows (Funk, 1957; Gerking, 1959; Cairns and Kaesler, 1971). Thus, sampling efficiency tends to be greatest during this time period (Allen and others, 1992).

FISH COMMUNITY SAMPLING CONSIDERATIONS

Fish community sampling considerations must be addressed before sampling takes place and fish community structure is characterized. Data collection is only a part of the process of gaining an understanding of fish community structure. In addition to analyses of retrospective data and reconnaissance of candidate sampling locations, consideration must be given to collecting permits; protecting endangered, threatened, or special-concern species; and coordinating sampling efforts with other fish ecologists.

Collecting Permits

Collecting permits must be obtained prior to sampling, and all project personnel must comply with State laws regarding fish sampling. The collection of fishes is regulated through State-issued collecting permits. State agencies typically require permit holders to submit a report summarizing data-collection efforts. Sufficient lead time (at least 2 months) must be allowed between the time of permit application and scheduled dates for sampling. The appropriate law enforcement authorities must be contacted prior to each sampling event, because some of the methods or gear approved in a collecting permit are illegal for use by nonpermit holders.

Endangered, Threatened, or Special-Concern Species

Endangered, threatened, or special-concern species require careful consideration during sampling. Endangered species are those in danger of extinction throughout all or significant parts of their ranges. Threatened species refers to those taxa that are likely to become endangered in the near future. These definitions were established by the Endangered Species Act of 1973, and aquatic organisms defined as endangered or threatened

are provided legal protection by one or more agencies as a result of this legislation. Species of special concern are recognized by agencies as declining in number or distribution, yet too few data are available to determine if they require designation as threatened or endangered. Although special-concern species may not be protected by legislation, they may receive some security through agency recommendations and regulations concerning collecting procedures (Johnson, 1987).

Williams and others (1989) provided a list of North American fishes that were classified as endangered, threatened, or special-concern species. This list consisted of 103 species classified as endangered, 114 as threatened, and 147 as special concern. The highest concentrations of listed taxa in the United States occurred in the southwest (Arizona, California, Nevada, New Mexico, and Texas) followed by the southeast (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia).

The collection of species listed as endangered, threatened, or special concern by the Federal government is regulated by the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service biologists serving as regional coordinators with the NAWQA Program can assist study-unit biologists in obtaining the necessary Federal permits for endangered, threatened, or special-concern species and ensuring that all regulations regarding these species are observed. Individual States also list and protect endangered, threatened, or special-concern species. Though the process of obtaining additional permits for the collection of these species may vary from State to State, regulations regarding collection must be observed and the necessary permits obtained before collections can be made.

Coordination of Sampling With Other Fish Ecologists

Efficient data collection requires coordination of sampling with other fish ecologists, including agency fisheries biologists, university fisheries scientists and ichthyologists, and fisheries professionals employed by private organizations. These fish ecologists may have ongoing or planned sampling activities within the study unit. Information on the location, timing, and objective(s) of their sampling activities is helpful. Repeated sampling of an area by a number of different fish ecologists may seriously bias fish community data. Repeated collections within a relatively short time period reduces species diversity, thereby providing an erroneous representation of the fish community. Also, coordination of sampling with other fish ecologists may result in collaborative efforts that could enhance the characterization of fish communities in the study unit.

METHODS FOR SAMPLING FISH COMMUNITIES

Electrofishing

Electrofishing is the use of electricity to capture fish. The electricity is generated by a system whereby a high voltage potential is applied between two or more electrodes that are placed in the water. The voltage potential is created using either of two basic types of electrical current--direct current and alternating current. Direct current leaves the cathode (negative electrode) and enters the anode (positive electrode), flowing in one direction only

because the electrodes of the circuit are always the same. Alternating current changes directions as the anode and cathode switch positions between the electrodes.

The types of electrical current produce different electrical current shapes or wave forms. Alternating current produces a wave form that consists of a sequence of positive and negative waves that are equal, usually sinusoidal, and follow each other alternately at regular time intervals. Direct current produces a unidirectional, constant electrical current. Pulsed direct current, a modified direct current, produces a unidirectional electrical current composed of a sequence of cyclic impulses.

The responses of fish to electricity are determined largely by the type of electrical current and its wave form. These responses include avoidance, electrotaxis (forced swimming), electrotetanus (muscle contraction), electronarcosis (muscle relaxation or stunning), and death. Forced swimming without orientation relative to the electrical current (oscillotaxis) is a typical fish response to alternating current. Alternating current can be damaging to fish, resulting in hemorrhaged tissue, ruptured swim bladders, and fractured vertebrae because of severe electrotetanus caused by the alternating polarity of alternating current. Direct current forces fish to swim with orientation toward the anode (galvanotaxis). The modified pulsed direct current can sustain galvanotaxis longer than unmodified direct current, and with less likelihood of damage to the fish than unmodified direct current or alternating current.

The frequency of the pulses produced when using pulsed direct current can be adjusted by the operator and usually ranges from 15 to 120 pulses per second (pps). High pulse frequencies (greater than 30 pps) have proven to be more effective in collecting fish but appear to cause spinal injuries, particularly in trout and salmon species (Coffelt Manufacturing, Incorporated, written commun., 1991). Pulse rates below 30 pps have caused low incidence of injury, but are generally ineffective in collecting fish. Therefore, a pulse rate range of 30 to 60 pps is recommended to provide maximum collection effectiveness with a minimum potential for damage to fish.

Water conductivity also influences the response of the fish to the electrical field and is the single most important limiting factor in electrofishing effectiveness. Low-conductivity water is highly resistant to the flow of electrical current, thereby reducing the amount of electrical current traveling through the water and passing through the body of the fish. Under such conditions the electrical field is limited to the immediate area of the electrode. Thus, a relatively high output voltage is required to create an electrical field of sufficient size and strength to stun fish. High-conductivity water produces the opposite effect by concentrating a narrow electrical field between the electrodes. In high-conductivity water, output voltage must be reduced to minimize potential damage to the fish. Most electrofishing equipment is designed to operate in water with conductivity ranging from 20 to 2,000 microsiemens per centimeter, and is usually capable of generating output voltages of 100 to 1,000 volts. An electrical field strength meter is used to determine the size and strength of the electrical field generated by the electrofishing equipment. The conductivity of the water must be measured prior to electrofishing to determine the appropriate output voltage for effective electrofishing.

Wadeable Streams

Backpack or towed electrofishing gear are used for sampling fish in wadeable streams. Backpack electrofishing units consist of electrofishing devices mounted on backpack frames. The power source is either a 24-volt deep cycle battery or a 115-volt gasoline-powered generator. Backpack electrofishing is usually most effective in relatively shallow (less than 1 m), small (not greater than 5 m wide) headwater streams. Towed electrofishing gear consists of a portable generator and electrical output control mechanism, placed within a small boat towed behind (or pushed in front of) an operator. Towed electrofishing gear is usually more effective in relatively wide (greater than about 5 m) wadeable streams with deep pools (greater than 1 m deep). Channel width, channel depth, and access for towed electrofishing gear must be considered in determining the choice between backpack and towed electrofishing methods.

Regardless of the gear chosen, electrofishing procedures for wadeable streams require an electrofishing crew consisting of three to six individuals. Using backpack electrofishing gear, one crew member is the operator of the electrofishing equipment. With towed gear, three crew members are needed to operate the electrofishing equipment. With either gear, two crew members collect fish with dip nets, while an additional crew member is sometimes needed to transfer collected fish to a holding container. All crew members must wear polarized glasses to enhance their ability to see fish that have been stunned by the electrical field.

Procedures for collecting samples using backpack or towed electrofishing gear are similar. Sampling begins at the downstream boundary of the sampling reach and is conducted in an upstream direction. Disturbance caused by electrofishing crews walking in the stream increases turbidity, thereby greatly reducing visibility and collection efficiency. Therefore, sampling in an upstream direction maximizes visibility and collection efficiency. Also, sampling in an upstream direction allows stunned fish to drift downstream, facilitating their capture by crew members. Thus, sampling in an upstream direction in wadeable streams is preferred over sampling in a downstream direction (Hendricks and others, 1980).

All geomorphic channel units and habitat features, such as log jams, macrophyte beds, or large boulders within the wadeable sampling reach, are sampled using pulsed direct current. This may require electrofishing from one shoreline to the other in a "zigzag" pattern, consistently sampling all areas within the sampling reach. Collecting fish from the entire length of the sampling reach is referred to as a "pass" and may require more than one electrofishing operating technique.

A common electrofishing operating technique is to apply electrical current to the water continuously. Fish tend to respond to continuously applied electrical current by attempting to avoid exposure to the electrical field. Thus, continuous application of electricity can result in fish moving just ahead and away from the operator. The operator should be aware of this response and take advantage of natural barriers such as banks or bars, or very shallow areas to "herd" fish into and facilitate their capture. If natural barriers are not available, then seines or other "blocking" nets can be used to create a barrier at the upstream boundary of the sampling reach, thereby increasing sampling efficiency. However, the use of blocking

nets at both the upstream and downstream boundaries to isolate the sampling reach is not required to collect a representative sample of fish. If blocking nets are used, they must be used in the same manner during repeated sampling of the reach for assessment of temporal trends.

A different electrofishing operating technique is required in areas of habitat complexity. Fish congregating near habitat features are generally dispersed by continuous application of electricity or they are difficult to remove once stunned by exposure to the electrical field. An effective technique for capturing fish associated with habitat features is to approach the habitat feature with the electrical current off. The anode is thrust close to the habitat feature, the electrical current is generated, and the anode is withdrawn in a sweeping motion away from the habitat feature. The fish response to this procedure is galvanotaxis, creating the effect of "pulling" the fish away from the habitat feature and facilitating their capture.

