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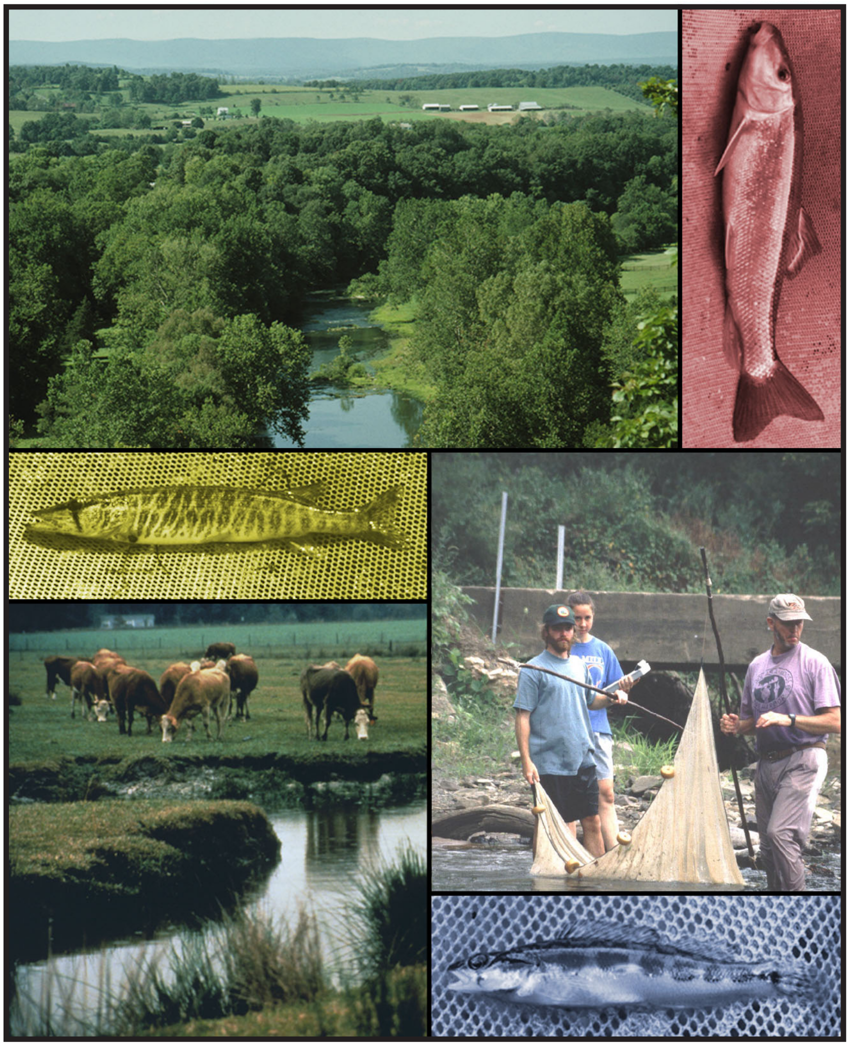
Technical Note

Fish Assemblages as Indicators of the Biological Condition of Streams and Watersheds



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Fish Assemblages as Indicators of the Biological Condition of Streams and Watersheds is the product of a number of Natural Resources Conservation Service (NRCS) efforts to evaluate the use of the Index of Biotic Integrity (IBI) as a tool for watershed assessment. The document is based on an extensive literature review of multimetric approaches, such as the Index of Biotic Integrity, and field studies to determine the application of IBI for NRCS watershed activities. The document provides guidance on how to develop a regional IBI based on fish assemblages and provides many contacts and references that will aid in that process. Several institutes and scientists are responsible for this publication. I specifically thank the following individuals who made significant contributions through their support in conducting field studies or peer review of the document:

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Introduction

During a century of evolution, through changing human impacts on water and its associated resources, biological monitoring has taken a variety of approaches. One of the more recent and successful is the Index of Biotic Integrity (IBI) (Karr et al. 1986), a multimetric approach that uses fish assemblages to assess the biological condition of streams and watersheds. Now well-documented and widely used, the IBI combines multiple indicators or "metrics" with appropriate sampling design and data analysis to evaluate a stream's ability to support unimpaired living systems. A metric is a measurable component of a fish assemblage that is empirically shown to change in value along a gradient of human influence (e.g., total number of species or the percentage of individuals that are omnivores) (Karr and Chu 1997). Metrics are chosen based on how well they reflect specific and predictable biological responses to human activities. The procedures for developing and applying an IBI, first detailed by Karr et al. (1986), have been adapted in this section for assessments in small watersheds typical of those in which NRCS provides technical assistance.

Background

According to Karr et al. (1986), performing biological assessments in streams is in a sense analogous to measuring human health. When blood pressure readings, white blood cell counts, and the results of stress tests fall within acceptable ranges, good human health is indicated. Good health, however, is not a simple function of these attributes. Rather, a biological system, whether it is a human system or a stream ecosystem, can be considered healthy when it has all its natural parts and has no signs of debilitating stress, injury, or disease.

Fish are useful organisms for biological assessments for several reasons. First, fish are sensitive to a wide array of stresses. Fish integrate the adverse effects of complex and varied stresses to other components of the aquatic ecosystem, such as habitat and macroinvertebrates, by virtue of their dependence on those components for reproduction, survival, and growth. Secondly, because fish are relatively long-lived, their populations show effects of reproductive failure and mortality in many age classes and hence provide a long-term record of environmental stress. Finally, fish assemblages can be used to evaluate societal costs of degradation more directly than other taxa because their economic and aesthetic values are widely recognized (Fausch et al. 1990).

The accurate assessment of biological condition requires a method that integrates biotic responses through the examination of patterns and processes from individual to ecosystem levels. The IBI accomplishes this through a combination of key metrics that have demonstrated response to the effects of human influence. In this multimetric approach, each metric is scored depending on whether its value approximates, deviates somewhat from, or deviates strongly from values expected from the region's least impaired streams.

The IBI has been used not only to assess the conditions of streams, but the condition of their contributing watersheds as well (Fausch et al. 1990, Roth et al. 1996, Wang et al. 1997). In addition, several authors have used it to assess the impacts of various human-induced disturbances. For example, Berkman et al. (1986) used the IBI to describe the effects of agriculture on stream quality. Leonard and Orth (1986) used it in small coolwater streams to describe the effects of pollution from small towns and mining. Steedman (1988) used it to classify various landscape disturbances and to establish impairment thresholds for water quality in southern Ontario watersheds. Hughes and Gammon (1987) used it to describe longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Various versions of the IBI are currently used in practically all U.S. states and Canadian provinces (Davis et al. 1996). The IBI has also been widely modified for use outside the USA and Canada (Hughes and Oberdorff 1999). The technique, because of its firm ecological foundation, also appears to be well suited to assessing the recovery of aquatic ecosystems (Hughes et al. 1990). However, like any tool, the IBI must be used appropriately. Protocols for fish sampling, establishment of reference conditions, and evaluation of metrics must be closely followed before it can accurately measure biological condition. Figure 1 details the major steps involved in constructing an IBI. Several of the steps include a number of subcomponents. Each of the steps and their subcomponents are described in more detail later under the section entitled "IBI development."

Many IBIs have been developed and are currently available for certain states, regions, or river basins. To avoid costly duplication and help achieve consistent results, state natural resource agencies may be contacted about the availability of an IBI for the area that you wish to study (table 1). In addition, many IBIs have been developed in universities and state water quality agencies. For additional information about other IBI applications, refer to Miller et al. (1988), Simon and Lyons (1995), Davis et al. (1996), and Simon (1999). Also see the text box entitled Sources for Metric Alternatives, page 24.

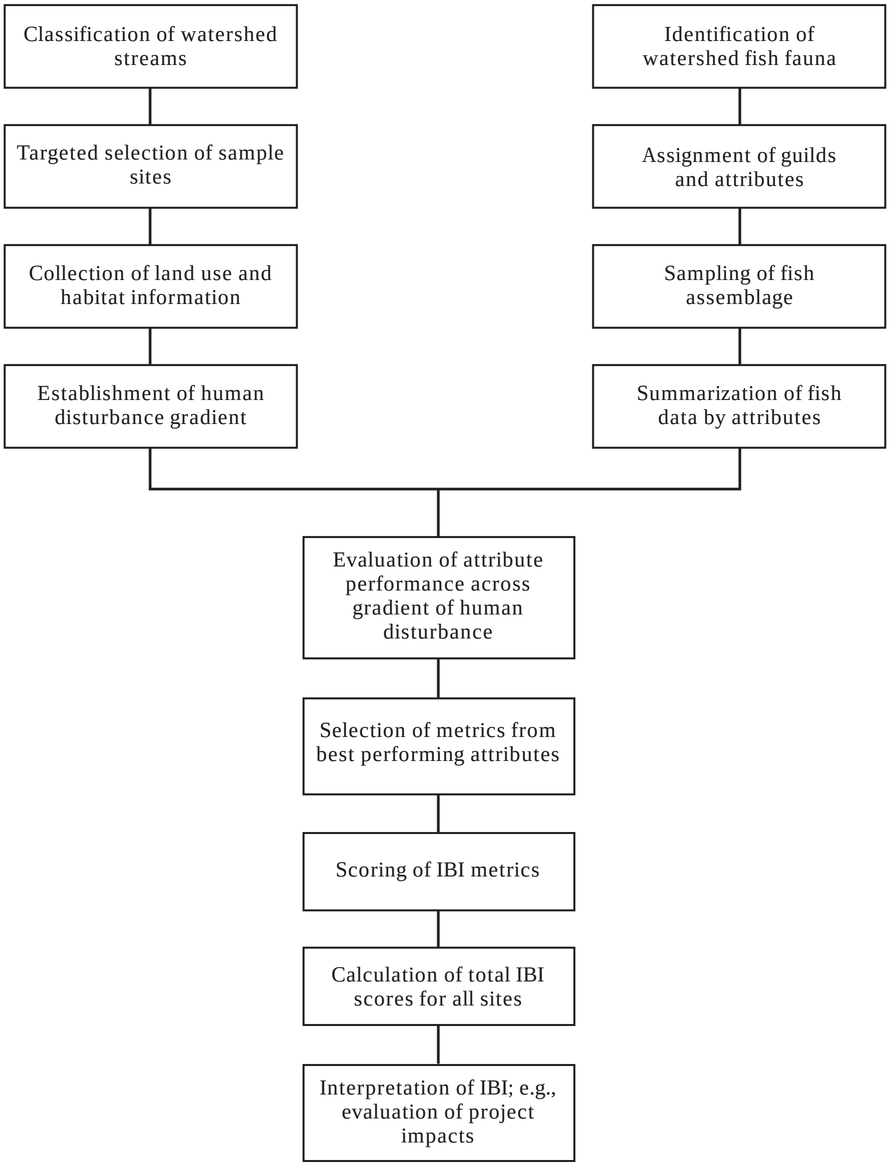


Figure 1 Sequence of activities in developing IBI (adapted from Karr et al. 1986)

Before collecting fish for IBI or other purposes, you should also contact the appropriate state agency to inquire about the need for a permit (table 1). In most states the collection of stream fishes requires a collection permit, even if fish are captured for only a short while and then returned to the stream. Not only does the permit allow collection to proceed under the prescribed authority, your survey results may be required for state databases that track species distribution in state waterbodies. In addition, upon request, location information from those databases may be made available to you for the streams you wish to study.

Another precursor to sampling is obtaining collection permits from the Fish and Wildlife Service and National Marine Fisheries Service (for anadromous species) under sections 4d, 7, and 10 of the Endangered Species Act (tables 2 and 3). These permits or consultations are required wherever a threatened or endangered species is likely to be encountered. The application or consultation process requires extensive information, and it takes several months to process the application. It is advisable to contact the district or regional biologist responsible for the species and waterbodies of interest before applying for State and Federal permits.

