Stream Ecosystem Structure: Biological Indices for Bioassessments

*What Are IBI’s?*

IBI stands for Index of Biological Integrity. Essentially, IBI’s use fish and/or insect community structure as indicators for the ecological condition of aquatic environments. Biotic communities are single parameters that are usually easily measured and community structure is known to vary along gradients of water and habitat quality in lotic ecosystems. Research has shown that various aspects of fish and insect communities change across ecological gradients, especially gradients of anthropogenic impacts. The IBI’s is based on the belief that aquatic organisms, living in streams, experience all the different conditions in an aquatic environments and their response (in terms of the community structure) can accurately summarize the overall state of the stream’s physical environment. Metrics are the specific aspects of communities that are used for assessing the state of the stream (See Below). The state of the insect community is not necessarily directly caused by the factors they represent in terms of stream health. For example, urbanization indirectly causes many alterations to lotic communities that actually are the direct result of specific changes to the watershed caused by urbanization (e.g. removal of riparian vegetation or toxic inputs). Also, more recently, other characteristics important to stream health and ecosystem function (namely, biogeochemical parameters) have been inadequately described by biotic community structure.

The goal of bioassessments using IBI’s is to use an easy measurement (biotic community structure) to indicate the level of impairment experienced by a particular stream reach. These assessments generate a single value that can be compared to reference sites or used alone and related to known target “values” for that particular region. The single value has the advantages of being concrete and easily interpreted by the public. However, a single value does little to describe any insight into the specific causes of degradation. The data analysis methods often must be standardized for a particular region to determine if a stream is in good health or bad health. In terms of restoration, IBI’s can be used in bioassessments to determine candidate streams for restoration or to monitor streams after restoration.

The application of these IBI’s should, however, be conducted with discretion. For example, in places like the Adirondacks, only one or two species of fish may naturally exist in undisturbed streams. In this case, low fish diversity would not be an indication of an anthropogenic impact; rather it suggests that few fish have colonized small headwater streams since the last glaciation.

*Sampling Effort vs. Data Obtained*

Because sampling for IBI’s is for comparative assessment purposes rather than for a pure description of the community, the amount of work done (money and time spent) must be weighed against the descriptive power of the data collected. The goal for sampling biotic communities for IBI’s in bioassessments is to perform the least amount of work to obtain data that provides accurate assessments of aquatic conditions (Figure 1). For aquatic macroinvertebrates, studies have shown communities found in riffle habitat are often best to examine for bioassessments but do not contain the entire species assemblage in the stream (See notes on Macroinvertebrate Sampling). On the other hand, because fish community structure is strongly related to habitat heterogeneity, a multi-habitat sampling protocol is required for fish IBI’s in bioassessments.
Figure 1. Shows how the amount of work performed must be balanced against the gains in information.

Aquatic Macroinvertebrate Metrics
Barbour et al. (1999) describes five general sets of “metrics” that are recognized as being consistently descriptive of impairment at large geographic scales: 1) Taxa Richness  2) Species Composition Measures (EPT’s, Exotic Invasives)  3) Biotic Indices (Tolerance/Intolerance)  4) Trophic Composition (Functional Feeding Groups)  5) Organism Habits.

Taxa Richness - Taxa richness is simply the number of taxa present within a sample. Taxa richness is a component of diversity and can be calculated at the species, genus, family, and even order level. Genus/Species level identifications are often considered the most appropriate for this metric. However, family level identifications can also be used especially given the time/skill required for species level identifications. Greater numbers of taxa usually represent “healthier” conditions and less anthropogenic effects. However, recent research has shown that some agricultural areas possess much greater taxa richness values compared to streams in urban watersheds (Moore and Palmer In Press).

Species Composition Measures (EPT’s, Exotic Invasives) - Species composition measures use the presence of certain taxa known to exist in varying degrees of stream “health” as indicators of impaired conditions. For instance, the EPT measure (Ephemeroptera – Mayflies, Plecoptera – Stoneflies, Trichoptera – Caddisflies) are often associated with unimpaired conditions and higher abundances of individuals in these families suggests high water quality. On the contrary, the presence of invasive/exotic species often suggests lower quality streams. It is better to use relative abundance rather than absolute abundance because it takes into account the structure of the entire community. Another common metric of this category is the evenness of the community. Poor quality streams often are dominated by a few taxa and have low evenness values.