Sampling in riffle areas requires the operator to sweep the anode across the riffle from upstream to downstream while walking in an upstream direction. Crew members with dip nets should be positioned downstream of the operator to allow the flow to carry stunned fish into the net. This minimizes escape and avoidance of the electrical field by fish species, such as darters and sculpins, that commonly inhabit riffles.

All captured fish are placed immediately in either a holding box or live well for later processing. A holding box is usually a net box (generally 1.2 m x 1.2 m x 1.2 m) used to hold fish. Because fish placed in a net holding box are held in ambient water, mechanical aeration is not necessary. However, in streams with high water temperatures and low dissolved-oxygen levels, fish placed in a holding box may become stressed and die as a result of crowding under poor water-quality conditions. Under such conditions a live well is preferable, but mechanical aeration and frequent changes of water are required. If a holding box is used, it should not be placed within the sampling reach where the fish being held could potentially be re-exposed to the electrical field. In either case, all fish are processed immediately following completion of the electrofishing pass and released downstream of the sampling reach to minimize the potential for re-capture.

After the first pass is completed and all fish are processed, a second pass is conducted in the same manner as the first. The second pass is generally, but not always, conducted through the same area as the first pass. For example, in a braided stream, a first pass can be conducted through one channel and the second pass through another channel.

Nonwadeable Streams

Nonwadeable streams are sampled using electrofishing boats. Electrofishing boats vary in design but usually consist of a gasoline-powered generator and an electrical output control mechanism in an aluminum boat. The electrical configuration of the boat also varies. However, generally the boat is configured as the cathode, with anode arrays consisting of single (stainless steel cable), circular (hollow stainless steel ball), or multiple (several stainless steel cables) configurations.

A boat electrofishing crew consists of a driver and one or two persons who collect the fish with dip nets. The driver should be skilled at maneuvering the boat as effectively as possible to allow crew members the best opportunity to capture stunned fish. As with wadeable electrofishing methods, all members of the boat electrofishing crew must wear polarized sunglasses.

Sampling begins at the upstream boundary of the sampling reach proceeding in a downstream direction by maneuvering the boat along one shoreline. The shoreline sampled during the first pass is decided at random. The boat is operated at a speed equal to or slightly greater than the water velocity. Sampling is conducted in a downstream direction because fish are usually oriented into the direction of the flow and therefore either swim into the approaching electrical field or turn to escape downstream. Turning to escape orients the fish perpendicular to the electrical field, exposing a greater surface area of the fish to the electrical field and thus making the fish more susceptible to the electrical field. Also, when fish are stunned they are carried downstream by the flow, providing greater opportunity for capture. Thus, when sampling with an electrofishing boat, sampling in a downstream direction is more efficient than sampling in an upstream direction (Ohio Environmental Protection Agency, 1987).

Habitat features along the shoreline are sampled by maneuvering the boat close to the habitat feature with the electrical current off. As the anode array is placed near the habitat feature, the electrical field is generated and the boat is backed away from the habitat feature. The fish are thus "pulled" away from the habitat feature to facilitate their capture. All captured fish are placed in a live well on the boat and processed after completion of the first pass. A second pass is conducted along the shoreline not sampled during the first pass.

Most electrofishing operations are conducted during normal daytime working hours. However, night electrofishing studies have shown that night sampling, particularly in nonwadeable waters, can yield more species and greater numbers of individuals than day sampling (Loeb, 1957; Paragamian, 1989). This is due to a variety of factors including reduced gear avoidance at night and diurnal movements of fish. Night electrofishing of nonwadeable streams has been suggested to provide a more representative sample of fish community structure, and therefore has been recommended for long-term monitoring programs that include large rivers (Sanders, 1992). Night sampling, however, requires overtime, can produce undue fatigue and additional safety risks, and should be avoided if satisfactory results can be obtained during day sampling. Analysis of retrospective information and consultation with other fish ecologists can provide information to assist in determining if day sampling of nonwadeable streams produces a representative sample of the fish community.

Safety

Although safety is a critical concern for all sampling procedures, it is particularly so when electrofishing. Any electrical equipment can be potentially hazardous to the operator if used improperly. A survey conducted by Lazauski and Malvestuto (1990) noted that more than 450 reported incidents of minor electrical shocks as a result of electrofishing occurred in

1982, with 2 deaths and 10 persons receiving injuries serious enough to require admission to a hospital. The authors attributed these accidents to poor training, use of homemade equipment or equipment in poor working condition, and failure to follow simple safety guidelines. However, the fact that electrofishing has been used to collect fish for nearly 90 years (Cowx and Lamarque, 1990) is an indication that it can be conducted in a safe manner with minimal risk to crew members if proper safety procedures are followed.

Certification and training in cardiopulmonary resuscitation (CPR) and electrofishing equipment is an important and essential component of safety. Respiratory arrest or asphyxia (caused by contracted chest muscles) are common physiological responses to electrical shock. All electrofishing crew members are required to become certified in CPR, which can be used to restore breathing. Following certification in CPR, study-unit biologists and at least one additional member of the field crew must become certified by the U.S. Fish and Wildlife Service in the use of electrofishing gear. Once certified in CPR and the use of electrofishing gear, study-unit biologists are responsible for training all electrofishing crew members in the safe operation of electrofishing gear. No individual can participate on an electrofishing crew who has not been certified in CPR and received training in the safe operation of electrofishing gear. The crew leader is designated to be in charge of crew safety and is responsible for ensuring that only trained individuals participate as crew members. In addition, the crew leader is responsible for ensuring that a safety checklist (fig. 2) is completed prior to sampling, that periodic safety inspections are conducted, and that an emergency plan is developed that includes a documented route to medical facilities.

Only commercially built electrofishing gear in good working condition should be used; homemade electrofishing gear should never be used to collect fish. Unlike most homemade gear, commercially designed units have many safety features built into the equipment. All equipment should receive periodic maintenance and inspection to ensure proper working condition. Equipment should never be altered or modified in such a way that creates the potential for an accident. For example, automatic shut-off or "deadman" switches must be kept in proper working order and must never be modified so that the electrical current cannot be turned off. Dip nets must be made of nonconducting material (fiberglass, polyvinyl chloride tubing, or nylon), and aluminum dip nets must not be used. All crew members must wear rubber gloves and waders. Rubber gloves should cover the forearm for maximum protection. Chest waders with nonslip soles should be worn when using wadeable methods; hip boots are preferable when boat electrofishing. Gloves and waders should be inspected for leaks before entering the water.

Safety guidelines must be followed to ensure safe operation of electrofishing gear. These guidelines include important rules for field operations, such as (1) leaving the water immediately if waders or gloves develop leaks; (2) avoiding operation of electrofishing equipment near people, pets, livestock, or wildlife that are in or near the water; (3) ceasing operations in inclement weather (moderate to heavy rain, lightning, or thunderstorms); (4) resting often to avoid fatigue; (5) making all electrical connections or disconnections while the unit is turned off; and (6) refueling generators with equipment turned off and when surfaces have cooled. Most importantly, all crew members should be alert and conscious of potential hazards, act in a professional manner, and use common sense. Additional

ELECTROFISHING FIELD SAFETY CHECKLIST

Electrical Equipment

- ❑ Electrical connections secure and protected
- ❑ Gages and wiring in proper working condition
- ❑ "Deadman switch" in operating condition
- ❑ Anodes in good condition; attached to handles securely [wadeable streams]

Ancillary Equipment

- ❑ Fire extinguisher - fully charged
- ❑ First-aid kit present
- ❑ Dip net handles constructed of nonconductive material

Crew Members

- ❑ Trained in electrofishing operation
- ❑ Wearing rubber gloves (inspected for leaks)
- ❑ Wearing chest waders (inspected for leaks) with nonslip soles [wadeable streams]
- ❑ Wearing hip boots (inspected for leaks) [nonwadeable streams]

Signature _____ Date _____

Figure 2.--Suggested field safety checklist for electrofishing operations.

guidelines for safe operation of electrofishing equipment are discussed by Reynolds (1983) and Goodchild (1991).

Seining

Seining is a common method for sampling fish communities in streams (Bagenal, 1978; Nielsen and Johnson, 1983) and is used to complement electrofishing collections in order to obtain a representative sample. Although electrofishing is viewed as the most effective single method for sampling fish communities in streams (Bagenal, 1978; Plafkin and others, 1989), it is reported to be size selective, with large fish more susceptible to capture than small ones (Wiley and Tsai, 1983). Therefore, electrofishing alone should not be used to assess fish community structure (Reynolds, 1983). Unlike electrofishing, seining is an effective technique for collecting small-size individuals and should be conducted following electrofishing to complement electrofishing collection efficiency and obtain a representative sample.

Seines are collection devices that trap fish by enclosing or encircling them. The fish are then sieved from the water by means of mesh panels. The bottom or lead line has lead weights strung or crimped onto it to weight the net. The top or float line includes cork, polystyrene foam, or plastic floats to keep the top of the seine near the water surface. The net is attached to wood or metal poles to handle the seine.

Seines are manufactured in a variety of dimensions and mesh sizes. However, three types of seines are commonly used to study fish community structure: (1) 3 x 1.2 m, (2) 7.6 or 9.1 x 1.2 m, and (3) about 30.5 to 61 x 1.8 m. The 3- x 1.2-m seine is referred to as a "common sense" seine (Hendricks and others, 1980; Bryan, 1984) and is attached to two wooden poles 31.8 mm in diameter. A mesh size of 6.4 mm is appropriate for the common sense seine. The 7.6- or 9.1-m seine has a bag or pocket in the center of the seine and, thus, is referred to as a bag seine. As the bag seine is pulled through the water, fish are herded toward the center of the net and into the bag. As with the common sense seine, a bag seine is attached to two 31.8-mm diameter wooden poles and usually has a mesh size of 6.4 mm. A beach or drag seine is typically used along the shorelines of large bodies of water and is usually greater than 30 m long. Because of the greater length, a larger mesh size (9.5 mm) and larger dimension poles (usually 51 mm x 51 mm) are required for the beach seine to maximize sampling efficiency and seine durability.

Wadeable Streams

Wadeable streams are sampled by seining using the common sense seine, the bag seine, or both. The choice of the method used is dependent on the geomorphic channel units present and the degree of complexity of the habitat features within a sampling reach. Riffle areas require a seining technique separate from that used in runs or shallow pools. Large areas of submerged objects make seining difficult, and the potential for collecting a representative sample should be evaluated before seining in an area with submerged objects.

In riffle areas, a common sense seine is used to conduct a technique known as "kick seining" (Hendricks and others, 1980; Matthews, 1986; Bramblett and Fausch, 1991). Kick seining is very effective for collecting fish species that live in association with riffles because it involves disturbing the bed material and letting the water current carry specimens into the seine. When kick seining, two persons hold the seine in a vertical position above the water and perpendicular to the flow at the downstream edge of a riffle. They then thrust the poles and lead line of the seine to the stream bottom. The poles are allowed to slant downstream so that the flow forms a slight pocket in the seine. A third person, upstream of the seine, disturbs or kicks the substrate, working downstream toward the seine. This procedure is continued from one shoreline across the width of the channel to the other shoreline so that the entire riffle is sampled. The seine is then lifted out of the water and the fish removed. A sample collected by kick seining is taken at every riffle within the sampling reach. The samples from all riffles are combined, and the fish are processed before release.

In wadeable sampling reaches that are relatively free of obstructions, the bag seine is used. Local fish ecologists should be consulted to assess the length of bag seine that has proven to be the most efficient for sampling the fish community in the study unit. Sampling with a bag seine involves sweeping the bag seine through the water, keeping the lead line as close as possible to the stream bottom, and finishing the haul by dragging the bag seine onto the shore. Seining downstream has proven to be the most effective in collecting fish (Hendricks and others, 1980). If the seine cannot be dragged onto shore easily, the bottom ends of the poles can be brought as close to shore as possible. The seine is then quickly stretched between the poles, lifted out of the water, and carried onto shore. Three bag seine hauls are conducted in the sampling reach, each covering an area of about 50 m, and taken from the upper, middle, and lower sections of the sampling reach. The fish from the three seine hauls are combined and processed before release.

Nonwadeable Streams

Nonwadeable streams can be sampled using a beach seine in wadeable shoreline areas, if present. As with the bag seine, the exact length of the beach seine should be determined after consultation with local fish ecologists. Beach seining is conducted by maintaining one end of the seine stationary on the shore while the remainder of the seine is deployed into the water so that it is roughly perpendicular to the shore. The seine is then pulled in a downstream direction and hauled through the water in a semi-circular movement. Three beach seine hauls are conducted in the nonwadeable sampling reach, the length of each equaling that of the seine. The three samples should be taken from accessible parts of the upper, lower, and middle sections of the nonwadeable sampling reach. The fish from the three seine hauls are combined and processed before release.

Other Sampling Methods

Other sampling methods in wadeable or nonwadeable streams may be necessary to obtain a representative sample of the fish community for NAWQA. In most cases, electrofishing and seining can be conducted in a sampling reach. However, there may be instances where these methods may not be effective in producing a representative sample.

For example, in extremely low-conductivity water (less than 20 microsiemens per centimeter), electrofishing is ineffective. In sampling reaches that do not contain riffles but do contain a large number of woody snags, debris, or other obstructions, seining may be ineffective. In these cases, other sampling methods may be necessary. The decision to substitute sampling methods is based on factors such as site conditions, consultation with local fish ecologists, and State regulations regarding the use of other sampling methods. The most commonly used other sampling methods for collecting a representative sample of fish include gill netting and hoop netting.

Gill Netting

Gill netting is the capture of fish by entanglement in a fabric mesh that is not actively moved by man or machine. Although gill netting requires little skill or special training, it requires two trips (one to deploy the net and one to collect the fish) and has a potential for vandalism of the gear. Gill netting also kills many fish caught in the net or injures fish upon removal. For this reason, gill netting must not be conducted in areas where endangered, threatened, or special-concern species may be present.

Gill nets are composed of fabric mesh attached to a lead line and float line. Gill nets vary in material, mesh size, and type, all contributing to the selectivity of the gear. Gill net mesh can be made of cotton, linen, nylon, and monofilament or multifilament twine. However, monofilament and multifilament mesh are considered superior to other materials because they are less visible to fish, easier to clean, and more durable. Mesh size is generally expressed as bar measure or stretch measure. Bar measure is the distance between knots. Stretch measure is the length of a single mesh when the net is stretched taut. Mesh sizes vary with the three types of gill nets available--standard, trammel, or experimental.

Standard gill nets are composed of a single panel of mesh of one size. Because standard gill nets are constructed of one mesh size only, they tend to be selective for individuals of the same size or in some cases a single species (Hubert, 1983). Therefore, standard gill nets are generally not effective for collecting a representative sample of the fish community.

Trammel nets are composed of three panels of mesh suspended from a float line to a single lead line. The two outer panels of mesh are constructed of a larger mesh size than the inner panel. Although trammel nets are less size selective than standard gill nets, trammel nets tend to be selective for fish species with rough surfaces and protrusions, such as sturgeon, catfish, or temperate basses (Hubert, 1983).

Experimental gill nets usually have several 4.5- to 15-m panels of various mesh sizes, thus reducing the potential for size selectivity. Unlike trammel nets, experimental gill nets are less selective for any particular groups of species. Experimental gill nets 1.8-m deep with six sections of monofilament mesh 7.6-m long each, using 13-, 25-, 38-, 51-, 76-, and 102-mm mesh size (bar measurements) are used to collect a representative sample for NAWQA (fig. 3).

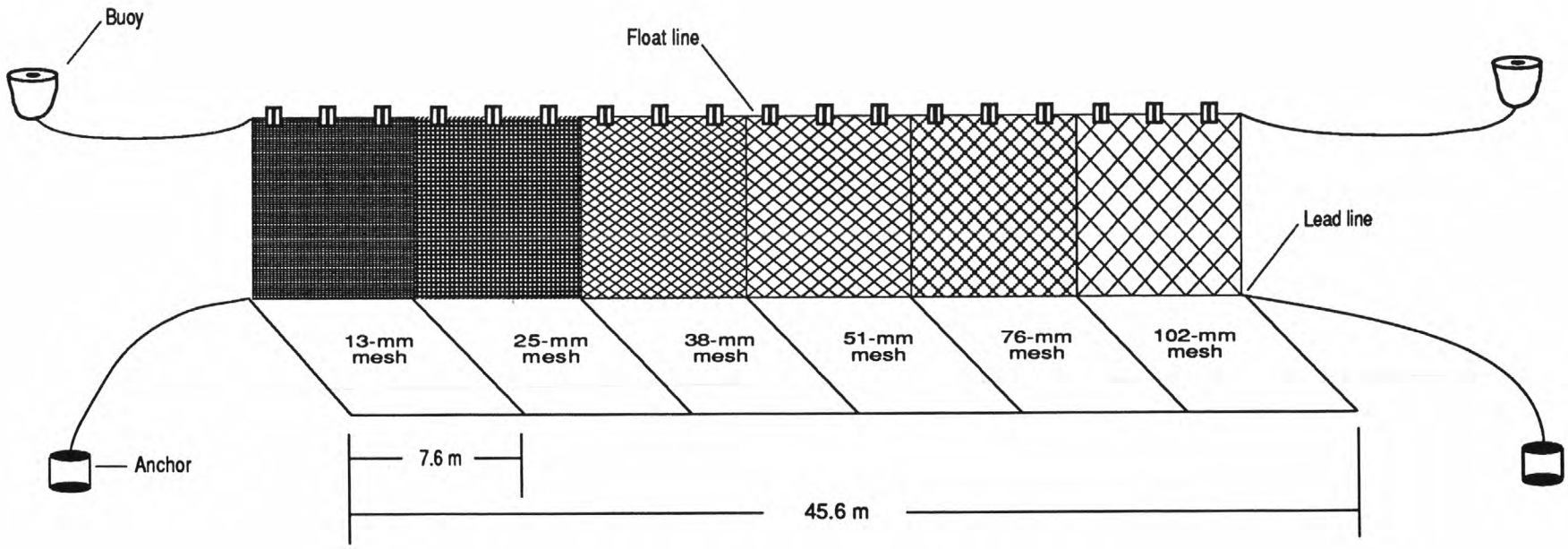

Figure 3.--Sketch of an experimental gill net.

The experimental gill net must be rigged with anchors on the lead line at both ends of the net, and buoys at the float line at both ends of the net. Also, the net must be tagged with some type of identification to indicate ownership. If the net is set (suspended in the water column) perpendicular to the shoreline, one end of the float line should be attached to the shore. The length of rope attaching the anchor to the lead line should be long enough so that the lead line of the net is resting on the stream bottom. However, if conditions do not permit a gill net set perpendicular to shore (high-water velocity carrying debris that could damage the net or reduce sampling efficiency), then the net should be set parallel to the current. The gill net set depends on flow conditions and procedures used by local fish ecologists.

The net should be set in the late afternoon and remain in the water for a period of several hours but no longer than 24 hours. The number of fish collected in a gill net is not linearly related to the duration of the set (Hubert, 1983). The exact duration of the set to achieve the maximum catch depends on flow conditions and the presence of drifting debris. Additional considerations concerning the duration of the set are high water temperatures (accelerating decomposition of fish that may die in the gill net) and State regulations that may restrict the duration of the set. The decision concerning the duration of the set should be made after consultation with local fish ecologists.

Two experimental gill nets are set for each nonwadeable sampling reach. Each experimental gill net should be located within the sampling reach where it would be (1) most effective in collecting a representative qualitative sample, (2) least likely to be damaged from snags or debris, (3) least likely to present a hazard to the public, and (4) least likely to be vandalized.

Hoop Netting

Hoop netting is the capture of fish by entrapment in an enclosed mesh trap. It has many of the advantages and disadvantages of gill netting; however, unlike gill netting, fish caught by hoop netting can be released with little or no harm to the fish.

Hoop nets are cylindrical traps that are fished passively in moderate or low velocities. They are usually constructed of nylon mesh hung on round frames (hoops) made of steel, fiberglass, wood, or flexible plastic pipe and have one or more funnel-shaped throats inside the net to retain the catch (fig. 4). Hoop net mesh sizes vary from 12.7- to 101-mm bar mesh, strung on hoops that vary from 0.3 m in diameter to 2.4 m, or greater. The mesh can be chemically treated to increase the durability of the hoop net. Though hoop nets are selective for certain species, they often collect species not caught by other gear. Some fishes that avoid or are not susceptible to gill netting, seining, or electrofishing can be captured with hoop nets (Hubert, 1983).

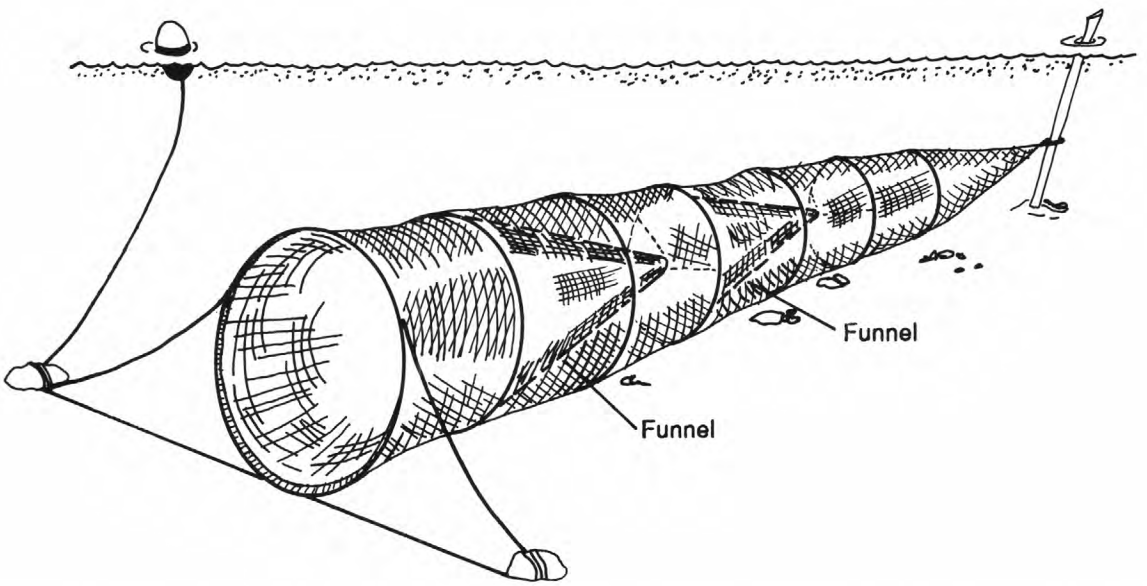

Figure 4.--Diagram of a typical hoop net (modified from Nielsen and Johnson, 1983).

Hoop nets with different mesh sizes are reported to be size selective and species selective (Starrett and Barnickol, 1955; Hubert and Schmitt, 1982; Holland and Peters, 1992). Holland and Peters (1992) compared the catch of baited hoop nets with mesh sizes of 25, 32, and 38 mm and noted that mean fish length and species diversity increased with increasing mesh size. The authors determined that 38-mm mesh hoop nets collected the greatest number of species.

Hoop nets used as part of NAWQA should be constructed of fiberglass hoops 0.6 m in diameter, with funnels on the second and fourth of the seven hoops, untreated 38-mm mesh (bar measure), and should be 3.7 m long. Hoop nets should be baited with cheese, pressed soybean cakes, or some other material and then set in the water along a steep bank or on the outside bend of the stream. The net is set by securing the cod or tapered end to a tree or post, or anchored to the bottom. The net is played out with the current until fully extended, and then is allowed to settle to the bottom. The mouth of the net is directed downstream to minimize clogging with debris. The current helps to keep the hoops separated and the net stretched. However, the mouth of the net may need to be secured to a tree, post, or anchor to ensure that the hoop net is set properly. The net is marked with a buoy for easy retrieval and identification purposes.

The duration of time that a hoop net is set depends on the same factors that influence the duration of the set of a gill net and should be determined in a similar fashion. To harvest, the hoop net is raised at the cod end and the fish are removed. Two hoop nets are set within the sampling reach, the location of which should be determined after consideration of the same factors that influence gill net locations.

Additional Methods

Additional methods have been described for collecting fish (Bagenal, 1978; Nielsen and Johnson, 1983; Bryan, 1984) and may be considered as possible substitutes for the methods previously described. For example, snorkeling or trawling may offer the best solution to collecting a representative sample in those areas where previously described methods are ineffective. However, all additional methods should be considered only in areas where the described methods are ineffective, after consultation with local fish ecologists concerning the most appropriate method for collecting a representative sample, and in cooperation with local fish ecologists. Once methods have been chosen for sampling a reach, the same methods must be used for subsequent sampling to assess temporal trends.

Sample Processing

Sample processing requires handling fish to collect information on taxonomic identification, length, weight, and the presence of external anomalies. Unfortunately, fish can suffer stress and mortality as a result of handling. Handling stress can be minimized and fish can be handled more easily if they are anesthetized. Quinaldine, tricaine methanesulfonate, and benzocaine are chemicals that are commonly used as fish anesthetics (Stickney, 1983). However, because of the restrictions on use of these chemicals (Schnick and others, 1979), they should not be used for NAWQA sampling. Carbon dioxide, present in carbonated water or generated from a solid tablet, serves as an effective fish anesthetic (Summerfelt and Smith, 1990). No restrictions exist concerning the use of carbon dioxide; therefore, it is the chemical used to anesthetize fish collected for NAWQA.

Fish are typically placed into a holding container filled with ambient water. Carbon dioxide (approximately 350 mL of carbonated water or two tablets containing carbon dioxide per 12 L of ambient water) is added to the water in the container. Only a relatively few fish should be anesthetized at one time to minimize any potential mortality as a result of prolonged sedation. Fish remain in the container until the desired level of sedation is achieved (about 2 to 5 minutes). Once sedated, the fish may be handled as needed but must not be kept out of water any longer than absolutely necessary.

Taxonomic Identification

Taxonomic identification is made only by an ichthyologist who is familiar with the taxonomy of fish species commonly found in the study unit. Taxonomic nomenclature follows that established by the American Fisheries Society's Committee on Names of Fishes (Robins and others, 1991). An attempt is made to identify all fish in the field to the species level. Measurements of length and weight and the presence of external anomalies are determined in the field for those fish that can be so identified. Uncertainty regarding identification requires that those specimens be preserved for later identification in the laboratory.

Length Measurements

Length measurements are determined using a measuring board consisting of a linear metric scale on a flat wooden or plastic base with a rigid head piece. Fish are measured with

the body positioned on its right side, the head facing the observer's left, and the mouth closed. Measuring boards can be constructed or purchased from commercial sources.

Total and standard length measurements are made and the data recorded to the nearest millimeter. Total length is the distance from the closed mouth to the extreme tip of the caudal or tail fin, when the lobes of the caudal fin are squeezed together (fig. 5). Total length is the conventional body-length measure of fish for fisheries agencies. Standard length is the length from the closed mouth to the posterior end of the fleshy caudal peduncle. Standard length is important to taxonomic studies because it is unaffected by caudal fin anomalies. Retrospective data may include both total length and standard length. Thus, both length measures are required for NAWQA samples.

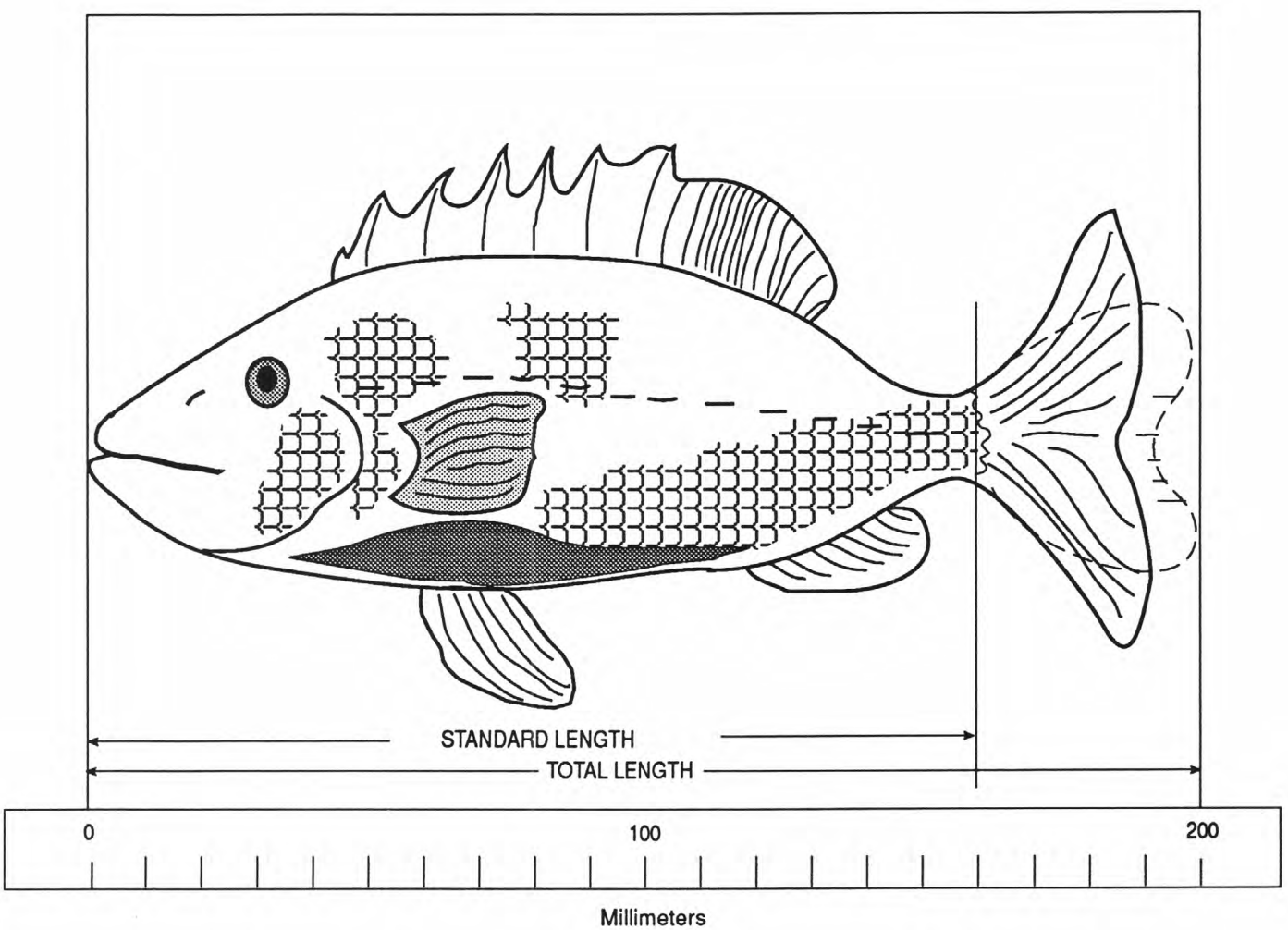

Figure 5.--Total and standard length measurements of a fish.

Length measurements are recorded individually for at least 30 individuals of a species collected from the sampling reach. These 30 specimens are randomly selected for measurement from the total number of individuals for each species so as to represent the variety of lengths present in the sample.

Weight Measurements

Weight measurements are recorded by placing the fish into a small plastic container set on a portable electronic balance. Care should be taken to ensure that the balance is reasonably level and protected from the weather to minimize any error associated with determining weight measurements under field conditions. A hanging scale is required in addition to a portable balance to determine the weight of large fish that exceed the limits of the portable balance. Weight should be recorded to the nearest gram.

Weight is recorded individually for all individuals of a species that are measured for length. For those individuals of a species weighing less than 1 g, an average weight of at least 30 individuals is determined.

External Anomalies

All fish, including those not measured and weighed, are examined for the presence of external anomalies. External anomalies are defined as the presence of externally visible skin or subcutaneous disorders, or parasites (Ohio Environmental Protection Agency, 1987) and require training to detect. The presence of external anomalies may indicate sublethal environmental stresses, intermittent stresses, behavioral stresses, or chemically contaminated substrates. External anomalies include deformities, eroded fins, lesions, tumors, diseases, and parasites.

Deformities are skeletal anomalies that affect the head, spinal vertebrae, and general body shape, and are easily detected. They can be produced by a number of factors, including toxic chemicals, viruses, bacteria, infections, and parasites. Komanda (1980) found that deformities were uncommon in fish populations exposed to optimal water-quality conditions.

Eroded fins are reductions in fin surface area and hemorrhaging along fin rays, which can be caused by chronic disease or parasite infestation. They are also frequently observed in areas of poor water quality, such as high water temperatures, or low dissolved oxygen or high ammonia levels. However, eroded fins can be caused by other factors such as mechanical erosion during spawning. Hatchery-raised fish stocked in streams may also have eroded fins as a result of prolonged holding under crowded conditions in concrete-lined raceways. In addition, damaged fins or fins with irregularities may be the result of tagging studies conducted by local fish ecologists to obtain information for research or management (Wydoski and Emery, 1983).

Lesions often appear as open sores or exposed tissue and can be caused by viral and bacterial infections. Prominent bloody areas on fish are also classified as lesions. However, obvious injuries (for example, lamprey scars) should not be included unless they are lesions. Lesions can result from exposure to poor water-quality conditions.

Tumors are produced by unregulated cellular growth in tissue and are generally the result of exposure to toxic chemicals or viral infections. Some parasites can cause tumor-like

masses, but these should not be considered tumors. Parasite masses can be squeezed and broken between the thumb and forefinger whereas tumors are firm and not easily broken.

Black spot is a disease caused by a parasite that can be identified by the presence of small black cysts on the skin and fins. Severe infections may cause spinal deformities or secondary infections. In some areas, habitat degradation accompanying agricultural and urban development has been shown to be associated with increased incidence of black spot (Steedman, 1991).

"Ich" is the common term for the disease caused by the protozoan, *Ichthyophthirus multifilis*. This organism can be identified by the presence of white spotting on the external surface of the fish. This disease can occur in wild fish populations but is more common in hatchery-raised fish.

The anchor worm (*Lernaea* spp.) is a parasite that can be identified by the presence of a slender, worm-like body buried in the flesh of a fish. A small, characteristic sore is left after the anchor worm detaches. Attachment sites are included even if the worm is no longer present. If the attachment site becomes infected, it should also be recorded as a lesion.

Leeches are green to brownish segmented worms that can be identified by the presence of two suckers (one on each end) and the ability to contract or elongate their bodies. They may occur anywhere on the external surface of the fish.

The presence of eye anomalies should also be noted. Eye anomalies include discoloration of the lens, blindness, missing eyes, and "popeye" disease. Parasites can attack the lens of the eye causing the eye to deteriorate. Popeye disease is identified by the presence of bulging eyes and is generally caused by gas accumulation in areas where the water is gas supersaturated. It can also occur as the result of fluid accumulation behind the eyes due to viral infection or parasites.

After examination of the fish for external anomalies, the fish is placed in a container of ambient water and allowed to recover from the effects of the anesthetic before release. Fish should be released downstream of the sampling reach so as to reduce the potential for re-sampling, and thereby bias the sample. Not all fish are released at a site; some fish must be fixed and preserved.

Fixing and Preserving of Specimens

Fixing and preserving of specimens are required for fish that cannot be taxonomically identified in the field and for voucher specimens (representatives of specimens collected from each sampling reach). The recommended fixative is a formaldehyde solution known as formalin. When formaldehyde, a gas, is dissolved in water to maximum saturation, it produces formalin, which is about 37- to 39-percent formaldehyde by weight. Formalin is considered a hazardous material and must be handled with care. It is poisonous if ingested, and exposure to small amounts can create such symptoms as a burning sensation in the eyes and nose, watering eyes, headaches, and a sore throat. Working with formalin should be done only in well-ventilated areas. Skin can become sensitized to formalin exposure,

resulting in skin rashes. Any direct skin contact with formalin should be avoided by wearing rubber gloves. If formalin does accidentally contact skin or eyes, the affected area should be washed immediately with water.

For fixing fish tissues, a 10-percent buffered formalin solution (one part formalin and nine parts water) is recommended. Three grams of borax are added per liter of fixative to act as a buffer, neutralizing the pH of the formalin, retarding tissue shrinkage, and preventing decalcification of the tissues. Buffered formalin is poured into a plastic collection jar, and a collection label (fig. 6) is placed inside the jar with an additional label taped to the outside of the jar. Labels should be preprinted on waterproof paper using ink that is resistant to water, formalin, and alcohol, and the information should be recorded on the label using a lead pencil.

U.S. GEOLOGICAL SURVEY
NAWQA FISH COLLECTION

Study Unit:_____ **Station Name:**_____
Station ID Number:_____ **State:**_____
Sampling Gear:_____ **County:**_____
Collected By:_____ **Date:**_____
Reference Location:_____
USGS Quad:_____

Figure 6.--Suggested collection label.

All fish to be preserved are first killed by overdose of carbon dioxide. When placing the fish in the collection jar, care should be taken to ensure that buffered formalin is not splashed into the investigator's mouth or eyes. For fish more than 150 mm in length, an incision about 30 mm long is made along the abdominal body wall on the right side of the fish to ensure penetration of fixative into the body cavity. Fish should be left in buffered formalin for 2 days to 1 week to ensure fixation of tissues.

Permanent preservation of fish specimens requires removing them from buffered formalin after fixation of tissues has occurred. The buffered formalin is treated as a hazardous material and is properly discarded according to State and local guidelines, and the fish is soaked in tap water for 48 hours with one change of tap water during this period. After 48 hours, all tap water is discarded and 40-percent isopropyl alcohol or 70-percent ethanol is added to the collection container for permanent preservation.

BIOLOGICAL QUALITY-ASSURANCE UNIT

The USGS Branch of Analytical Services' Biological Quality-Assurance Unit (Biological QA Unit) located at the National Water-Quality Laboratory provides verification of taxonomic identifications through the collection of voucher specimens and the establishment of a fish reference collection. At each sampling reach, voucher specimens (representatives of taxonomically difficult nongame species collected from each sampling reach) are collected, fixed, and preserved to document and verify species identifications. Occasionally, game fish species may be included as voucher specimens in the unlikely event of questions regarding taxonomy of game fish. However, game fish species generally should not be included as voucher specimens because of their economic and recreational value. If a wide range of sizes occurs for a species collected within a sampling reach, two voucher specimens for that species should be collected--a small-size individual and a larger specimen. Preserved voucher specimens are shipped to the Biological QA Unit for verification and establishment of a reference collection.

A fish reference collection is maintained to corroborate the correct identification of a reported species. A reference collection is necessary because of changes in taxonomy, questions regarding taxonomically difficult specimens, and the fact that there are still new species native to the United States that are occasionally discovered (Jenkins, 1976; Lundberg and McDade, 1990). The importance of establishing a reference collection is further described by Crossman (1980), Haedrich (1983), and Lundberg and McDade (1990).

FIELD DATA SHEETS

Field data sheets should be printed on waterproof paper using water-, formalin-, and alcohol-resistant inks. Recommendations are provided for two data sheets--a fish sampling equipment data sheet (fig. 7) and a fish species data sheet (fig. 8).

Fish Sampling Equipment Data Sheet

The fish sampling equipment data sheet (fig. 7) is divided into two sections--site information and equipment use information. Site information includes the study unit designation, the sampling date, the station name and identification number, investigators, reach conditions, reference location, reach length, and water-quality information. Equipment use information includes specific information about the types of sampling gear used. The purpose of the fish equipment data sheet is to provide a record of all methods and gear used at a sampling reach. One fish equipment data sheet is completed per sampling reach.

The first component of the site information section is the study unit designation. The four-letter code of the study unit name (table 1) is recorded for the NAWQA study unit designation (for example, ALBE for Albemarle-Pamlico Drainage). The sampling date is entered in numeric format for month, day, and year (for example, December 1, 1992, is 12-01-92). The station name may be a descriptive name (for example, Yakima River at Kiona,

Fish Sampling Equipment

1. Study Unit ____ ____ ____ ____ **2. Date** __ __--__ __--__ __
Month Day Year

3. Station Name _____ **4. Station Identification Number** _ _ _ _ _ _ _ _ _ _ _ _

5. Investigators

_____

6. Reach Conditions

_____

7. Reference Location _____
Latitude __ __ deg __ __ min __ __ sec Longitude __ __ deg __ __ min __ __ sec

8. Reach Length _____ **9. Water Quality:** Conductivity _____
Temperature _____ Dissolved oxygen _____

10. Sampling gear:

ELECTROFISHING (CODE)

____ **BACKPACK-First Pass (11A)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

____ **BACKPACK-Second Pass (11B)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

____ **TOWED-First Pass (12A)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

____ **TOWED-Second Pass (12B)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

____ **BOAT-First Pass (13A)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

____ **BOAT-Second Pass (13B)** Model _____ Output voltage_____ Seconds _____
Beginning Time _____ Ending Time _____

SEINING (CODE)

____ **HAUL (21A)** Number of _____ Beginning Time _____ Ending Time_____
____ **KICK (22A)** Number of _____ Beginning Time _____ Ending Time_____
____ **BEACH (23A)** Number of _____ Beginning Time _____ Ending Time_____

GILL NETTING (CODE)

____ **EXPERIMENTAL (31A)** Number of _____ Beginning Time _____ Ending Time_____

HOOP NETTING (CODE)

____ **(41A)** Number of _____ Beginning Time _____ Ending Time_____

ADDITIONAL METHODS (CODE)

____ **(method 1) (51A)** Number of _____ Beginning Time _____ Ending Time_____

COMMENTS: _____

_____

_____

Figure 7.--Fish sampling equipment field data sheet.

Fish Species

1. Study Unit ___ ___ ___ ___ 2. Date __ __--__ __--__ __ Page ____ of ____

Month Day Year

3. Station Name ______________________________ 4. Station Identification Number _ _ _ _ _ _ _ _ _ _ _ _ _

5. Investigators

____

6. Taxonomic Specialist ______________________________ 7. Sampling gear code ________________

SPECIES	TOTAL LENGTH	STANDARD LENGTH	WEIGHT	ANOMALIES	NUMBER

Figure 8.--Fish species field data sheet.

Table 1.--*Four-letter codes for National Water-Quality Assessment Program study units*

Study Unit	Code	Study Unit	Code
Albemarle-Pamlico Drainage	ALBE	Northern Rockies Intermontaine Basins	NROK
Allegheny and Monongahela Basins	ALGH	Oahu	OAHU
Apalachicola-Chattahoochee-Flint River Basin	ACFB	Ozark Plateaus	OZRK
Central Columbia Plateau	CCPT	Potomac River Basin	POTO
Central High Plains	CHPL	Puget Sound Drainages	PUGT
Central Nebraska Basins	CNBR	Red River of the North	REDN
Central Oklahoma	COKL	Rio Grande Valley	RIOG
Cheyenne and Belle	CHEY	Sacramento Basin	SACR
Chicot-Evangeline	CHEV	San Joaquin-Tulare Basins	SANJ
Connecticut, Housatonic, and Thames River Basins	CONN	Santa Ana Basin	SANA
Cook Inlet	COOK	Santee Basin and Coastal Drainage	SANT
Delaware River Basin	DELR	South Central Texas	SCTX
Delmarva Peninsula	DLMV	South Platte River Basin	SPLT
Eastern Iowa Basins	EIWA	Southeastern New England	SENE
Georgia-Florida Coastal Plain	GAFL	Southern Arizona	SOAZ
Great and Little Miami River Basin	MIAM	Southern Florida	SOFL
Great Salt Lake Basins	GRSL	Southern High Plains	SHPL
Hudson River Basin	HDSN	Southern Illinois	SILL
Kanawha River Basin	KANA	Trinity River Basin	TRIN
Kansas River Basin	KANS	Upper Arkansas River	UARK
Kentucky River Basin	KNTY	Upper Colorado River Basin	UCOL
Lake Erie-Saint Claire Drainage	LERI	Upper Illinois River Basin	UIRB
Long Island-New Jersey Coastal Plain	LINJ	Upper Mississippi River Basin	UMIS
Lower Susquehanna River Basin	LSUS	Upper Snake River Basin	USNK
Lower Tennessee River Basin	LTEN	Upper Tennessee River Basin	UTEN
Mississippi Embayment	MISE	Western Lake Michigan Drainages	WMIC
Mobile River	MOBL	White River Basin	WHIT
Nevada Basin and Range	NVBR	Willamette Basin	WILL
New Hampshire and Southern Maine Basins	NHME	Yakima River Basin	YAKI
North Platte Basin	NPLT	Yellowstone River Basin	YELL

WA) or a designated USGS station name, if the site has a gaging station. The station identification number is the designated USGS station number. The full names of all sampling crew members should be entered as the investigators, with the crew leader's name in parentheses. Information on reach conditions is also noted and includes relevant observations concerning recent flooding or local weather conditions. The reference location is a permanent structure that is easily identifiable, such as a USGS gage or bridge pier. This location is recorded as a description of the structure (for example, USGS gage) and by latitude and longitude coordinates. In addition, the exact reach length sampled is noted and information on water quality (conductivity, temperature, and dissolved oxygen) is recorded. Conductivity is recorded at ambient water temperature and thus is ambient conductivity, not specific conductance.

The equipment use section provides the opportunity to record the methods used (for example, electrofishing and seining), the gear used (backpack, towed, or boat electrofishing gear), and aspects of how the gear was used (the length of time that sampling was conducted). When using electrofishing gear, a field strength meter is used to determine the strength of the electrical field, and this information is recorded on the data sheet. Relevant information concerning the use of a particular gear is noted under "Comments" (for example, "Electrofishing gear developed mechanical problems during sampling and may not be operating at peak efficiency").

Fish Species Data Sheet

The fish species data sheet is also divided into two sections--site information and species information. The study unit designation, sampling date, station name and identification number, and investigators are completed as with the fish equipment data sheet. The name of the fish taxonomic specialist is recorded. The code for the sampling gear as provided on the fish equipment data sheet, such as "11A" for backpack electrofishing, first pass, is also entered. The fish species data sheet has an entry for a page number and a cumulative page number. The page number is used by the sampling crew to consecutively number field data sheets; therefore, the page number is unique only for a particular field sampling team during a specific field effort. At least one fish species data sheet is completed for each of the two electrofishing passes and for each additional method. For example, when recording species data for a sampling reach that is sampled using backpack electrofishing and kick seining, at least three fish species data sheets are completed--one for each electrofishing pass and one for kick seining.

The species information section provides the opportunity to record the data collected from each fish. Fish are identified to the species level, and the scientific name is recorded following the taxonomic nomenclature of fish as established by the American Fisheries Society's Committee on Names of Fishes (Robins and others, 1991). Total length, standard length, and weight are entered as previously described. The presence of external anomalies is noted using a two-letter code (table 2) similar to that used by the Ohio Environmental Protection Agency (Ohio Environmental Protection Agency, 1987).

The presence of multiple anomalies should be recorded. For example, if a fish has a skeletal deformity, lesions, and unidentified external parasites, then "DE, LE, PA" should be recorded in the "ANOMALIES" column. For each fish that is measured for length (total and standard), weighed, and examined for external anomalies, a "1" is entered in the "NUMBER" column. When 30 individuals of a species have been measured, weighed, and examined for external anomalies, the remaining number of individuals of that species are counted. The species name is entered and the total number of remaining individuals is entered in the "NUMBER" column. For example, if 42 bluegill (*Lepomis macrochirus*) are collected, 30 individuals representing the range of sizes present in the sample are individually measured, weighed, examined for external anomalies, and a "1" is recorded in the "NUMBER" column for each individual. An additional entry for *Lepomis macrochirus* is made, with all columns except for the "NUMBER" column left blank. The number "12" is then entered in the "NUMBER" column.

Table 2.--*Two-letter codes used to record external anomalies on fish*
(Ohio Environmental Protection Agency, 1987)

Code	Description
AA	No anomalies
DE	Deformities of the head, skeleton, fins, and other body parts
ER	Eroded fins
LE	Lesions, ulcers
TU	Tumors
AL	Anchor worms
BL	Black Spot
CL	Leeches
FU	Fungus
IC	Ich
NE	Blind - one or both eyes, includes missing and grown-over eyes (does not include eyes missing due to popeye disease)
PA	Other external parasites (not previously specified)
PE	Popeye disease

SUMMARY

The National Water-Quality Assessment Program is designed to assess status of and trends in the Nation's water quality and to develop an understanding of the major factors that affect observed water-quality conditions and trends. Characterization of fish community structure is conducted as part of NAWQA to relate fish community characteristics to physical, chemical, and other biological factors as part of an integrated assessment of the Nation's water-quality conditions. To accomplish this, fish community structure is described at sites representing selected environmental settings. In addition,

spatial and temporal patterns in fish community structure are examined at local, regional, and national levels.

The fish community sampling design incorporates existing data with assessments of the fish community at sites representing selected environmental settings. The type of sample collected to describe fish community structure is a representative sample and requires that geomorphic channel units (pools, riffles, and runs) of the sampled stream section are representative of the geomorphology of the stream and use of multiple sampling methods.

The sampling reach is the section of stream sampled for fish and should include at least two examples each of two different types of geomorphic channel units. Where this is not possible, the length of the sampling reach should include one meander wavelength, based on a distance of 20 times the channel width. In addition, a minimum-maximum sampling reach length of 150 to 300 m (500 m in wide streams) for wadeable streams, and 500 to 1,000 m for nonwadeable streams, is established to provide a minimum sampling reach length necessary to ensure the collection of a representative sample of the fish community and limit sampling reach length to a distance that prevents unnecessary sampling and minimizes crew fatigue (and associated reduction of sampling efficiency). Sampling should take place during low- and stable-flow periods. Prior to sampling, consideration must be given to collecting permits; protecting endangered, threatened, or special-concern species; and coordinating sampling efforts with other fish ecologists.

Each of the methods designed to collect fish is selective for some component of the fish community and varies in its sampling efficiency. Using sampling methods that complement each other takes advantage of differences in selectivity and efficiency among methods.

Electrofishing and seining are the two methods used to obtain a representative sample of the fish community. Backpack electrofishing gear are used in relatively shallow (less than 1 m deep), small (less than 5 m wide) headwater streams. Towed electrofishing gear are used in relatively wide (greater than 5 m) wadeable streams with sufficient access for towed gear. Sampling of wadeable streams using electrofishing gear begins at the downstream boundary of the sampling reach and is conducted in an upstream direction. Two passes are conducted, and all fish are processed immediately following completion of each pass and released downstream of the sampling reach. Electrofishing boats are used to sample nonwadeable streams. Sampling begins at the upstream boundary of the sampling reach proceeding in a downstream direction by maneuvering the boat along one shoreline. A second pass is conducted along the shoreline not sampled during the first pass.

Seining is conducted after electrofishing to complement electrofishing collection efficiency and obtain a representative sample. Three types of seines are used to collect a representative sample: (1) a common sense seine, (2) a bag seine, and (3) a beach seine. Wadeable streams are sampled by seining using the common sense seine, the bag seine, or both. In riffle areas, a common sense seine is used to conduct kick seining. A sample collected by kick seining is taken at every riffle within the sampling reach. The samples from all riffles are combined, and the fish are processed immediately. In wadeable sampling reaches that are relatively free of obstructions, the bag seine is used. Seining downstream

has proven to be the most effective in collecting fish. Three bag seine hauls are conducted in the sampling reach, each covering an area of about 50 m, and taken from the upper, middle, and lower sections of the sampling reach. The fish from the three seine hauls are combined and processed before immediate release.

Nonwadeable streams can be sampled using a beach seine in wadeable shoreline areas, if present. Three beach seine hauls are conducted in accessible parts of the upper, lower, and middle sections of the nonwadeable sampling reach, the length of each equaling that of the seine. The fish from the three seine hauls are combined and processed before release.

Other sampling methods may be necessary to obtain a representative sample of the fish community for NAWQA. These methods include gill netting, using experimental gill nets, and hoop netting. Experimental gill nets 1.8 m deep with six sections of monofilament mesh 7.6 m long each, using 13-, 25-, 38-, 51-, 76-, and 102-mm mesh sizes (bar measurements), can be used to collect a representative sample. Two experimental gill nets are set for each nonwadeable sampling reach.

Hoop nets should be constructed of fiberglass hoops 0.6 m in diameter, with funnels on the second and fourth of the seven hoops, untreated 38-mm mesh (bar measure), and should be 3.7 m long. Two hoop nets are set within the sampling reach. Hoop nets should be baited with cheese, pressed soybean cakes, or other material and set in the water along a steep bank or on the outside bend of the stream parallel to the current with the opening facing downstream.

During sample processing, carbon dioxide is used to anesthetize the fish and thereby minimize handling stress. Taxonomic identification is made only by an ichthyologist who is familiar with the taxonomy of fish species found in the study unit. Both total and standard length measurements are made, and the data are recorded to the nearest millimeter; weight is recorded to the nearest gram. The presence of external anomalies, including skeletal deformities, eroded fins, lesions, tumors, diseases, and parasites, is also recorded.

The fixing and preserving of specimens are required for those fish that cannot be taxonomically identified in the field and for voucher specimens (representatives of nongame species collected from each sampling reach). Fixing fish tissues is achieved by using 10-percent buffered formalin. Permanently preserving fish specimens requires storage in 40-percent isopropyl alcohol or 70-percent ethanol.

The USGS Branch of Analytical Services' Biological Quality-Assurance Unit located at the National Water-Quality Laboratory provides verification of taxonomic identifications through the collection of voucher specimens and the establishment of a reference collection. At each sampling reach, voucher specimens are collected, fixed, and preserved to document and verify species identification.

REFERENCES CITED

Allen, D.M., Service, S.K., and Ogburn-Matthews, M.V., 1992, Factors influencing the collection efficiency of estuarine fishes: Transactions of the American Fisheries Society, v. 121, p. 234-244.

American Society for Testing of Materials, 1988, Standard practice of conducting acute toxicity tests with fish, macroinvertebrates, and amphibians: Standard Practice E 729-88, Committee E-47 on Biological Effects and Environmental Fate, ASTM, 1916 Race Street, Philadelphia, Pa.

Angermeier, P.L., and Karr, J.R., 1986, Applying an index of biotic integrity based on stream-fish communities: considerations in sampling and interpretation: North American Journal of Fisheries Management, v. 6, p. 418-429.

Angermeier, P.L., and Schlosser, I.J., 1989, Species-area relationships for stream fishes: Ecology, v. 70, p. 1450-1462.

Backiel, Tadeusz, and Welcomme, R.L., 1980, Guidelines for sampling fish in inland waters: European Inland Fisheries Advisory Commission Technical Paper 33, 176 p.

Bagenal, Timothy, 1978, Methods for assessment of fish production in fresh waters: Oxford, Blackwell Scientific Publications, 365 p.

Bramblett, R.G., and Fausch, K.D., 1991, Fishes, macroinvertebrates, and aquatic habitats of the Purgatoire River in Pinon Canyon, Colorado: Southwestern Naturalist, v. 36, p 281-294.

Britton, L.J., and Greeson, P.E., 1988, Methods for analysis of aquatic biological and microbiological samples: U.S. Geological Survey Open-File Report 88-190, 685 p.

Bryan, C.F., ed., 1984, Warmwater streams techniques manual: fishes: Baton Rouge, La., Southern Division, American Fisheries Society.

Cairns, John, Jr., and Kaesler, R.L., 1971, Cluster analysis of fish in a portion of the Upper Potomac River: Transactions of the American Fisheries Society, v. 100, p. 750-756.

Collete, B.B., and Lachner, E.A., 1976, Fish collections in the United States and Canada: Copeia, v. 1976, p. 625-642.

Cowx, I.G., and Lamarque, P., eds., 1990, Fishing with electricity: Oxford, Fishing News Books, Blackwell Scientific Publications.