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)

State	State natural resources agency	Reporting requirements
Alabama	Alabama Department of Natural Resources Game and Fish Division 64 N. Union Street Montgomery, AL 36130 (334) 242-3469	Report due within 10 days of expiration
Alaska	Alaska Department of Fish and Game Division of Sport Fish P.O. Box 25526 Juneau, AK 99802-5526 (907) 465-4180	Report due within 30 days of expiration
Arizona	Arizona Game and Fish Department Nongame Branch 2221 West Greenway Road Phoenix, AZ 85023-4399 (602) 789-3504	Report due within 30 days of expiration
Arkansas	Arkansas Game and Fish Commission Fisheries Division 2 Natural Resources Drive Little Rock, AR 72205 (501) 223-6371	Report due within 30 days of expiration
California	California Department of Fish and Game License and Revenue Branch 3211 S Street Sacramento, CA 95816-7088 (916) 227-2225	Report due within 30 days of expiration unless waived

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
Colorado	Colorado Department of Natural Resources Division of Wildlife 6060 Broadway Denver, CO 81601-1000 (970) 945-4717	Report due within 30 days of expiration
Connecticut	Connecticut Department of Environmental Protection Fisheries Division 79 Elm Street Hartford, CT 06106-5127 (860) 424-3474	Report due at expiration
Delaware	Delaware Department of Natural Resources Division of Fish and Wildlife P. O. Box 1401 Dover, DE 19903 (302) 739-3441	Report due within 30 days of expiration
Florida	Florida Game and Freshwater Fish Commission Division of Fisheries Farris Bryant Building 620 South Meridian Street Tallahassee, FL 32399-1600 (904) 488-1600	Report due at expiration or 30 days prior to renewal
Georgia	Georgia Department of Natural Resources Wildlife Resources Division Special Permit Office 2109 U. S. Highway 278 S.E. Social Circle, GA 30025 (770) 761-3044	Report due at expiration
Hawaii	Hawaii Department of Land and Natural Resources Division of Aquatic Resources 1151 Punchbowl Street, Room 330 Honolulu, HI 96813 (808) 587-0097	Report due within 30 days of expiration
Idaho	Idaho Department of Fish and Game P.O. Box 25 Boise, ID 83707 (208) 334-3791	Report due at end of calendar year
Illinois	Illinois Department of Natural Resources Division of Fisheries Office of Resource Conservation 524 S. 2nd Street Springfield, IL 62701-1787 (217) 524-8285	Report due at end of February

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
Indiana	Indiana Department of Natural Resources Division of Fish and Wildlife Commercial License Clerk 402 West Washington Street, Room 273 Indianapolis, IN 46204 (317) 232-4080	Report due within 15 days of expiration
Iowa	Iowa Department of Natural Resources License Bureau Wallace State Office Building Des Moines, IA 50319-0035 (515) 281-8688	Report due by January 10
Kansas	Kansas Department of Wildlife and Parks Fish and Wildlife Division 512 S.E. 25th Avenue Pratt, KS 67124-8174 (316) 672-5911	Report due by January 31
Kentucky	Kentucky Department of Fish and Wildlife Resources Division of Fisheries 1 Game Farm Road Frankfort, KY 40601 (502) 564-3596	Report due by January 31
Louisiana	Louisiana Department of Wildlife and Fisheries Inland Fisheries Division P.O. Box 98000 Baton Rouge, LA 70898 (504) 765-2865	Report due within 60 days of permit expiration
Maine	Maine Department of Inland Fisheries and Wildlife Fisheries Research and Management Division 284 State Street 41 State House Station Augusta, ME 04333 (207) 287-5263	Report due at end of calendar year
Maryland	Maryland Department of Natural Resources Fisheries Service Tawes State Office Building 580 Taylor Avenue, B-2 Annapolis, MD 21401 (410) 260-8323	Report due by January 31

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
Massachusetts	Massachusetts Division of Fisheries and Wildlife Executive Office of Environmental Affairs Permit Office 100 Cambridge Street Boston, MA 02202 (617) 727-9800 ext. 327	Report due at end of calendar year
Michigan	Michigan Department of Natural Resources Fisheries Division P.O. Box 30028 Lansing, MI 48909 (517) 373-1280	Report due at end of calendar year
Minnesota	Minnesota Department of Natural Resources Division of Fisheries 500 Lafayette Road St. Paul, MN 55155-4012 (612) 296-3325	Report due at end of calendar year
Mississippi	Mississippi Department of Wildlife, Fisheries, and Parks Division of Wildlife and Fisheries P.O. Box 451 Jackson, MS 39205 (601) 354-7303	Report due within 15 days of expiration
Missouri	Missouri Department of Conservation Wildlife Division P.O. Box 180 Jefferson City, MO 65102 (573) 751-4115 ext. 167	Report due within 1 year of expiration date
Montana	Montana Fish, Wildlife, and Parks 1420 East 6th Avenue P.O. Box 200701 Helena, MT 59620-0701 (406) 444-2449	Report due March 1
Nebraska	Nebraska Game and Parks Commission Wildlife Division 2200 N. 33rd Street P.O. Box 30370 Lincoln, NE 68503-0370 (402) 471-0641	Report due by February 1
Nevada	Nevada Dept. of Conservation and Natural Resources Division of Wildlife P.O. Box 10678 Reno, NV 89520 (702) 688-1549	Report due within 30 days of expiration

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
New Hampshire	New Hampshire Fish and Game Department Fisheries Division 2 Hazen Drive Concord, NH 03301 (603) 271-1139	Report due by January 31
New Jersey	New Jersey Department of Environmental Protection Division of Fish, Game, and Wildlife CN 400 Trenton, NJ 08625-0400 (609) 292-8642	Report due within 30 days of expiration
New Mexico	New Mexico Department of Game and Fish Villagra Building P.O. Box 25112 Santa Fe, NM 87504 (505) 827-9904	Report due by January 31
New York	New York Department of Environmental Conservation Division of Fish and Wildlife Special Licenses Unit 50 Wolf Road Albany, NY 12233-4752 (518) 457-0689	Report due at expiration
North Carolina	North Carolina Wildlife Resources Commission Division of Boating and Inland Fisheries Archdale Building 512 N. Salisbury Street Raleigh, NC 27604-1188 (919) 733-3633	Report due quarterly
North Dakota	North Dakota Game and Fish Department Licensing Division 100 N. Bismarck Expressway Bismarck, ND 58501-5095 (701) 328-6300	Report due at expiration
Ohio	Ohio Department of Natural Resources Division of Wildlife Fountain Square 1840 Belcher Drive Columbus, OH 43224-1329 (614) 265-6666	Report due at expiration
Oklahoma	Oklahoma Department of Wildlife Conservation 1801 North Lincoln P. O. Box 53465 Oklahoma City, OK 73152 (405) 521-3721	Report due by January 31

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
Oregon	Oregon Department of Fish and Wildlife Fish Division 2501 S.W. First Avenue P. O. Box 59 Portland, OR 97207 (503) 872-5252	Report due at expiration
Pennsylvania	Pennsylvania Fish and Boat Commission Nongame and Endangered Species Unit 450 Robinson Lane Bellefonte, PA 16823-9616 (814) 359-5113	Report due by January 31
Rhode Island	Department of Environmental Management Rhode Island Division of Fish and Wildlife 4808 Tower Hill Road Wakefield, RI 02879-3075 (401) 222-3075	Report due at expiration
South Carolina	South Carolina Department of Natural Resources Freshwater Fisheries P.O. Box 167 1000 Assembly Street Columbia, SC 29202 (803) 734-3943	Report due annually within 120 days of termination of sampling
South Dakota	South Dakota Department of Game, Fish, and Parks Scientific Collector’s Permit 523 East Capitol Avenue Pierre, SD 57501-3182 (605) 773-4191	Report due by January 31
Tennessee	Tennessee Wildlife Resources Agency Ellington Agricultural Center P.O. Box 40747 Nashville, TN 37204 (615) 781-6575	Report due at expiration
Texas	Texas Parks and Wildlife Department Permits Section 4200 Smith School Road Austin, TX 78744 (512) 389-4491	Report due at expiration
Utah	Utah Department of Natural Resources Division of Wildlife Resources 1594 West North Temple, Suite 2110 P.O. Box 146301 (801) 538-4781	Report due within 30 days of expiration

Table 1 State natural resources agencies responsible for issuing scientific collecting permits and reporting requirements (adapted from Walsh and Meador 1998)—Continued

State	State natural resources agency	Reporting requirements
Vermont	Vermont Agency of Natural Resources Fish and Wildlife Department 103 S. Main Street, 10 South Waterbury, VT 05676 (802) 241-3708	Report due within 30 days of expiration
Virginia	Virginia Department of Game and Inland Fisheries Wildlife Information and Enhancement Division 4010 West Broad Street Richmond, VA 23230-1104 (804) 367-1185	Report due by January 31
Washington	Washington Department of Fish and Wildlife Enforcement Program 600 Capitol Way North Olympia, WA 98501-1091 (360) 902-2380	Report due by January 31
West Virginia	West Virginia Division of Natural Resources Wildlife Resources Section Scientific Collecting Permits P.O. Box 67 Elkins, WV 26241 (304) 637-0245	Report due within 30 days of expiration
Wisconsin	Wisconsin Department of Natural Resources Division of Fisheries South Central Regional Headquarters 3911 Fish Hatchery Road Fitchburg, WI 53711 (608) 275-3242	Report due by January 10
Wyoming	Wyoming Game and Fish Department Wildlife Division 5400 Bishop Boulevard Cheyenne, WY 82006 (307) 777-4559	Report due by December 31

Table 2 United States Fish and Wildlife Service Regional Offices responsible for consultations and issuing collection permits where threatened and endangered species may be encountered

Region	Office Address and Telephone Number	States
1	U.S. Fish and Wildlife Service Ecological Services Division 911 NE 11th Avenue Portland, OR 97232 (503) 231-6118	CA, HI, ID, NV, OR, WA, Pacific
2	U.S. Fish and Wildlife Service Ecological Services Division 500 Gold Avenue S.W. P.O. Box 1306 Albuquerque, NM 87103 (505) 766-2321	AZ, NM, OK, TX
3	U.S. Fish and Wildlife Service Ecological Services Division Federal Building 1 Federal Drive Fort Snelling, MN 55111-4056 (612) 713-5301	IA, IL, IN, MI, MN, MO, OH, WI
4	U.S. Fish and Wildlife Service Ecological Services Division 1875 Century Blvd. Atlanta, GA 30345 (404) 679-4000	AL, AR, FL, GA, KY, LA, MS, NC, PR, TN, SC
5	U.S. Fish and Wildlife Service Ecological Services Division 300 Westgate Center Drive Hadley, MA 01035-9589 (413) 253-8300	CN, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VA, VT, WV
6	U.S. Fish and Wildlife Service Ecological Services Division P.O. Box 25486 Denver Federal Center Denver, CO 80225 (303) 236-7920	CO, KS, MT, NE, ND, SD, UT, WY
7	U.S. Fish and Wildlife Service Ecological Services Division 1011 East Tudor Road Anchorage, AK 99503 (907) 786-3542	AK

Table 3 National Marine Fisheries Service Regional Offices responsible for consultations and issuing collection permits where anadromous threatened and endangered species may be encountered

Region	Office Address and Telephone Number	States
Northeast	National Marine Fisheries Service One Blackburn Drive Gloucester, MA 09130-2298 (508) 281-9250	CN, DE, DC, IL, IN, ME, MD, MA, MI, MN, NH, NJ, NY, OH, PA, RI, VT, WV, WI
Southeast	National Marine Fisheries Service 9721 Executive Center Drive, North St. Petersburg, FL 33702 (727) 570-5333	AL, AR, FL, GA, IA, KS, KY, LA, MS, MO, NE, NM, NC, OK, PR, SC, TN, TX, Virgin Islands
Southwest	National Marine Fisheries Service 501 W. Ocean Boulevard, Suite 4200 Long Beach, CA 90802-4213 (562) 980-4000	American Samoa, AZ, CA, Guam, HI, NV, Trust Territories of the Pacific Islands
Northwest	National Marine Fisheries Service 7600 Sand Point Way, N.E. BINC 15700 Building 1 Seattle, WA 98115-0070 (206) 526-6150	CO, ID, MT, ND, OR, SD, UT, WA, WY
Alaska	National Marine Fisheries Service Federal Building Annex, Suite 6 9109 Mendenhall Mall Road Juneau, AK 99802-7221 (907) 586-7221	AK

Fish assemblage sampling methods

General

The effectiveness of sampling stream fish varies according to many factors (e.g., size of stream, amount of cover, type of sampling gear, staff expertise). Nevertheless, a basic premise of the IBI is that the entire fish assemblage has been sampled in its true relative abundances without bias toward taxa or size of fish (Karr et al. 1986). Therefore, sampling methods must be standardized to ensure the quality of the data and to accurately reflect the fish assemblage present in a stream reach for a given time. According to Karr et al. (1986), several problems in sampling stream fishes particularly affect the accuracy of the data for IBI analyses. Each of the following sampling problems should be reviewed before data for IBI calculations are made and especially when the use of historical data is being considered (Karr et al. 1986).

First, the purpose for which the data were collected governs the nature of the data. Fish captured for taxonomic purposes, for example, are usually identified correctly, but may not be accurately counted; species common to a region may be ignored. Conversely, fish captured for purposes of fishery management will probably be counted, but small nongame species may be ignored or lumped into such categories as *forage fish* or *miscellaneous minnows.* For IBI purposes, an attempt should be made to collect fish species within a given reach or timeframe in a manner that represents their relative abundance.