Biotic Indices (Tolerance/Intolerance) - Biotic indices apply tolerance values to taxa (at all taxonomic levels) that indicate their ability to survive different levels of impaired conditions. These numbers are developed through specific studies of presence/absence, species morphology, etc., and are often regionally applied. Many tolerance index values are developed specifically to
detect organic pollution. Overall scores can be assigned to particular sites depending on the presence and abundance of species with particular values or designations. Hilsenhoff’s (1987) paper (which reports earlier work) is one classic example of the development of a regional tolerance index for benthic macroinvertebrates.

**Trophic Composition (Functional Feeding Groups)** - Functional feeding groups are designations provided to groups of benthic invertebrates based on the method by which they feed. Groups that are missing or overrepresented can indicate “unhealthy” conditions. However, the proportions of different functional feeding groups also are known to change predictably from the headwaters to large rivers along the stream continuum (See Notes on Sampling Macroinvertebrates). As a result, the expected proportions of these metrics should take into account stream order and physiographic province. This is one of the less reliable metrics. In general, specialized feeders such as scrapers and shredders are thought to be more indicative of healthy conditions while generalist feeders such as collectors can tolerate stressful conditions and may suggest impaired conditions.

**Organism Habits** - Organism habits refer to the mode of movement and the habitats occupied by benthic macroinvertebrates. An abundance of organisms that inhabit certain conditions can tell us about the health of the stream. For instance, an abundance of burrowers may exist in areas where siltation is prevalent. However, a metric like this may not be as useful in coastal plain streams where sandy substrates are expected. Similarly, a predominance of species with multivoltine life cycles (short generation time, multiple generations per year) may indicate that disturbances occur often during the year and univoltine (moderate generation time, one generation per year) and semivoltine (long generation time, one generation occurs over several years) cannot exist in the stream reach. The utility of metrics based on organism habits will vary greatly but have been found to be useful for detecting impaired conditions.

**Fish Metrics**

Barbour et al. (1999) describes three general groups of “metrics” that are recognized as being consistently descriptive of impairment at large geographic scales: 1) Species Richness and Composition 2) Trophic Composition 3) Fish Abundance and Condition. Below I provide brief summaries of the groups of metrics but Barbour et al. (1999) should be consulted for detailed explanations of metrics and possible alternatives for each metric.

**Species Richness and Composition** - The metrics in this group use species richness in a similar way as described above for macroinvertebrates. However, fish metrics must also take into account exotic species since they can inflate richness measures but are indicative of poor stream “health”. This groups also includes metrics that examine the presence/absence of particular indicator species and species tolerances. Tolerance indices can be developed for fish communities similar to macroinvertebrates but are sometimes given more generic designations than numbers (e.g. Pirhalla 2004). Barbour et al. (1999) contains a list of tolerance values and designations for different taxa of fish (and macroinvertebrates) across the entire country. When metrics are used that include some measure of taxa richness, sampling must include a variety of habitat types since species diversity is so closely related to habitat heterogeneity. This is in contrast to invertebrates that can be sampled in only one habitat.
**Trophic Composition** - The metrics in this group use the presence/absence and abundances of species in different feeding guilds or at different trophic levels to indicate the quality of the food resources and trophic structure of the community. Similar to macroinvertebrates, increased generalist feeders usually indicates impaired conditions.

**Fish Abundance and Condition** - The metrics in this group are used to estimate population level conditions of fish in streams. This type of assessment is not used in macroinvertebrates. The metrics include examining the presence of hybrids in the community as well as morphological problems with individual fish (e.g. disease, tumors, physical damage, etc.).

**Other Considerations**

*What to do about Chironomids*
Chironomidae (midges) are controversial in bioassessments. As stated previously, bioassessment protocols are usually designed to minimize the amount of work required to obtain informative results. The identification of midges to genus/species is time consuming and requires training. As a result, many have looked at the possibility of not identifying midges past family. Studies have shown that different genera of chironomidae have different tolerances to pollution and can be informative when included in bioassessments. However, other studies have suggested that bioassessments excluding chironomids can discriminate between degraded and healthy sites and including midges may actually obscure results (Rabeni and Wang 2000). Ultimately, the inclusion of midges in bioassessments must be decided by the investigators and based upon the goals of the study. However, this decision should be done prior to sampling in order to avoid bias.