Crossman, E.J., 1980, The role of reference collections in the biomonitoring of fishes *in* Hocutt, C.H., and Stauffer, J.R., Jr., eds., Biological monitoring of fish: Lexington, Mass., Lexington Books, p. 357-378.

Day, K.E., and Scott, I.M., 1990, Use of acetylcholinesterase activity to detect sublethal toxicity in stream invertebrates exposed to low concentrations of organophosphate insecticides: Aquatic Toxicology, v. 18, p. 101-114.

Fausch, K.D., Lyons, J., Karr, J.R., and Angermeier, P.L., 1990, Fish communities as indicators of environmental degradation, *in* Adams, S.M., ed., Biological indicators of stress in fish: Bethesda, Md., American Fisheries Society, p. 123-144.

Funk, J.L., 1957, Movement of stream fishes in Missouri: Transactions of the American Fisheries Society, v. 85, p. 39-57.

Gerking, S.D., 1959, The restricted movement of fish populations: Biological Review, v. 34, p. 221-242.

Goodchild, G.A., 1991, Code of practice and guidelines for safety with electric fishing: European Inland Fisheries Advisory Commission Occasional Paper No. 24, 16 p.

Gorman, O.T., and Karr, J.R., 1978, Habitat structure and stream fish communities: Ecology, v. 59, p. 507-515.

Haedrich, R.L., 1983, Reference collections and faunal surveys, *in* Nielsen, L.A., and Johnson, D.L., eds., Fisheries techniques: Bethesda, Md., American Fisheries Society, p. 275-282.

Heins, D.C., and Matthews, W.J., 1987, Community and evolutionary ecology of North American stream fishes: Norman, Okla., University of Oklahoma Press, 310 p.

Hendricks, M.L., Hocutt, C.H., and Stauffer, J.R., Jr., 1980, Monitoring of fish in lotic habitats, *in* Hocutt, C.H., and Stauffer, J.R., Jr., eds., Biological monitoring of fish: Lexington, Mass., Lexington Books, p. 205-231.

Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Hocutt, C.H., 1981, Fish as indicators of biological integrity: Fisheries (Bethesda), v. 6, p. 28-31.

Hocutt, C.H., Kaesler, R.T., Masnick, M.T., and Cairns, J., Jr., 1974, Biological assessment of water quality in a large river system: Archives fur Hydrobiologie, v. 72, p. 245-252.

Hocutt, C.H., and Wiley, E.O., 1986, The zoogeography of North American freshwater fishes: New York, John Wiley and Sons, 866 p.

Holland, R.S., and Peters, E.J., 1992, Differential catch by hoop nets of three mesh sizes in the lower Platte River: North American Journal of Fisheries Management, v. 12, p. 237-243.

Hontela, A., Rasmussen, J.B., Ko, D., Lederis, K., and Chevalier, G., 1991, Arginine vasotocin, an osmoregulatory hormone, as a potential indicator of acid stress in fish: Canadian Journal of Fisheries and Aquatic Sciences, v. 48, p. 238-242.

Hubert, W.A., 1983, Passive capture techniques, *in* Nielsen, L.A., and Johnson, D.L., eds., Fisheries techniques: Bethesda, Md., American Fisheries Society, p. 95-122.

Hubert, W.A., and Schmitt, D.N., 1982, Factors influencing hoop net catches in channel habitats of Pool 9, Upper Mississippi River: Proceedings of the Iowa Academy of Science, v. 89, p. 84-88.

Jenkins, R.E., 1976, A list of undescribed freshwater fish species of continental United States and Canada, with additions to the 1970 checklist: Copeia, v. 1976, p. 642-644.

Johnson, J.E., 1987, Protected fishes of the United States and Canada: Bethesda, Md., American Fisheries Society, 42 p.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J., 1986, Assessing biological integrity in running waters. A method and its rationale: Champaign, Ill., Illinois Natural History Survey, Special Publication 5, 28 p.

Komanda, N., 1980, Incidence of gross malformations and vertebral anomalies of natural and hatchery *Plecoglossus altivelis*: Copeia, v. 1980, p. 29-35.

Lazauski, H.G., and Malvestuto, S.P., 1990, Electric fishing: results of a survey on use, boat construction, configuration and safety in the USA, *in* Cowx, I.G., and Lamarque, P., eds., Fishing with electricity: Oxford, Fishing News Books, Blackwell Scientific Publications, p. 327-339.

Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 90-174, 10 p.

Lee, D.S., Gilbert, C.R., Hocut, C.H., Jenkins, R.E., McCallister, D.E., and Stauffer, J.R., Jr., 1980, Atlas of North American freshwater fishes: Raleigh, N.C., State Museum of Natural History, 854 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, W.H. Freeman, 522 p.

Loeb, H.A., 1957, Night collection of fish with electricity: New York Fish and Game Journal, v. 4, p. 109-118.

Lundberg, J.G., and McDade, L.A., 1990, Systematics, *in* Schreck, C.B., and Moyle, P.B. eds., Methods for fish biology: Bethesda, Md., American Fisheries Society, p. 65-108.

Lyons, John, 1992, The length of stream to sample with a towed electrofishing unit when fish species richness is estimated: North American Journal of Fisheries Management, v. 12, p. 198-203.

Matthews, W.J., 1986, Fish faunal structure in an Ozark stream: stability, persistence and a catastrophic flood: Copeia, v. 1986, p. 388-397.

_____ 1990, Fish community structure and stability in warmwater midwestern streams, *in* Bain, M.B., ed., Ecology and assessment of warmwater streams: Workshop synopsis, U.S. Fish and Wildlife Service, Biological Report, v. 90, no. 5, p. 16-17.

Monod, G., and Vindimian, E., 1991, Effect of storage conditions and subcellular fractionation of fish liver cytochrome P-450 dependent enzymatic activities used for the monitoring of water pollution: Water Research, v. 25, p. 173-178.

Nielsen, L.A., and Johnson, D.L., 1983, Fisheries techniques: Bethesda, Md., American Fisheries Society, 468 p.

Ohio Environmental Protection Agency, 1987, Biological criteria for the protection of aquatic life: volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities: Columbus, Ohio, Division of Water Quality Monitoring and Assessment, 58 p.

Paragamian, V.L., 1989, A comparison of day and night electrofishing: size structure and catch per unit effort for smallmouth bass: North American Journal of Fisheries Management, v. 9, p. 500-503.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers: U.S. Environmental Protection Agency, EPA/444/4-89-001.

Reynolds, J.B., 1983, Electrofishing, *in* Nielsen, L.A., and Johnson, D.L., eds., Fisheries techniques: Bethesda, Md., American Fisheries Society, p. 147-163.

Robins, C.R., Bailey, R.M., Bond, C.E., Brooker, J.R., Lachner, E.A., Lea, R.N., and Scott W.B., 1991, Common and scientific names of fishes from the United States and Canada: Bethesda, Md., American Fisheries Society, Special Publication 20, 183 p.

Sanders, R.E., 1992, Day versus night electrofishing catches from near-shore waters of the Ohio and Muskingum Rivers: Ohio Journal of Science, v. 92, no. 3, p. 51-59.

Schnick, R.A., Meyer, F.P., and Van Meter,H.D., 1979, Announcement of compounds registered for fishery use: Progressive Fish-Culturist, v. 41, p. 36-37.

Schoor, W.P., Williams, D.E., and Takahashi, N., 1991, The induction of cytochrome P-450-IA1 in juvenile fish by creosote-contaminated sediment: Archives of Environmental Contamination and Toxicology, v. 20, p. 497-504.

Smith, P.W., 1971, Illinois streams: a classification based on their fishes and an analysis of factors responsible for the disappearance of native species: Illinois Natural History Survey, Biological Notes 76.

Starrett, W.C., and Barnickol, P.G., 1955, Efficiency and selectivity of commercial fishery devices used on the Mississippi River: Illinois Natural History Survey Bulletin, v. 26, p. 325-366.

Steedman, R.J., 1991, Occurrence and environmental correlates of black spot disease in stream fishes near Toronto, Ontario: Transactions of the American Fisheries Society, v. 120, p. 494-499.

Stickney, R.R., 1983, Handling of live fish, *in* Nielsen, L.A., and Johnson, D.L., eds., Fisheries techniques: Bethesda, Md., American Fisheries Society, p. 85-94.

Summerfelt, R.C., and Smith, L.S., 1990, Anesthesia, surgery, and related techniques, *in* Schreck, C.B., and Moyle, P.B., eds., Methods for fish biology: Bethesda, Md., American Fisheries Society, p. 213-272.

Tonn, W.M., Magnuson, J.J., and Forbes, A.M., 1983, Community analysis in fishery management: an application with northern Wisconsin lakes: Transactions of the American Fisheries Society, v. 112, p. 368-377.

Wiley, M.L., and Tsai, Chu-Fa, 1983, The relative efficiencies of electrofishing vs. seines in piedmont streams of Maryland: North American Journal of Fisheries Management, v. 3, p. 243-253.

Williams, J.E., Johnson, J.E., Hendrickson, D.A., Contreras-Balderas, Salvador, Williams, J.D., Navarro-Mendoza, Miguel, McAllister, D.E., and Deacon, J.E., 1989, Fishes of North America endangered, threatened, or of special concern: 1989: Fisheries (Bethesda), v. 14, p. 2-20.

Wootton, R.J., 1990, Ecology of teleost fishes: Chapman and Hall, London, 404 p.

Wydoski, R.S., and Emery, Lee, 1983, Tagging and marking, *in* Nielsen, L.A., and Johnson, D.L., eds., Fisheries techniques: Bethesda, Md., American Fisheries Society, p. 215-238.


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