Second, sampling gear, water conditions, and fish behavior affect the accuracy of the sample. Certain species are difficult to capture with standard electrofishing or seining gear. Finding darters, for example, requires the thorough disturbance of riffles, and catfishes are often best sampled at night. High flows or turbid water, on the other hand, affect collection of all species.

Third, the range of habitats sampled greatly affects data collection, and often the entire range of riffle, pool, and extra-channel habitats is not sampled, especially where large rivers are surveyed.

Fourth, atypical samples result when unrepresentative habitats are adjacent to the sampling site. Species richness near bridges or near the mouth of tributaries entering larger rivers, lakes, or reservoirs is, for example, more likely to be characteristic of larger-order habitats than the habitat under consideration (Fausch et al. 1984).

Lastly, the sample reach should be long enough to account for discontinuities in fish distribution. Recent studies have found that many traditional approaches to fish sampling provide reach distances that are too short to provide an adequate estimate of species richness (Lyons 1992b, Angermeier and Smogor 1994, Hughes et al. 1995, Paller 1995, and Patton et al. 2000). Hughes et al. and Paller (1995) found that increasing sampling distance is more effective in estimating species richness than increasing the sampling effort at the same site.

Sampling gear

Fish sampling requires a moderate amount of gear for field procedures as well as some supplies and equipment for the laboratory (Walsh and Meador 1998, Peck et al. 2000a). Most products, such as electrofishing equipment, seines, dip nets, waterproof paper, collection jars, and preservation chemicals, are commercially available from a variety of fishery suppliers. A supplier list can be accessed through the Web on the American Fisheries Society Homepage at www.main@fisheries.org. Look under **Resources/ Links** and then **Advertisers**.

Sampling large rivers and lakes

Fish sampling should account for the species present in a given stream reach in proportion to their relative abundance. The type of gear used is generally dependent on the size of stream. For larger streams and rivers, boats with mounted electrofishing equipment are generally used. For smaller streams, seines or portable electrofishing equipment are generally used. The drainage area of sites where boats are employed usually exceeds 75 square miles; however, local site conditions that may limit launching or maneuvering the boat may be a better gauge of where the technique can actually be applied (USEPA 1988, Peck et al. 2000b). In fact, a great deal of overlap occurs in the size of the drainage area where either boats or wading can be used. Generally, for the small watersheds that are so often the subject of NRCS investigations, wading is the more applicable technique.

Electrofishing wadeable streams

All types of fish sampling gear are generally considered selective to some degree; however, electrofishing has become the preferred method for collecting stream fishes. Pulsed DC (direct current) is generally considered the method of choice to obtain a representative sample of the fish assemblage (Barbour et al. 1999). Various electrical units have been used to sample wadeable streams. Practically all employ the use of generators and electrofishers that may be used in various combinations with light plastic tow-barges, or carried in a single backpack unit (Peck et al. 2000a, Yoder and Smith 1999). Net-poles or electrode devices (probes) are attached to the electrofisher unit and used to probe habitat where the fish are stunned and then collected. Procedures for sampling require a two- or three-person crew, all insulated from the water and electrodes by wearing chest waders (or hip boots for shallow streams) and rubber gloves. One person operates the probe while another guides the shocker and a third nets the fish. With some backpack units the person carrying the electrofisher may also probe, thus reducing the need for a third person to tend the electrofisher. Some probes, such as net-poles, are devised with net attachments so that the person operating the probe can also collect fish. In other instances, electric seines have been rigged to produce an electrical field and capture fish. All crew members should be trained in electrofishing safety precautions and the operation procedures identified by the unit manufacturer.

With backpack electrofishers, the person operating the probe works it around brush piles, log jams, boulders, and other submerged structures, generally in an upstream fashion. An effective technique for capturing fish under such objects is to thrust the probe into or under the structure with the current on and then quickly withdraw it in one swift motion. This has the effect of drawing fish out of the structure, making their capture possible. In riffle and run areas, the probe is raked over the substrate from upstream to downstream. At the same time, the netter may block off the area immediately downstream of the probe. This minimizes escape and avoidance of the electrical field by riffle species (USEPA 1988). Block nets placed at the upstream and downstream ends of the sample reach may be used to enhance sampling efficiency and help define the reach.

With electric seines, the upstream and downstream ends of a pool or riffle section are typically blocked with nets, and the electric seine is then dragged slowly upstream between the nets. The poles of the seine are rigged with electrical brails that are operated by the person on each end. Brails can be used to probe in and around instream cover in a manner similar to that described for backpack shockers. One or two people walk behind the seine to retrieve fish with dip nets. In addition, fish are removed from the downstream block net (Angermeier and Smogor 1994).

Since electrofishing is the most commonly used technique to collect fish for IBI purposes, most state agencies with developed IBIs have established protocols to detail how the technique is employed. For consistency, those state agencies should be consulted before designing a fish sampling technique of your own. Although electrofishing is effective and commonly used, like all fish sampling techniques, it can be selective. For example, electrofishing may stun and capture fish attempting to hide in vegetation, brush piles or on the shallow bottom, whereas some fish may detect the advancing electrical field and swim ahead, escaping the current unless they are cornered. Some benthic fishes (e.g., catfish, certain species of suckers) may be seldom taken because they are stunned in deeper water where they are difficult to see and collect (Bennet 1971). In addition, large fish may be captured at a higher rate than small fish with most electrofishing devices (Cooper 1952 and Johnson 1965).

Although most fish revive within 30 seconds to 2 minutes after being shocked (Bennet 1971), some mortality is inevitably experienced with electrofishing. For example, occasionally individuals are paralyzed or killed by direct contact with an electrode, and some may succumb to the electrical field itself (Wiley and Tsai 1983). Water quality conditions, such as salinity and hardness, greatly affect electrical conductivity, and thus the intensity and scope of the electrical field. As a result, care should be taken to set electrofisher unit adjustments to enable fish capture without unnecessarily harming individuals. Also, note that electrofishing in any form has been banned from certain salmonid spawning streams in the Northwest. Check with your appropriate state natural resources agency to determine where those restrictions have been placed (table 1).

Seining wadeable streams

Seines are reportedly the best tools for sampling fish in small, relatively simple streams (Karr et al. 1986). However, as streams increase in size and structural complexity, the efficiency of seines is diminished. Seining is performed by capturing fish from stream habitats in a small minnow seine. A 6-foot (length) by 4-foot (depth), 1/8 inch square mesh seine is the size most often employed for IBI analyses. In small streams it is important to use a seine that is not too large because they can be awkward to use and easily entangled.

Generally, a three-person crew is necessary to conduct the sampling, with one person handling each of the seine poles and another recording data. All habitat types, such as pools, runs, riffles, backwater areas, and isolated pools, are sampled in proportion to their occurrence within a sample reach or specified timeframe. Seining can proceed in either an upstream or downstream fashion. Microhabitats, such as spaces beneath logs and boulders, undercut banks, and aquatic vegetation, are sampled by kicking or otherwise disturbing the cover and then quickly seining through. Short, repeated hauls generally are more productive than long, continuous hauls. Short hauls also reduce fish mortality as does sorting fish in the bag of the seine while it is still in the water. As with electrofishing, the most productive efforts are realized when fish are cornered or disturbed from protective cover.

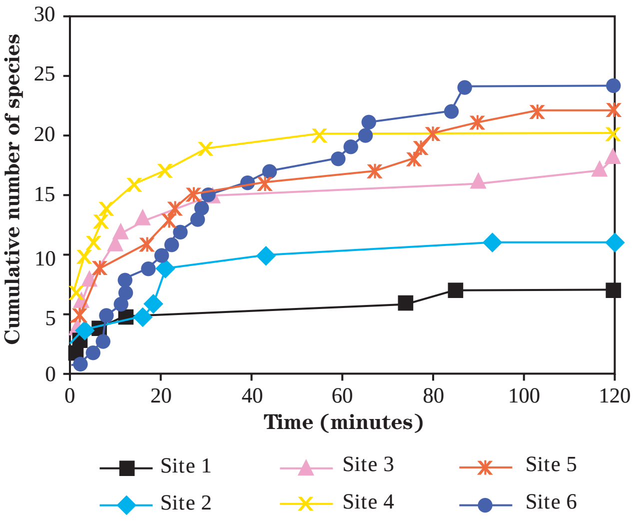
Seines are efficient in that they may collect smaller fishes from certain habitats (e.g., gravel riffles) that may be missed by electrofishing. Seines are also inexpensive, simple, easy to use, and seldom break down. However, as several studies have suggested, seining also has disadvantages that may, if not properly addressed, inappropriately influence the IBI. For example, in several studies seining was found to underestimate species richness in streams with slab boulders and cobbles, which interfered with efficient use of the seine (Hoover 1938, Wiley and Tsai 1983, Yoder and Smith 1999). In addition, in Ohio, seining was found to produce variable results caused by differing levels of skill between field crews (USEPA 1988). If the seining method is used, special care should be taken to maintain consistency across sample locations (e.g., primary investigator always present and rigid standardization of the sample effort).

Sample effort

Whereas several methods may be appropriately used to sample fish assemblages, sampling should always be conducted in a way that attempts to collect the species present, represents their relative abundance, and maintains sample consistency. Biologists have traditionally employed several techniques in this regard; for example, by using 100 meters of stream as a standard frame of reference. However, recent studies demonstrate that such techniques may not always provide a reach that is long enough to account for discontinuity in fish distributions (Lyons 1992b, Angermeier and Smogor 1994, Paller 1995, and Patton et al. 2000). Accordingly, care should be taken not to misrepresent species composition or relative abundance because sampling effort has been too little. In some instances 300 meters of stream or more is required to include all the habitat types that occur and account for discontinuity. Therefore, alternative techniques may be necessary to ensure that the sample length is adequate. For example, conducting pilot studies with oversampling may be needed to assess the effort needed to collect all species.

Angermeier and Smogor (1994) suggested that interactive approaches might be most effective for determining the appropriate sampling effort. For example, biologists could maintain a cumulative list of species found and stop sampling when a predetermined number of additional sampling efforts fail to yield additional species. Lyons (1992b) concludes that meaningful estimates of species richness for assessments of environmental quality or community-level ecological analyses can be achieved only if the length of each stream segment sampled approaches or exceeds the length at which the cumulative species number becomes asymptotic (fig. 2). Accordingly, for electrofishing, he recommends sampling 35 times the mean

Figure 2 Species/area curves for sites (1–6) that are progressively more speciose, demonstrating the asymptotic relationship (leveling of the curve) that should be considered for determining the level of sampling effort (Teels and Danielson 2001)



stream width to yield an acceptable estimate of species richness. However, he acknowledges that that distance might not be appropriate for all sampling gears. For example, that distance may be greater for seining, or it may be more useful to base the sample effort on the amount of time, rather than distance, that is required to produce an asymptotic curve. Regardless of the length of the reach sampled or the technique used, the location of the starting and ending points of the sample reach should be precisely recorded so that sampling can be repeated at that location in the future.

Seasonal considerations

Selecting the appropriate time of year for sampling is also critical. Although there is most likely no single best period to recommend, periods of low to moderate streamflow generally are preferred, and the variable flow conditions of early spring and autumn should be avoided. It is also best to maintain temporal consistency so data between sites can be accurately compared. For example, sampling can be limited to daylight hours at those times of the year when high streamflows are typically at a minimum.

Identification and enumeration

Because IBI derives its metrics from species assemblages, each individual specimen that is collected must be identified at least to the species level. The most controlled approach to ensure accurate taxonomic identification of fish specimens is to remove all fish specimens from the field and determine species' identification in a laboratory setting. However, it is not legal, ethical, or necessary to remove all fish specimens from the field (Walsh and Meador 1998). In most cases an experienced biologist can readily identify the adults and larger juveniles of most species in the field; thus, their numbers can be recorded and the fish then returned to the stream. If there is any uncertainty about the field identification of an individual fish, then it should be preserved in 10 percent formalin for later laboratory identification. Fish preserved in this manner should be labeled by date, time, and location.

Each individual specimen greater than 20 mm long should be counted. Most sampling procedures do not effectively sample individuals less than 20 mm in length. Such fish are also difficult to identify and may contain significant numbers of young-of-the-year that may inappropriately influence the IBI (Karr et al. 1986). Care should be taken not to collect or count the same individuals more than once. This can be done either by removing the fish temporarily to a bucket before additional sampling or by simply moving onto a different area of the stream. Each fish should also be examined for external anomalies. These are visible abnormalities that can observed with the naked eye during the field sorting process and include, for example, deformities, eroded fins, lesions, ulcers, tumors, or excessive external parasites. Numbers and types of anomalies should be recorded by species. In addition, the number of hybrid individuals should be recorded.

Proper handling maximizes the survival of live fish following their return to the stream. Care should be taken to count and record specimens quickly. If fish are held temporarily in buckets, then water temperature and dissolved oxygen in those buckets should be maintained as closely as possible to that in the stream. Examples of fish that may be difficult to hold live, even temporarily, are clupeids (shads and herrings) and atherinids (silversides) (Walsh and Meador 1998).

Although reference collections may at times be helpful in the identification of fish, personal reference collections are generally discouraged. Not only do they require space and considerable maintenance; they are generally unnecessary due to the availability of reference material housed elsewhere, such as ichthyological curation centers, local academic institutions, or museums (table 4). To help with species identification, many state or regional fish texts are available; most with keys, photos, line drawings, and species distribution maps (see appendix). If a fish cannot be identified through such means, then consult a fish identification expert in your area; typically an ichthyologist at a local academic institution or natural resources agency or at one of the centers listed in table 4.

Table 4 Ichthyological curation centers in the United States with significant freshwater holdings (Walsh and Meador 1998)

International

Academy of Natural Sciences of Philadelphia
Department of Ichthyology
19th and The Parkway
Philadelphia, PA 19103

American Museum of Natural History
Department of Ichthyology and Herpetology
79th Street and Central Park West
New York, NY 10024

California Academy of Sciences
Department of Ichthyology
Golden Gate Park
San Francisco, CA 94118

Field Museum of Natural History
Division of Fishes
Roosevelt Road at Lake Shore Drive
Chicago, IL 60605

Museum of Comparative Zoology
Harvard University
26 Oxford Street
Cambridge, MA 02138

National Museum of Natural History
Division of Fishes
Smithsonian Institution
Washington, DC 20560

Natural History Museum of Los Angeles County
Ichthyology Section
900 Exposition Boulevard
Los Angeles, CA 90007

University of Michigan Museum of Zoology
Division of Fishes
Ann Arbor, MI 48109-1079

National

Bernice P. Bishop Museum
Ichthyology Collection
P.O. Box 19000-A
1355 Kalihi Street
Honolulu, HI 96817-0916

Cornell University
Ichthyology Collection
Research Park, Building 3
Ithaca, NY 14850

National (continued)

Tulane University Museum of Natural History
Ichthyological Collection
Route 1, Box 46–B
Belle Chase, LA 70037

University of Florida
Florida Museum of Natural History
Gainesville, FL 32611

Regional

Gulf Coast Research Laboratory Museum
P.O. Box 7000
Ocean Spring, MS 39564-7000

Illinois Natural History Survey
607 E. Peabody Drive
Champaign, IL 61820

Northeast Louisiana University
Museum of Zoology
Monroe, LA 71209

Ohio State University
Museum of Zoology
1813 N. High Street
Columbus, OH 43210

Other important collections

University of Alabama
Ichthyological Collection
Museum of Natural History
Box 870344
University, AL 35487-0344

University of Washington
Fish Collection
FTR Building HF-15
Seattle, WA 98195

Auburn University
Museum Fish Collection
Department of Zoology and Wildlife Science
Auburn, AL 36849

James Ford Bell Museum of Natural History
University of Minnesota
Minneapolis, MN 55455

Table 4 Ichthyological curation centers in the United States with significant freshwater holdings (Walsh and Meador 1998)—Continued

Other important collections (continued)

Louisiana State University Museum of Zoology
Division of Fishes
Baton Rouge, LA 70803

Milwaukee Public Museum
Vertebrate Zoology
800 W. Wells Street
Milwaukee, WI 53233

New York State Museum
CEC 3140
Albany, NY 12230

North Carolina State Museum of Natural History
P.O. Box 27647
102 Salisbury Street
Raleigh, NC 27611

Oklahoma State University
Department of Zoology
Collection of Vertebrates
Stillwater, OK 74078

Pennsylvania State University
Fish Museum
School of Forestry
University Park, PA 16802

Other important collections (continued)

Southern Illinois University at Carbondale
Ichthyology Collection
Department of Zoology
Carbondale, IL 62901-6501

Texas Cooperative Wildlife Collection
Texas A&M University
College Station, TX 77843

University of Georgia Museum of Natural History
Ichthyological Collection
Athens, GA 30602

University of Tennessee
Fish Collection
Department of Zoology
Knoxville, TN 37996-0810

University of Washington
Fish Collection
FTR Building HF–15
Seattle, WA 98195

Yale University Peabody Museum
170 Whitney Avenue
New Haven, CT 06520

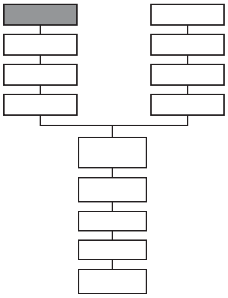
IBI development

General

Although the IBI is widely used, it is not a standard method. Essentially, an IBI must be built for each regional faunal assemblage based on an evaluation of metric responses to a human disturbance gradient. Collecting and interpreting IBI information is an hierarchical process (Karr et al. 1986) (fig. 1). It begins with defining the fish assemblage to be studied and building an appropriate study design and reference. In instances where an applicable IBI has been developed and undergone the necessary revisions, there is no need to build a separate IBI for your area. Alternatively, if one does not exist, it is possible to develop your own. However, appropriate use of an IBI requires experience and training in study design, fish assemblage sampling, species identification, ichthyogeography, reference condition determination, data analysis, and stream ecology. IBI development is discouraged without such skills and knowledge.

The process of developing an IBI begins by selecting an appropriate study design that is influenced by the scale at which the IBI is expected to function. Watersheds that are typically the focus of NRCS assistance are comparatively small (e.g., less than 250,000 acres). The boundaries of a focus watershed and the area for which an IBI is developed do not necessarily need to be the same. Ideally, the area for which an IBI is developed should be larger, such that most focus watersheds can be nested within. Although the size of the area for which an IBI is developed may vary, that area should be large enough to represent the various degrees of prevailing regional disturbances, yet small enough to account for differences in natural variables, such as landscape (or eco-region) and composition of the fish fauna. The area chosen to represent the IBI may be termed the reference area, which forms the boundary within which all sampling for that IBI will take place. It is important to note, that although most smaller watersheds can fit within a larger IBI framework, a number of metrics may be scale dependent or may not function at all at a smaller scale. Recognizing the influence of scale in the study design leads to the establishment of more accurate reference conditions, increased metric sensitivity, and a more meaningful and robust IBI. The following subsections provide guidance for the design and construction of an IBI following the general sequence of activities outlined in figure 1.

Classification of watershed streams



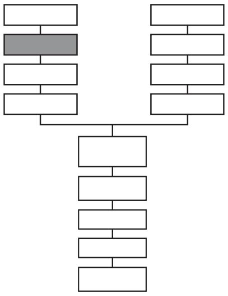
Because the IBI measures human impact, it is important to first sort out the natural from the human influences that affect the fish assemblage. Such sorting may require classification of sites. For example, because of natural differences in their biotic makeup, high-gradient streams should not be compared with low-gradient streams, even though they may be in close proximity. However, such classification need not be too rigorous; rather just enough, based on professional judgment, to ensure that "apples are being compared to apples and oranges to oranges." The challenge is to create a system with only as many classes as are needed to represent the range of relevant biological variation in a region and the level appropriate for detecting and defining the biological effects of human activity in that place (Karr and Chu 1997).

Because stream size affects biological assemblages in several ways, it may also be important to group sites by size. This process does not need to be too rigorous. Most studies do not separate streams into more than three size classes. As an alternative, size-related faunal differences can be accounted for in metric scoring using a trisection technique (Lyons 1992) (fig. 6). However, grouping streams according to size may also be useful for other purposes; e.g., to ensure that a relatively even distribution of different sized streams is included within the study. Sometimes it helps to review previously collected data or conduct some pre-project sampling to help determine the meaningful size classes to represent.

Another alternative is to categorize sites by stream order according to the system developed by Horton (1945) and modified by Strahler (1957). According to this system, the smallest streams in a watershed are first order. When two streams of the first order join, they form a stream of the second order; when two second-order streams join, they form a third-order stream, and so on. Although this classification is generally useful, the effects of stream order can vary among watersheds. Differences in climate, geology, and watershed geomorphology, for example, affect the nature of the stream-order pattern (Hughes and Omernik 1981, 1983), and thus the area of the watershed may be a more useful means of classification.

The use watershed area also facilitates smooth or continuous metric calibration instead of stepped calibrations that increase metric variability and noise.

Targeted selection of sample sites



Once classification has been accomplished, sample sites should be selected within the area for which the IBI is to be developed (reference area). These sites form the reference upon which the IBI is based. Since human influences arise from varied and complex sources, it may be virtually impossible to develop an IBI through a random process of site selection. Rather, a targeted approach is recommended to ensure that sites represent a full range of human disturbance and that relatively secure and accessible sites are selected. Within each stream class, at least three least-impaired and three most-impaired sites should be established to "pin down" the ends of the disturbance gradient. As much information as possible should be gathered to support the selection of those sites. Historical fish distribution, beaver abundance, vegetation, hydrology, and channel morphology data are valuable at this stage because it is extremely important to document the degree to which the watersheds have already been altered. Soil surveys, highway maps, local zoning maps, aerial photography, and other such information should be consulted to identify impairment sources. A field reconnaissance of the reference area should also be made. This is an extremely important part of the IBI development process. Without early attention to establishing the ends of the gradient, sampling may overlook the very sites that contain the most valuable information.

Least-impaired sites should be incorporated into the reference to represent the high end of the disturbance gradient. As the name implies, least-impaired sites are the stream sample reaches selected within the reference area because they are least impacted by human influences. In reality, there are no absolutely pristine habitats, and in certain instances, least-impaired sites may be hard to find. For example, in a small urban watershed or political area (e.g., a county) there simply may not be streams that are not at least moderately influenced by man. In such cases it would be advisable to look over a broader area so that least-impaired reference sites can be found, thus expanding the area of reference. Again, it is important that the size of the reference area not be too small to represent the full range of human disturbance. Although no standard protocol for selecting least-impaired reference sites is available, the following factors may be considered:

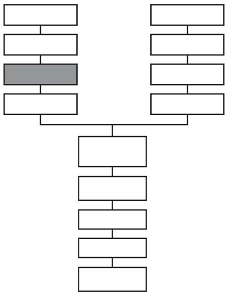
- no upstream or downstream impoundments,
- no known discharges,
- no known spills or other pollution incidents,
- low human population density,
- low agricultural activity,
- low road and highway density,
- minimal nonpoint source pollution, and
- no known intensive fish stocking (Gibson 1996).

Some pilot sampling of the fish assemblage may also be used to support the identification of least-impaired sites.

Equally important to the process of establishing the reference is the targeted selection of most-impaired sites. These sites represent the low end of the gradient and can be selected based on the same factors used to identify least impaired-sites, only with reverse logic. Strong candidates are sites with large amounts of urban drainage or intensive agriculture. Often not enough attention is given to including these highly impacted areas within the reference. However, they are extremely important because they provide tangible demonstration of what a stream should not look like and offer a tool to test negative metrics (those that respond positively to degradation).

After sites have been located to represent either end of the gradient, other sites should be selected to represent intermediate degrees of impairment. Sites with intermediate impairments are useful for evaluating metric sensitivity to subtle increases in stressors. This process can be performed either by random selection, or more comprehensively, by selecting sites within each of the reference area's primary stream systems. To draw relevant statistical comparisons, at least 12 sites should be included within each stream size class.

Collection of land use and habitat information



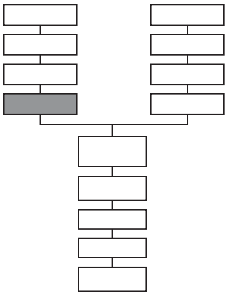
Before starting the field sampling, gather information about the study sites through published sources and field reconnaissance. The overall goal of this stage is to learn as much as possible about the sites so that you have as complete an understanding of them as possible. The information gathered during this stage can (1) help verify that streams are classified correctly, (2) provide information for constructing human disturbance gradients, and (3) provide insights into why biological communities are damaged during the IBI interpretation phase. A wealth of information can be collected about sites without even leaving your office. Some sources of information are

- USGS quadrangle topographic maps can provide baseline information on slope, elevation, land use and the hydrological network of watersheds and proximity of dams or other barriers to fish movement.
- NRCS soil surveys are an invaluable source of information on watershed soils, geologic and landscape features.
- USDA aerial photos, if available, are useful to gather information on watershed land use. They can also be used to reconstruct historical changes in land use by analyzing a series of photos taken over past years.
- Historical fish distribution data from state fish books and museum records are also valuable.

The collection of habitat and land use information may also be greatly aided by a Geographic Information System (GIS). GIS can be used to delineate boundaries of drainages above fish sample points. Those data can then be overlaid with other spatial data, such as land use information, to help assess the broad impacts of human influence. For example, several recent GIS studies have found significant negative correlations between watershed-wide agricultural or urban land uses and stream health, as represented by the IBI (Lenat and Crawford 1994, Richards et al. 1996, Roth et al. 1996, and Wang et al. 1997). Although GIS can be a powerful tool for helping define a disturbance gradient, it is not a replacement, or even a good surrogate, for the IBI itself or for biological monitoring (Karr and Chu 1997). In addition to the broad spatial relationships examined by GIS, onsite visits are generally required to define more local impacts.

Several onsite techniques have been developed to assess the habitat of streams. Examples include U.S. EPA, Rapid Bioassessment Procedures (RBP) and EMAP; Ohio EPA, Qualitative Habitat Evaluation Index (QHEI); and NRCS, Stream Visual Assessment Protocol (SVAP). Although any of those techniques can be used to help define a disturbance gradient, users should sort out those components of the assessment that are not related to human influence (e.g., stream gradient) from the ones that are (e.g., riparian quality).

Establishment of human disturbance gradient



Once sites have been targeted for selection into the reference, they should be ranked according to degrees of human disturbance. This is important to ensure that metrics are sensitive. Human disturbance serves as the gradient along the X-axis to which biological attribute data along the Y-axis are compared. Determining the disturbance gradient must be done before sampling begins, rather than as an afterthought, because post-hoc categorization may reveal that the full range of human disturbance was not captured, thus requiring additional sampling or limiting the usefulness of the IBI.

In most circumstances, diverse human activities interact to affect conditions in watersheds, waterbodies, or stream reaches (Karr and Chu 1997). In fact, in most instances it is virtually impossible to find regions influenced by only a single human activity, thus making the disturbance gradient difficult to construct. Where there is adequate information, the development and use of a Human Disturbance Index may greatly help to define the disturbance gradient. Such an index should incorporate values representing various degrees and combinations of prevailing human disturbances for all sites, not just the least- and most-disturbed. Although there is no standard protocol for constructing such an index, it should be derived from a variety of disturbances, rather than from a single source. Furthermore, the disturbances should be represented from both watershed and local scales. For example, scores from the landscape (e.g., percent cropland, pastureland, and urban land) should be combined with scores from onsite assessments. In addition, the adverse effects of isolating mechanisms, such as dams, drop structures, culverts, or other fish barriers have been widely documented (Avery 1978, Etnier and Starnes 1993, Minckley and Deacon 1991, Winston et al. 1991) and may be considered as features of the index (fig. 3).

Figure 3 Criteria and scoring for ranking sites according to a human disturbance index (HDI) (Teels and Danielson 2001)

Urban/Cropland (condition applies that would result in lowest score)

<5% of drainage urban; or <11% cropland	5-10% of drainage urban; or 11-20% cropland	11-15% of drainage urban; or 21-29% cropland	16-20% of drainage urban; or 31-38% cropland	>20% of drainage urban; or >38% cropland
10	8	6	4	2

Urban/Pastureland (condition applies that would result in lowest score)

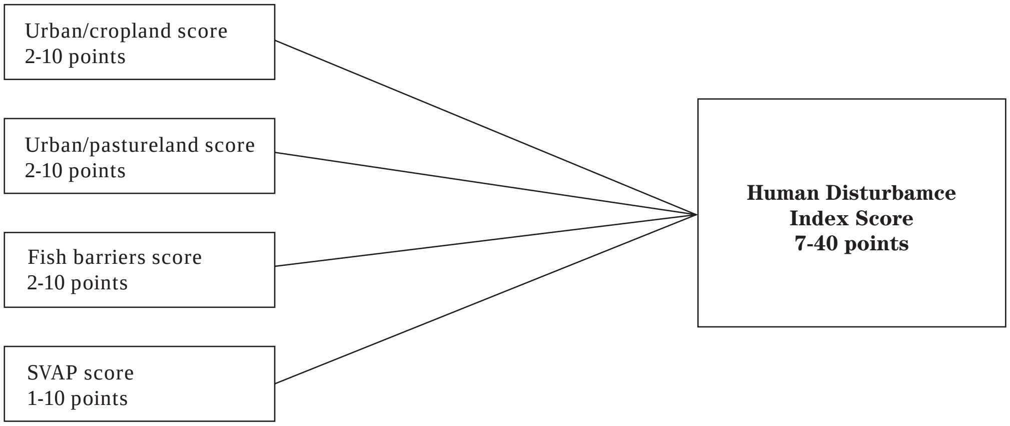
<5% of drainage urban; or <13% pasture	5-10% of drainage urban; or 13-22% pasture	11-15% of drainage urban; or 23-32% pasture	16-20% of drainage urban; or 33-42% pasture	>20% of drainage urban; or >42% pasture
10	8	6	4	2

Fish Barriers

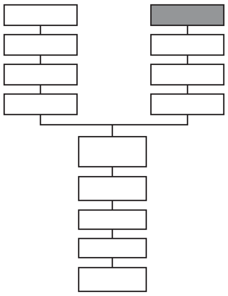
No barriers	Season water withdrawals inhibit fish movement	Drop structures, culverts, dams, or diversions(<0.3m drop) within the reach	Drop structures, culverts, dams, or diversions (>0.3m drop) within 5 km of the reach	Drop structured, culverts, or diversions (>0.3m drop) within or bordering the reach
10	8	6	4	2

Reach Impairment (SVAP) Score

>9.6	9.0-9.6	8.3-8.9	7.6-8.2	6.9-7.5	6.2-6.8	5.5-6.1	4.8-5.4	4.1-4.7	<4.0
10	9	8	7	6	5	4	3	2	1

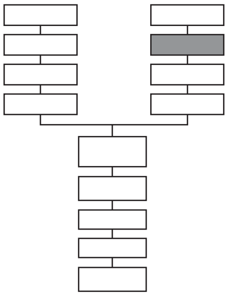


Identification of watershed fish fauna



The area for which the IBI is developed must be composed of a similar fauna, or at least one that was similar historically. In certain instances, significant differences occur in species assemblages across major drainage boundaries, for example between the Gulf and Atlantic drainages of a single state. If such conditions occur, then a separate IBI may need to be developed for each drainage. However, there are advantages and disadvantages of having a separate IBI for each drainage or region. Depending upon study objectives, a single IBI can generally be used across a relatively large area with some modifications in metric scoring and calibration. In any case, before fish are sampled and their numbers recorded, the species that will likely be encountered in your focus watershed should be listed and assigned guild designations for purposes of the IBI.

Assignment of guilds and attributes



The IBI requires the classification of species from the regional fish fauna into "guilds" or biological groupings from which potential metrics (attributes) are proposed and tested (table 5). To aid this process, recent works (e.g., Smogor 1996, Whittier and Hughes 1998, Zaroban et al. 1999, Barbour et al. 1999, Simon 1999) have developed such groupings that may apply to your area. However, species classifications may differ among regions. For example, an intolerant Midwestern species may not be intolerant in Western mountains. Therefore, caution should be exercised in extending those classifications beyond their intended scope.

After defining the watershed fish fauna and classifying species into the appropriate biological groupings, attributes should then be developed. Attributes, in the context of biological assessments, are defined as measurable components of a biological system (Karr and Chu 1997). They include characteristics of an individual or assemblage of species that may or may not provide useful information regarding response to a disturbance. After defining the list of taxa, make a list of attributes that you think will change in value along a gradient of human influence from least to most disturbed streams. Also, predict whether each attribute will increase in value or decrease in value as impairment increases or decreases.

Again, scale is important to consider in this part of the process because some attributes may need to be altered. Each attribute should be composed of species that you would expect to be sensitive to human disturbances in your focus watershed. For example, the use of an intolerant group of species as an attribute may function well at a state level; however, that same group of species may be extremely rare or totally absent from your focus watershed. However, this does not mean that the *number of intolerant species* should be excluded as a potential metric. It merely means that the species composition of the attribute should be modified to include those species that fit the concept of intolerant within your area of concern.

Each attribute considered for an IBI should be based on sound ecological theory. Although theory can be a good guide for selecting metrics, the theory must be tested with real-world data before a metric is used. Ecology's path as a scientific discipline is littered with the carcasses of "good" theoretical constructs that evidence later showed were flawed (Karr and Chu 1997). Even if the underlying theory is sound, many variables control an attribute's response to human disturbance, which in turn affects its utility. For example, an attribute that works in one stream may not in another because of differences in the prevailing human influence. For example, the anomalies metric (percent of individuals with lesions, tumors, eroded fins) may function only in extremely degraded conditions; providing valuable information to a region if at least some of the streams are severely degraded, but little information if all streams are only moderately degraded to unimpaired. Sometimes there may even be inherent differences in how an attribute relates biologically to human disturbances. For example, the number of native species typically declines with added human disturbance except, however, in some coldwater streams where the effect may actually be reversed because increased nutrients and temperatures may result in increased species numbers (Lyons et al. 1996, Mundahl and Simon 1999). Thus, attributes and their underlying assumptions need to be tested not only to validate that there is an empirical dose-response relationship, but also to be able to understand and predict the nature of that relationship. The

Table 5 Biological groupings for the Occoquan River (VA) Watershed fish species (Teels and Danielson 2001)

Scientific name	Tol[1]	No. food groups	Trophic[2]	Ben[3]	Lith[4]	Pio[5]	Late maturing
Esocidae							
Esox americanus Gmelin	I	1	PIS				
Umbridae							
Umbra pygmaea (DeKay)		1	INV				
Cyprinidae							
Notemigonus chrysoleucas (Mitchill)		2	AHI			x	
Clinostomus funduloides Girard		1	INV		x		
Semotilus corporalis (Mitchill)		4	IP				
Semotilus atromaculatus (Mitchill)	T	4	IP				
Nocomis micropogon (Cope)		3	INV	x			x
Exoglossum maxillingua (Lesueur)		1	INV				
Rhinichthys atratulus (Hermann)		3	INV		x		
Rhinichthys cataractae (Valenciennes)	I	2	INV	x	x		
Hybognathus regius Girard		2	DAH				
Luxilus cornutus (Mitchill)		4	INV		x		
Cyprinella analostana Girard		2	INV				
Pimephales notatus (Rafinesque)		3	AHI			x	
Pimephales promelas Rafinesque		3	AHI			x	
Notropis amoenus (Abbott)		1	INV		x		
Notropis hudsonius (Clinton)		2	INV				
Notropis procne (Cope)		2	INV		x		
Notropis rubellus (Agassiz)		1	INV		x		
Catostomidae							
Catostomus commersoni (Lacepede)	T	3	AHI	x	x		x
Erimyzon oblongus (Mitchill)		3	INV	x		x	
Hypentelium nigricans (Lesueur)		2	INV	x	x		x
Moxostoma erythrurum (Rafinesque)		3	INV	x	x		x
Fundulidae							
Fundulus diaphanus (Lesueur)		1	INV				
Poeciliidae							
Gambusia holbrooki Girard		1	INV			x	
Ictaluridae							
Ameiurus natalis (Lesueur)		3	IP			x	
Ameiurus nebulosus (Lesueur)		3	IP				x
Noturus insignis (Richardson)	I	2	INV				x
Centrarchidae							
Lepomis auritus (Linnaeus)		2	IP				
Lepomis cyanellus Rafinesque	T	2	IP				
Lepomis gibbosus (Linnaeus)		1	INV			x	
Lepomis macrochirus Rafinesque	T	1	INV				
Lepomis microlophus (Gunther)		1	INV			x	
Pomoxis annularis Rafinesque		2	IP			x	
Micropterus dolomieu (Lacepede)		2	PIS				
Micropterus salmoides (Lacepede)		1	PIS				
Percidae							
Percina peltata (Stauffer)	I	1	INV	x	x		
Etheostoma olmstedi Storer		1	INV	x			
Etheostoma flabellare Rafinesque		1	INV	x			

1 Tolerance: T = tolerant, I = intolerant

2 Trophic groups: PIS = piscivore, INV = invertivore, AHI = algivore/herbivore/invertivore, IP = invertivore/ piscivore, DAH = detritivore/algivore/herbivore

3 Ben = benthic

4 Lith = simple lithophil

5 Pio = pioneer

primary underlying assumptions that have been used in most IBIs follow. These assumed effects of environmental degradation on biological assemblages are modified from Hughes and Oberdorff (1999).

- Number of native species, and those in specialized taxa or guilds, declines. (In some instances, particularly in oligotrophic environments, reverse relationships may be observed.)
- Number of sensitive species declines.
- Percent of trophic and habitat specialists declines.
- Total number of individuals declines. (In some instances, particularly in oligotrophic environments, reverse relationships may be observed.)
- Percent of large individuals and the number of size classes decrease.
- Percent of alien or non-native species or individuals increases.
- Percent of tolerant individuals increases.
- Percent of trophic and habitat generalists increases.
- Percent individuals with anomalies increases.

For most watersheds, 20 or 30 attributes can be proposed that you believe would be most sensitive to human disturbance in your region. This should be influenced by the metric composition of IBIs in neighboring regions or the IBI area in which your watershed is nested. Some studies suggest that attributes can be conveniently grouped into the following categories:

- Species richness and composition
- Tolerance and intolerance
- Trophic structure
- Reproduction, abundance, and condition

A balance of attributes from each category should be proposed and tested for your area. The biological basis for attribute/metric development is aptly described in Karr et al. (1986) and summarized in the following subsection. Examples of attributes that have been successfully used in various regions of North America are provided in table 6.

Species richness and composition

Attributes from this category are generally the most common feature of most IBIs. In most cases they display a declining response to added human disturbance (Karr 1981). Usually, a population must be viable at a site for some time before a species' presence can be consistently detected (Karr and Chu 1997). The absence of a species at a site (especially species with low dispersal abilities) may suggest that viable populations are not being maintained. Over time, species assemblages have evolved that are capable of withstanding or rapidly recovering from most natural perturbations. However, changes in the chemical, physical, and biological environment caused by humans often cannot be tolerated and thus one or more species declines in abundance or becomes extirpated (Karr et al. 1986). Attributes within this category generally include total species richness and species richness for taxa that are particularly sensitive to specific kinds of degradation (e.g., sensitivity of darters to benthic impairments). Attributes have often been refined by restricting the groupings to native species.

Tolerance and intolerance

Tolerance, as it relates to IBI development, implies a general tolerance of a species to a number of human influences, rather than tolerance to a specific variable. A number of species are very intolerant (i.e., are very sensitive) to a variety of perturbations, whereas others are adept at exploiting particular types of disturbances. Intolerant species are among the first to be decimated after perturbation and the last to recolonize after normal conditions have returned (Karr et al. 1986). Trends (increases or decreases) in distribution or abundances from historical data can be examined to help assign taxa to these attributes. Endangered or threatened species should not automatically be considered intolerants because their low numbers may be due to factors other than human disturbance. They might be, for example, glacial relics (Karr et al. 1986).

The mere presence of intolerant species is a strong indicator of good biological condition. The relative abundance of these species, in contrast, is difficult to estimate accurately without extensive and costly

Sources for Metric Alternatives
(Barbour et al. 1999)

Karr et al. (1986)
Leonard and Orth (1986)
Moyle et al. (1986)
Fausch and Schrader (1987)
Hughes and Gammon (1987)
USEPA, Ohio (1988)
Miller et al. (1988)
Steedman (1988)
Simon (1991)
Lyons (1992a)
Barbour et al. (1995)
Simon and Lyons (1995)
Hall et al. (1996)
Lyons et al. (1996)
Roth et al. (1997)
Simon (1999)

Table 6 Original Karr (1981) IBI metrics (bold) and alternative metrics from various regions of North America (adapted from Barbour et al. 1999)

Alternative IBI metrics	Midwest	New England	Ontario	Ohio	Colorado	Oregon	California	\Wisconsin	Maryland
1. Total number of species	x	x			x		x		x
# native fish species	x			x		x		x	
# salmonid age classes			x			x	x		
2. Number of darter species	x			x	x				
# sculpin species						x			
# benthic inveretivore species		x							x
# darter and sculpin species	x	x							
# salmonid yearlings							x		
3. Number of sunfish species	x			x	x			x	
# cyprinid species	x				x				
# water column species		x							
# sunfish and trout species			x						
# salmonid species							x		
# headwater species	x						x		
4. Number of sucker species	x	x		x		x		x	
# adult trout species	x					x	x		
% round-bodied suckers	x					x	x		
# sucker and catfish species			x						
5. Number of intolerant species	x	x		x	x		x	x	
# sensitve species	x								
presence of brook trout			x				x		
6. Percent green sunfish	x					x			
% tolerant species	x			x		x		x	x
% common carp									
% white sucker		x			x				
% creek chub									
% pioneering species	x								
% dominant species									
7. Percent omnivores	x	x	x	x	x			x	
% yearling salmonids					x				
% generalists/herbivore/invertivores									x
8. Percent insectivorous cyprinids	x								x
% benthic invertivores									
% speicialist insectivores					x				
% insectivores	x	x		x		x	x	x	
# juvenile trout									
9. Percent top carnivores	x	x	x	x				x	
% specialist carnivores									
% catchable salmonids						x			
% catchable trout							x		
10. Number of individuals	x		x	x	x	x	x	x	x
density of individuals		x							
11. Percent hybrids	x	x		x					
% introduced species					x	x			
% simple lithophils	x							x	x
% native species							x		
12. Percent anomalies	x	x	x	x	x	x		x	x

sampling efforts (Karr and Chu 1997). Therefore, intolerant species generally should be represented simply as the number of intolerant species per unit sample effort. In contrast to intolerant species, the presence alone of tolerant taxa says little about biological condition since tolerant groups inhabit a wide range of places and conditions. Therefore, tolerance attributes are generally expressed as percent of tolerant individuals from either a single species or a grouping of highly tolerant species. If a high number of tolerant or intolerant species are included in the composition of attributes, then the usefullness of those attributes may be diminished. In general, it is recommended that only about 10 percent (no fewer than 5% or no more than 15%) of species in a region should be classed as intolerant or tolerant. The point of these metrics is to highlight the strong signal coming from the lowest and highest ends of the biotic integrity continuum without being swamped by the weak or intermediate signals from in-between (Karr and Chu 1997).

Trophic composition

Because the food base is central to the maintenance of a community, information about trophic composition is important to an IBI (Karr et al. 1986). All organisms require a reliable source of energy. Stream fishes are affected dramatically by changes or reductions in those energy sources. The dominance of trophic generalists occurs as specific components of the food base become less reliable and the opportunistic foraging habits of the generalists make them more successful than trophic specialists (Karr et al. 1986). In some instances little sensitivity may be displayed by certain trophic metrics because most species are composed of only one feeding group (e.g., in high gradient coldwater streams most species are invertivores). However, sometimes entire groups of organisms, such as top carnivores, have been extirpated from aquatic ecosystems using persistent pesticides and the process of biological magnification. Thus, the trophic structure of a community can provide information on patterns of consuming and producing organisms that are affected by impairment. To improve attribute performance, tolerant species may be subtracted from attributes of this and the next category.

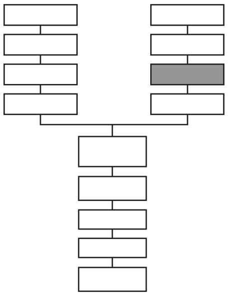
Reproduction, abundance, and condition

The attributes in this category assess characteristics of populations, such as reproduction, growth, and condition of individual organisms belonging to populations. Ecosystems can maintain themselves only if populations of organisms are able to compensate for loss of members through reproduction. Human influences that negatively affect reproduction are ordinarily indicated by an accompanying reduction in the proportion of reproductive specialists (percent nest spawners, percent simple lithophils). In addition, conditions must also be favorable for the young of a population to survive, disperse, and to grow to sexual maturity. Therefore, attributes that characterize population structure (number of late-maturing species, abundance or size of key species) can also be effective indicators of human disturbance.

Individual abundance is a common surrogate for system productivity, and some types of highly disturbed sites are expected to support fewer individuals than high-quality sites (Karr 1981). However, Karr and Chu (1997) suggest that abundance may be a poor candidate for a multimetric index because it varies too much even when human influence is minimal, and is also difficult to measure and score. Recognizing the tendency for moderate levels of nutrient and thermal enrichment to elevate fish abundance, Oberdorff and Hughes (1992) scored this metric so that very high abundances received lower metric scores than moderate numbers; only very low abundances received the lowest score. This scoring adaptation is an example of the need to evaluate metric performance across disturbance gradients before applying the IBI in resource assessments (Hughes and Oberdorff 1999).

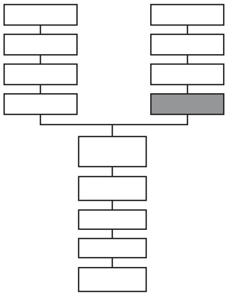
Sites with especially severe degradation often yield a high number of individuals in poor health (Mills et al. 1966; Brown et al. 1973; Sanders et al. 1999). Parasitism has been shown to reflect poor environmental condition and reduction in reproductive capacity (sterility) in fish (Mahon 1976). Indications of poor health include individuals with tumors, limb damage or other deformities, heavy infestations of parasites, discoloration, excessive mucus, and hemorrhaging. Leonard and Orth (1986) found increases in the incidence of disease and anomalies only after substantial degradation was evident, indicating that this metric may be sensitive only at the most severely impacted sites. In certain instances the metric has been dropped (e.g., in the absence of severely impaired sites); however, it should be considered wherever the possibility exists for changes in the incidence of disease or deformed organisms (Hughes and Oberdorff 1999).

Sampling of fish assemblage



A basic premise of IBI is that the entire fish fauna has been sampled in its true relative abundance without bias toward taxa or size of fish (Karr et al. 1986). As this assumption is relaxed, the reliability of inferences based on the IBI is reduced. However, with any single sampling technique there are certain inherent biases that affect the quality of the sample. Therefore, it is important to understand method limitations and adhere as strictly as possible to sampling protocols to maintain consistency of data and reduce sampling variability. Protocols for sampling are described in the Fish assemblage sampling methods section of this technical note.

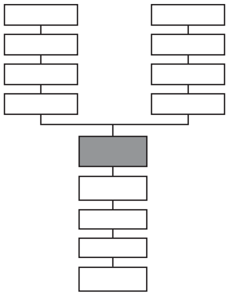
Summarization of fish data by attributes



Sampling will generate numbers for fish species collected at a given site that are typically recorded on field data sheets. The species counts from field data sheets should be entered into a computer spreadsheet for summary and simple analysis (e.g., Lotus 1-2-3, Microsoft Excel). Regardless of the type of computer software being used, the data must be summarized based on the list of attributes. For example, if 10 species compose the benthic invertivore attribute, then the total number of individuals of those species should be summed and then divided by the total number of species collected at that site. In this example, the attribute is expressed as percent benthic invertivores.

The process for evaluating metric performance involves the testing of a larger set of biological attributes (candidate metrics) and boiling them down to the 12 or so metrics that work best and will ultimately compose the IBI. This process generally can be performed with spreadsheet functions or more sophisticated database or statistical software (e.g., SAS).

Evaluation of attribute performance across gradient of human disturbance

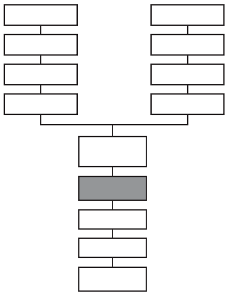


The need to test and validate biological responses of attributes across degrees of human influence is a core assumption of IBI (Karr and Chu 1999). From such testing sensitive metrics are developed and refined. Metrics are attributes empirically shown to change in value along a gradient of human influence. The biological metrics incorporated into a multimetric index are selected because they

- reflect specific and predictable responses of organisms to changes in landscape condition,
- are minimally affected by natural variability,
- are sensitive to a range of factors that stress biological systems, and
- are relatively easy to measure and interpret (Karr and Chu 1997).

Ideally, metrics should be sensitive to a range of biological stresses and not narrowly focused on one particular aspect of the community or another (e.g., species richness). Most importantly, metrics must be able to discriminate human influences from the background "noise" of natural variability (Karr and Chu 1997).

Selection of metrics from best performing attributes



At least 5 (but preferably 8 to 12) metrics should be defined and selected to construct the IBI. Each chosen metric should reflect the quality of a different aspect of biota that responds in a different manner to disturbances in streams (Fausch et al. 1990; Hughes and Noss 1992) (table 7). Therefore, whenever possible some care should be taken to select metrics from the different categories (species composition and richness, tolerance and intolerance, trophic structure, reproduction, and individual condition). Generally, the wider the range of ecological conditions represented by the chosen metrics the better.

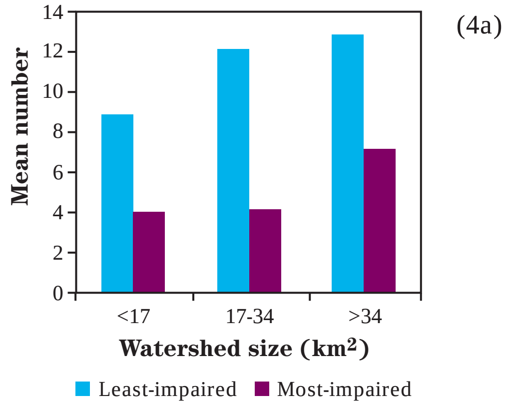
The performance of each attribute should be evaluated by assessing how well it

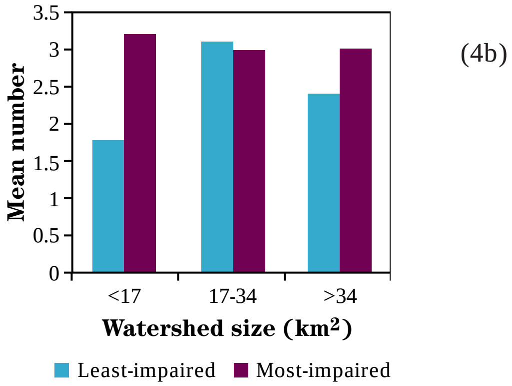
- increases or decreases along a gradient of human influence,
- separates the least from the most impaired sites,
- provides similar values for similarly impaired sites, and
- provides a unique (nonredundant) discriminatory response (Karr and Chu 1997).

Several graphical and statistical approaches may be used to evaluate attribute performance. Each may be used individually or in concert with another to screen out attributes that do not perform acceptably while retaining those that do. One frequently used approach is to construct bar graphs to compare the mean or median attribute values between least- and most-disturbed sites (fig. 4a and b). The degree of separation can then form the basis for retaining or discarding the attribute for subsequent analyses. The statistical significance of the separation can be determined using standard statistical tests (e.g., t-test).

Another frequently used test is to compare attribute data not just from the extreme sites, but from all sites across the spectrum of human disturbance. That relationship can be expressed either graphically (scatter plot) or by a comparison of correlation coefficients (fig. 5a and b). Attributes that contain many of the same species can be expected to be redundant. Redundancy can be tested statistically (e.g., factor analyses (Hatcher 1994)) or by simply examining similarities in the taxa groupings that form each attribute. Although some redundancy is acceptable in a multimetric mix, selected metrics should tend to avoid using the same set of species repeatedly. Simple tables can be con-

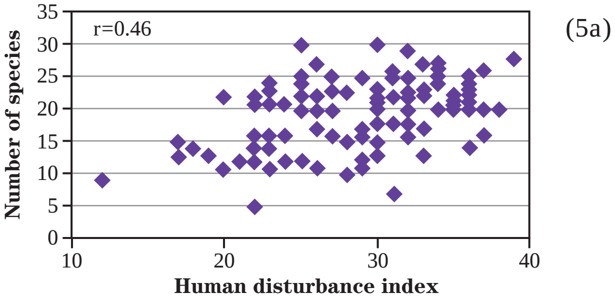
Figure 4 Separation of least- from most-impaired sites*

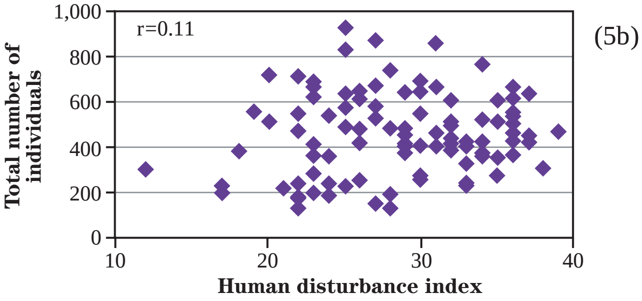




* The metric number of minnow species (4a) predictably separates least- from most-impaired sites and therefore may be retained for further analysis, whereas the attribute number of sunfish species (4b) does not and may be eliminated (Teels and Danielson 2001).

Figure 5 Correlation to disturbance gradient (gradient decreases in disturbance from left to right along the x-axis)*





* Based on degree of correlation, only one metric, total number of species (5a), should be retained for further evaluation (Teels and Danielson 2001).

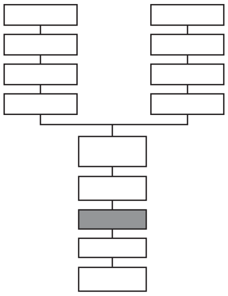
Table 7 Example metric evaluation process used to screen attributes to select the metrics that would best compose the IBI (Teels and Danielson 2001)

Species richness and composition	Separates least from most impaired sites ($p<0.05$)	Correlates with Human Disturbance Index ($r>0.35$)	Performs notably better than one of Karr's (1981) original metrics	Surviving metrics that can be further evaluated by redundancy analysis
1. Total # of species	yes	yes	*	✓
2. # of native species	yes	yes	no	
3. # of non-native species	no	no	no	
4. # of darter species	yes	yes	*	✓
5. # of darter and sculpin sp.	yes	no	no	
6. # of sunfish species	no	no	*	
7. # of sucker species	no	no	*	
8. # of minnow species	yes	yes	yes	✓
Tolerance/intolerance				
9. % dominant species	yes	yes	yes	✓
10. % pioneers	yes	yes	yes	✓
11. # of intolerant species	yes	yes	*	✓
12. % tolerant individuals	yes	yes	*	✓
Trophic				
13. % AHI (omnivorous)	yes	yes	*	✓
14. % AHI + DAH	yes	yes	no	
15. % generalist feeders	no	no	no	
16. % insectivorous minnows	yes	yes	*	✓
17. % benthic invertivores	yes	yes	yes	✓
18. % specialist carnivores	no	no	no	
19. % specialist carn. - tol	no	no	yes	✓
20. % piscivores	no	no	*	
Abundance, condition, and reproduction				
21. % simple lithophils	yes	no	no	
22. % simple lith. – tol	yes	yes	yes	✓
23. # late maturing species	yes	yes	yes	✓
24. % manipulative spawners	yes	yes	yes	✓
25. Total individuals	yes	no	*	
26. % anomalies	yes	yes	*	✓
27. % hybrids	yes	no	*	
28. % anomalies + hybrids	yes	yes	no	

AHI	algivore/herbivore/invertivore trophic group
DAH	detritivore/algivore/herbivore trophic group
*	one of Karrs original metrics

structed to compare metric performance over the various tests and summarize the screening results (table 6). The purpose of this stage of the process is to cull attributes, even those that may show some relationship to the human disturbance gradient, to select those few metrics that are highly sensitive to human disturbance yet not redundant, to form the IBI.

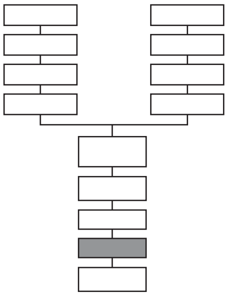
Scoring of IBI metrics



The selected metrics can then be scored by assigning values depending on whether the data they represent are comparable to, deviate somewhat from, or deviate greatly from values exhibited by the reference area's least- impaired streams (Karr et al. 1986). Such scoring allows for the fine-tuning of metrics that is tied to the reference. Such calibration increases regional metric sensitivity and may preclude the need to develop a new IBI for every region. For example, Ohio EPA has effectively used a single IBI for streams statewide through setting different IBI scoring criteria by region and designated use (USEPA 1988).

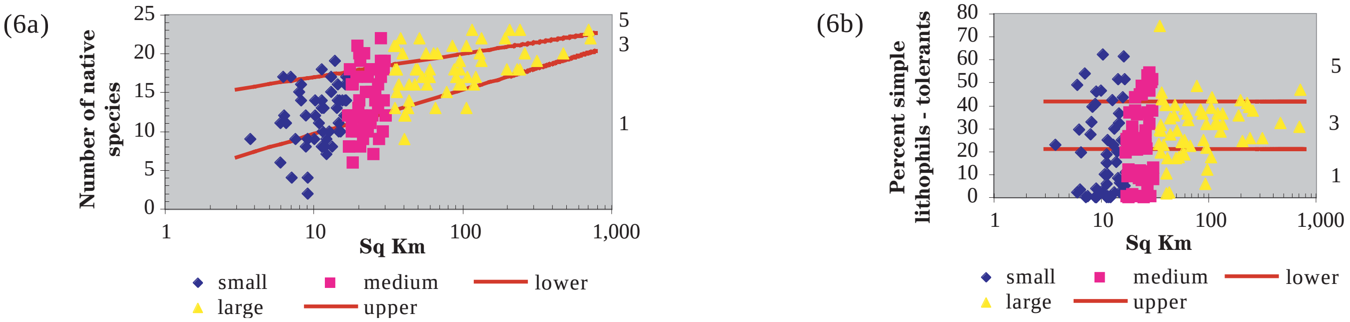
Since species richness tends to increase with increasing stream size, the scoring for species richness metrics must be adjusted accordingly (Lyons 1992a). Recent studies have demonstrated that a number of other metrics may be influenced by stream size as well (Smogor and Angermeier 1999a). Therefore, it is a good idea to examine each metric in light of the size gradient to detect corresponding relationships and then score metrics accordingly. Scoring may be accomplished either by determining the range in values (minimum and maximum) for each metric within each stream size class (table 8), and then dividing that data into equal thirds; or, by trisecting metric versus watershed area data with best-fit lines (fig. 6a and b). Best-fit lines can be established through either professional judgment or regression analysis; however, outliers in data should be avoided when constructing such lines. Metric values falling in the higher third of the range have traditionally been assigned a score of 5, those in the middle third scored a 3, and those in the lower third scored a 1. If the data are negatively correlated, the scoring is reversed. However, increasing numbers of practitioners are scoring metrics on a continuous (0–1 or 0–10) scale to reduce the noise and arbitrariness of the scoring classes (Minns et al. 1994; Howlin et al. in review; McCormick et al. in review).

Calculation of total IBI scores for all sites



An IBI is composed of the sum of the individual metrics that collectively provide a relative measure of biological condition and individually point to likely causes of degradation at different sites (Karr et al. 1986, Yoder and Rankin 1995). An IBI score can be calculated for each site by applying the scoring criteria to the data from each site. This can be easily done in most modern worksheet programs (e.g., Excel, Lotus) or alternatively, in statistical software packages (e.g., SAS).

Figure 6 Example of metric scoring using the trisection technique (Lyons 1992)*



* The metric number of native species (a) demonstrates a clear size influence; whereas percent simple lithophils minus tolerants (b) does not. Best-fit lines have been drawn accordingly (Teels and Danielson 2001).

Interpretation of IBI; e.g., evaluation of project impacts

Once IBI scores have been calculated for each sample location, various interpretations can then be made. For example, sites and their contributing watersheds can be categorized by degrees of impairment by establishing IBI integrity classes (table 9). As a result, watersheds or individual drainages that are highly impaired can be identified. Geographic information systems can help define the distribution and spatial relationships of those drainages and aid in the development of targeted solutions (fig. 7).

By examining the specific metrics affected, the IBI can also help users diagnose sources of impairment. For example, streams with high nutrient inputs often have high proportions of tolerant and omnivorous individuals and low proportions of trophic specialists (Karr and Chu 1997). To help locate impairment sources, scores from the IBI and Human Disturbance Index (HDI) can be compared (fig. 8a). Where the two procedures agree, sites with low scores can be further examined to determine which HDI components are most responsible for impairment (e.g., broad land use patterns, fish barriers, local reach impairments). In that regard, the individual components of the HDI can be compared against the IBI to detect significant correlation (fig. 8b). For example, in a Michigan watershed, Roth et al. (1996) found that stream biotic integrity was more strongly influenced by broad land use patterns than by local land use. In that study, sites where upstream drainages were dominated by agriculture ranked lowest by both the IBI and HDI, whereas sites with land areas that had higher percentage of naturally vegetated land, particularly wetlands, tended to rank higher.

Although Roth et al. found watershed-wide land use patterns tended to be a better predictor of biological integrity, in other instances local impairments may be a greater influence. For example, in a Wisconsin study, Wang et al. (1997) found in a number of sites that grazing in the riparian area had removed bank grasses and woody vegetation, resulting in higher stream temperature and loss of overhanging cover for fish.

Table 8 Example of metric scoring by size of watershed area

Metric	Size class <17 km^2			Size class 17–34 km^2			Size class >34 km^2		
	- - - - - - Score - - - - - -			- - - - - - Score - - - - - -			- - - - - - Score - - - - - -		
	1	3	5	1	3	5	1	3	5
Species richness and composition									
1. Total number of species	<11	11–15	>15	<16	16–20	>20	<17	17–23	>23
2. Number of darter species	<2	2	>2	<2	2	>2	<2	2	>2
3. Number of minnow species	<5	–8	>8	<6	6–9	>9	<7	7–11	>11
Tolerance/intolerance									
4. Percent dominant species	<40	40–20	<20	<40	40–20	<20	<40	40–20	<20
5. Number of intolerant species	<2	2	>2	<2	2–3	>3	<2	2–3	>3
6. Percent tolerant individuals	>61	31–61	<31	>61	31–61	<31	>61	31–61	<31
Trophic composition									
7. Percent omnivores	>35	17–35	<17	>35	17–35	<17	>35	17–35	<17
8. Percent insectivorous minnows	<22	22–44	>44	<22	22–44	>44	<22	22–44	>44
9. Percent specialist carnivores	<20	20–40	>40	<20	20–40	>40	<20	20–40	>40
10. Percent benthic invertivores	<25	25–50	>50	<25	25–50	>50	<25	25–50	>50
Abundance/reproduction/condition									
11. Percent simple lithophils	<25	25–50	>50	<25	25–50	>50	<25	25–50	>50
12. Number of late maturing species	<2	2–3	>3	<2	2–3	>3	<2	2–3	>3

Figure 7 Example of identification of problem drainages using IBI integrity classes (Teels and Danielson 2001)

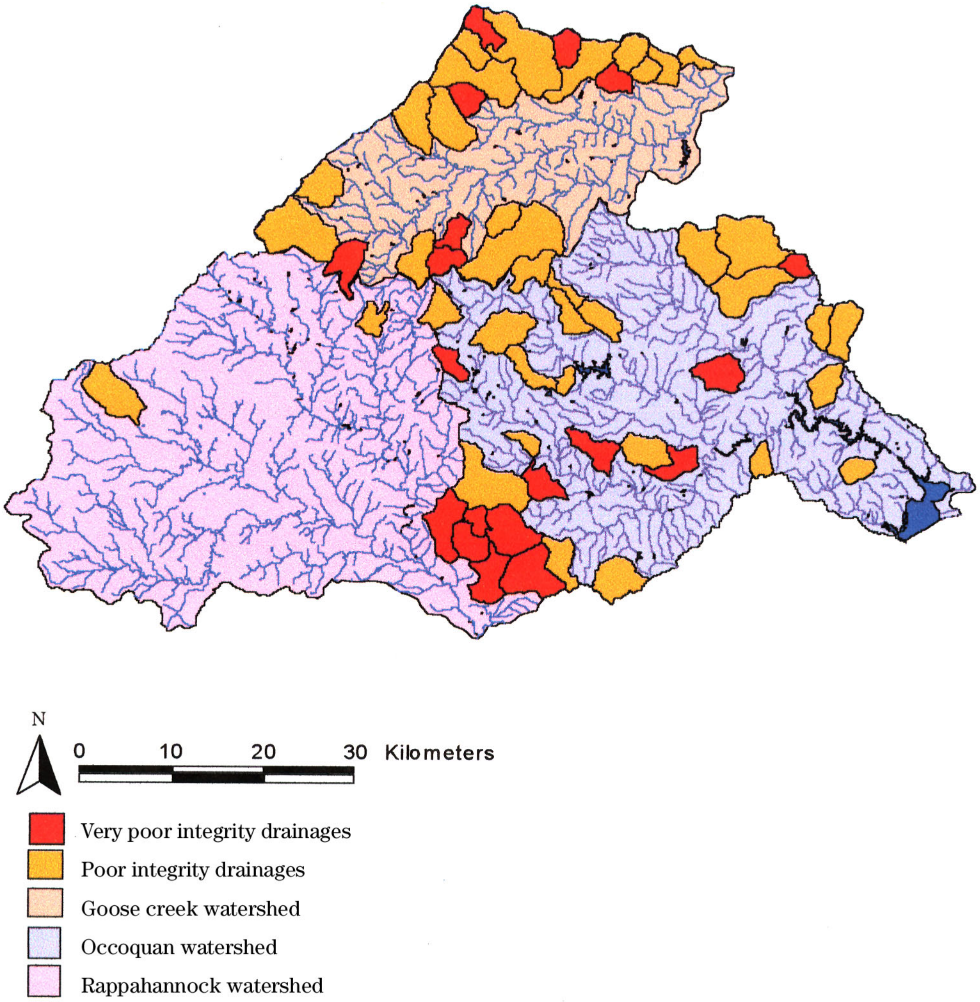
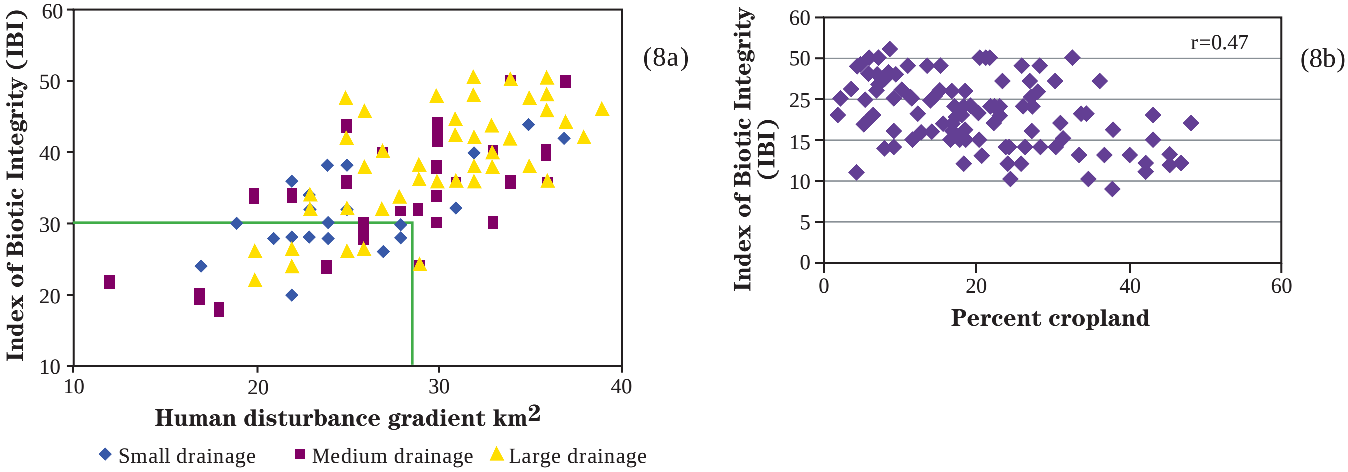


Figure 8 Examples of IBI application*



* In (8a) the IBI and HDI in conjunction can identify sites that are highly impaired (e.g., sites scoring less than 30). Further analysis of the HDI may help identify impairment sources by examining the individual HDI components (e.g., percent cropland, percent urban land) that are responsible for the low scores (8b) (Teels and Danielson 2001).

Along with high watershed slope, livestock grazing and trampling had destabilized the banks, leading to extensive erosion and sedimentation. For those sites the local impairments influenced the IBI more than broader, watershed-wide impacts. To help detect localized impairments, reach assessment scores from techniques, such as SVAP (USDA NRCS 1998), should be compared against the IBI (fig. 9a). Where there is mutual agreement for the highly impaired sites, the SVAP can be further analyzed to determine which of its individual components are most responsible for low scores (fig. 9b). Through such stepwise analysis, not only may the causes of impairment be pinpointed, but information may be gained that will lead to the selective design of conservation practices needed to correct watershed problems.

Although the IBI and HDI are expected to agree in most instances, in some instances they will not. For example, the HDI cannot possibly account for all causes of impairment (e.g., toxic chemical spills, historical pesticide use) and does not effectively deal with temporary disturbances. However, such impacts are integrated by the IBI. If low IBI scores should occur without HDI agreement, then you should still suspect that some disturbing factor is responsible. In such instances the metrics that are most affected should be identified and reasons for their impairment should be explored. In some cases a full explanation may not be revealed without examining historical land use practices (e.g., the application of persistent pesticides) or designing more comprehensive monitoring of current physical and chemical stream parameters.

In addition to helping diagnose sources of impairment, the IBI can also effectively assess the impacts of water resource projects by comparing IBI scores from before and after project installation (e.g., dams, wetland mitigation, stream restoration) (fig. 10). By knowing the response of individual metrics to project activities, projects may be designed to accommodate the metrics either individually or collectively. Thus, using the IBI as a gauge, projects may be built with the least amount of environmental harm. Because the IBI is able to integrate both positive and negative effects of human influence, it may also afford a measure of the combined effects of conservation practices (e.g., buffer strips, conservation tillage, terraces, windbreaks) that are typical of those planned by NRCS in cooperation with private landowners. It may also serve as a useful tool to assess the success or failure of conservation programs that are designed at the landscape level to solve specific watershed problems through targeted conservation (e.g., the Conservation Reserve Enhancement Program).

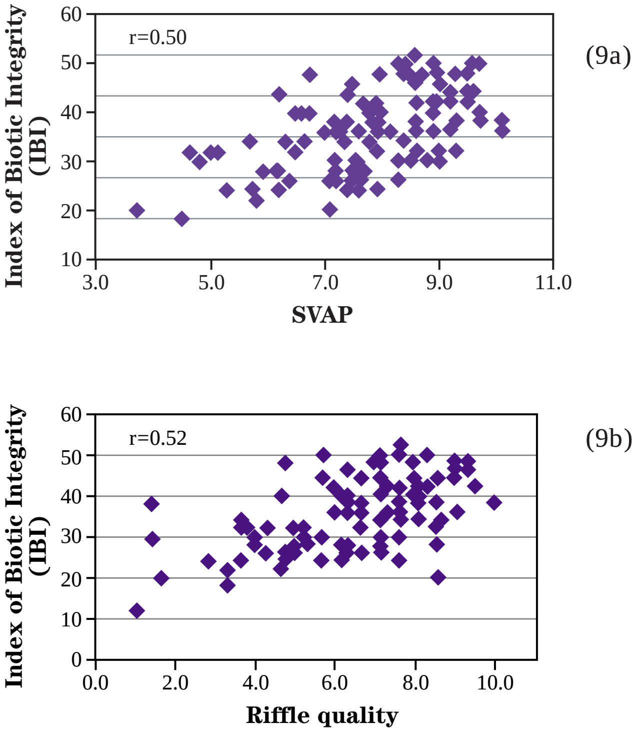
Table 9 Total IBI scores, integrity classes, and their attributes for stream reaches in a watershed (adapted from Karr et al. 1986)

Total IBI score*	Integrity class	Attributes
51–60	Excellent	Comparable to the best situations in the watershed without human disturbance; contains all species expected for the watershed for the habitat and stream size, including the most intolerant forms; exhibits balanced trophic structure and reproductive success.
41–50	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundance; trophic structure and reproduction shows some sign of stress.
31–40	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g., increasing frequency of omnivores or tolerant species); older age classes of top predators may be rare.
21–30	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; reproductive and condition factors commonly depressed; hybrids or diseased fish often present.
11–20	Very poor	Dominated by highly tolerant forms (e.g., green sunfish or creek chubs), hybrids may be common; disease, lesions, parasites, fin damage, and other anomalies may be regular.

* Sum of the 12 metric scorings.

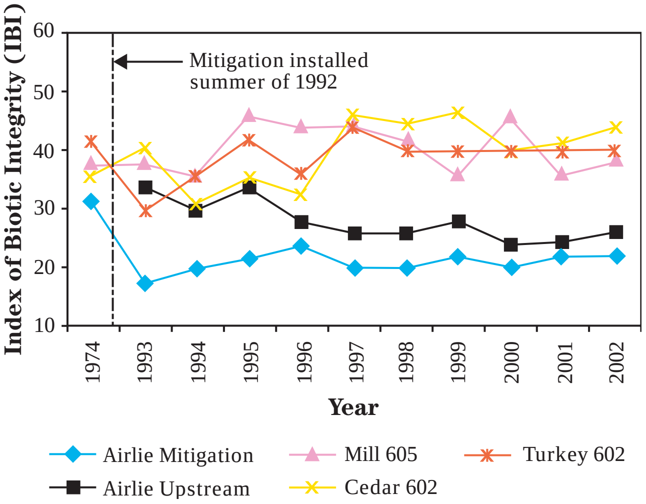
In summary, the IBI is a robust management tool that can rapidly assess the biological condition of aquatic resources. Perhaps the greatest benefit of an IBI is that it summarizes and presents complex biological information in a format that is easily communicated to managers and the public. Not only can it accurately reflect stream and watershed conditions, most people can relate more easily to fish as an indicator of condition than with complex statistical calculations or more abstract chemical and physical measures.

Figure 9 Examples of IBI application*



* Local impacts (e.g., livestock overgrazing) can be assessed by comparing the IBI to reach assessment scores (e.g., SVAP)(9a). Individual SVAP component scores can then be examined to help identify specific causes of impairment (9b)(Teels and Danielson 2001).

Figure 10 Example of IBI application*



* Water resource project impacts may be assessed using the IBI by studying before and after conditions. In this instance the IBI detected the immediate effects of stream inundation and isolation for two stream reaches (mitigation site and mitigation upstream) resulting from construction of a dam and upstream mitigation cells. The effect has persisted at both sites over a 10-year period; whereas the IBI scores of other nearby sites (Mill 605, Cedar 602, and Turkey 602) used as reference have varied, but remained higher over that same period.

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Appendix

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(Walsh and Meador 1998)

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