*Rare Species*
Rare species can be important to bioassessments. Obviously, when the restoration project includes goals about endangered or rare species, including rare species in the assessment will be important. However, in terms of measuring stream “health”, rare species are most important for metrics that are related to taxa richness. However, extra work to include rare species may just add redundancy to the other metrics that do not include richness (e.g. community composition, tolerance index, species habits). Including rare species can be done by increasing sampling intensity, increasing subsample size (or not subsampling at all), and increasing taxonomic resolution (see below). (Note: Cao et al (1998) provides evidence that rare species are important overall for bioassessments, but Marchant (1999) provides an alternative view through a comment on Cao et al’s (1998) study. Similarly, Cao and Williams supply a reply to Marchant (1999). These papers discuss the controversy for using rare species in bioassessments)

*Taxonomic Resolution?*
As stated previously, taxonomic resolution is important for metrics using taxa richness and for including rare species. In general, taxonomic resolution will be determined by the skill of the individuals working on the project. Ultimately, it is most important to be confident in the identifications made for both fish and invertebrates. Besides metrics using taxa richness, tolerance values can change greatly from genus to species. However, no study to my knowledge
has examined if these few exceptions affect the ability of bioassessments to detect impaired conditions.

**Study Design**

**Reference Conditions**

Some assessments do not require a “reference” condition. In this case, the IBI score denotes the ecological health of the stream because the protocols are already standardized for a particular geographic region. Here single values developed from many individual metrics can stand alone as indicators of impaired conditions. While a single score is easy for government officials and the general public to understand, it has very little descriptive power about which specific indicators suggest that the stream is impaired.

In other instances, assessments are done by comparing IBI scores to reference data collected at streams nearby. When selecting reference sites, it is important to understand exactly what the question is. If there are specific structural and community endpoints that are desired, specific comparisons between experimental and reference sites need to be made. If the general idea is for the restoration project to improve water quality in a general matter, the reference site only needs to provide some background about the potential improvement for a given area. For example, large scale natural variability may occur and could explain changes (or no changes) in insect and fish communities that would not be considered without reference information. Reference sites should be similar in morphology, stream order, and in close proximity to the restoration site. White and Walker (1997) discuss the important parts of a reference site.

**BACI Design**

BACI is a specific type of design that works well with restoration projects. BACI stands for Before, After, Control, Impact. The general idea is to measure certain biological indicators before and after a specific impact (in this case restoration) and compare that to a control (reference site) over the same time period. This allows the investigator to take into account the natural variation that may occur following the restoration by comparing the temporal trends at the restoration site to those at a control site. For example, if a drought occurs following restoration, without comparing the indicators to those in a reference stream, it may appear that the restoration was causing harmful effects when in fact, all sites in that area are experiencing natural disturbances. Conversely, if a restoration site shows no improvement while reference sites do, this may indicate that the biotic community in the restored site is not improving and the restoration is not working properly. Smith (2002) provides a detailed explanation of the BACI design. This design can work independent or in conjunction with IBI’s and other rapid bioassessment protocols.

**Multimetric vs. Multivariate**

The metrics used and manner in which they are analyzed will depend on the reference conditions you select. In all cases, the assessments may require sampling many reference sites (at the beginning of the study) and then using those that are most appropriate. However, it is also possible to simply choose reference sites a priori and use them regardless of how they related to the study site (in terms of the values for the metrics you use).
The multi-metric assessments require the development of component metrics that are calibrated to the reference conditions. When calibration is complete, the values for each metric are aggregated and an individual score is determined. Each individual score is characterized by where it falls in relation to the scores for the reference sites chosen (i.e. what percentile it falls into). Each percentile is given a designation (usually a number) that describes the “health” of the stream (e.g. good / poor). Barbour et al. (1999) provides a detailed explanation of use of multi-metric indices for assessing stream health.

The multivariate approach creates a predictive statistical model for species presence/absence based on reference conditions. Rather than having to calibrate individual metrics, species assemblages are predicted for a given site based on environmental conditions not likely impacted by anthropogenic activities. The assessment of the stream is done by comparing species observed and species expected at that site. Hawkins et al. (2000) provides an example of this type of assessment called RIVPACS and discusses briefly its historical significance.

*The Above Information is Adapted From:*

*Works Cited:*
Cao, Y. and D.D. Williams. 1999. Rare species are important in bioassessment (Reply to the comment by Marchant). Limnology and Oceanography 44:1841-1842.


Other Sources of Information:


Macroinvertebrates as Bioindicators


Fish as Bioindicators:


