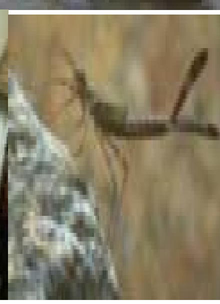
Watershed Condition Series
Technical Note 1
Biotic Condition Indicators for Water Resources








Contents

Biotic indicators[1] are widely used outside NRCS by state water quality agencies and universities to assess water quality. More commonly, biotic indicators are integrated to derive scores or indices describing water quality. A series of technical notes were written to acquaint field conservationists with biotic indicators and their application for assessing water quality. This publication, Technical Note 1, provides an overview of biotic indicators. Technical Notes 2 and 3 present biotic indicators and how they are used to derive two common biotic *indices,* the Index of Biotic Integrity (IBI) and the Ephemeroptera, Plecoptera, and Trichoptera Index (EPT). The first, the *Index of Biotic Integrity* (IBI), uses fish surveys to assess human effects on a stream and its watershed. The second, the *EPT Index*, is also used to assess land use and water quality within a watershed, but uses *benthic macroinvertebrates*, such as *stoneflies, mayflies*, and *caddisflies* as indicators. Case studies are included

Introduction

Watersheds are complex systems that integrate many factors (Figure 1). For this reason, a select group of indicators are often used to examine a limited number of these factors and infer watershed condition. For example, state agencies and others may use measurements of fecal coliform, turbidity, and nutrient and pesticide concentration to evaluate compliance with water quality standards. Others may use any of a multitude of habitat features (Figure 2), such as riparian corridor width and vegetative condition, and in-stream habitat features, such as riffles and bank stability, to assess fish productivity potential (Figure 3).

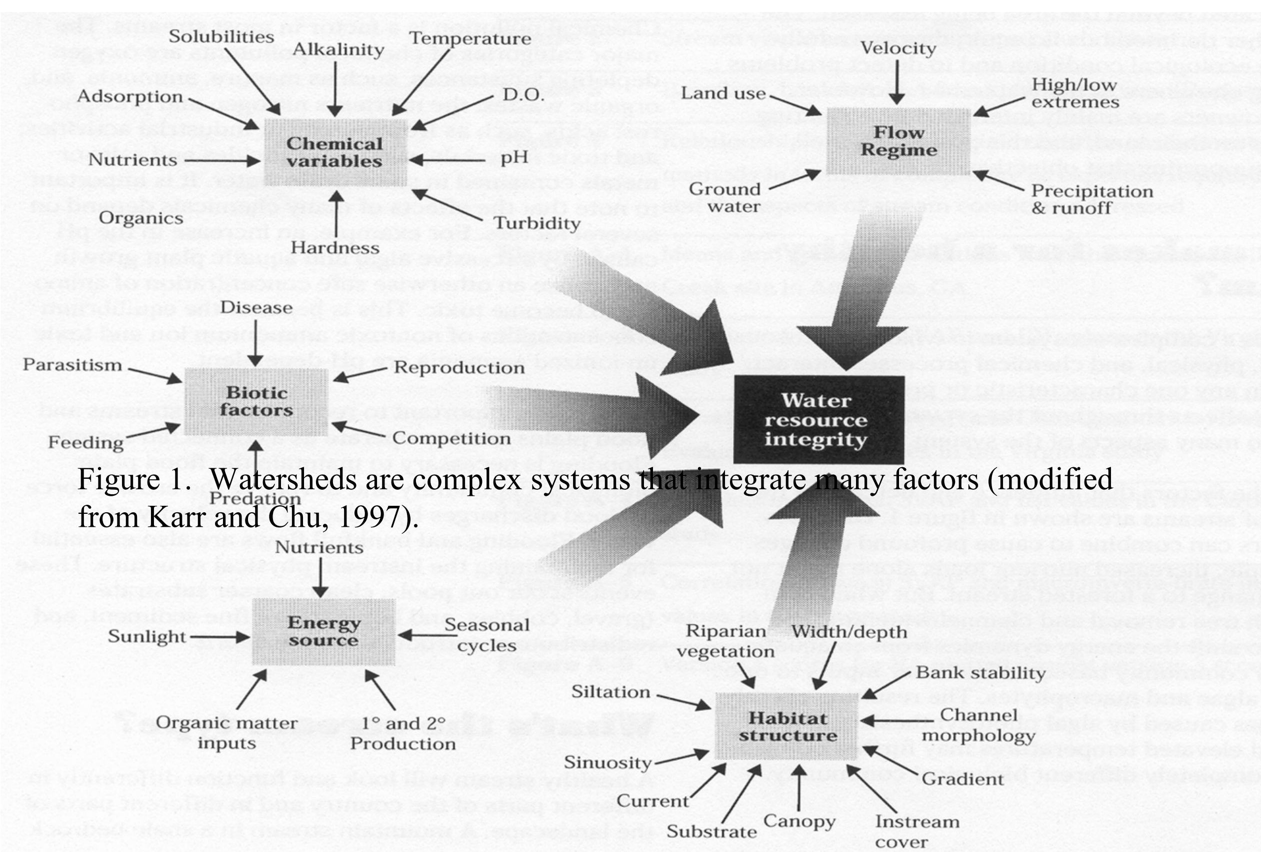


Figure 1. Watersheds are complex systems that integrate many factors (modified from Karr and Chu, 1997).

Riparian zone features

Natural vegetation extends at least two active channel widths on each side	Natural vegetation extends one active channel width on each side. *Or* If less than one, covers entire floodplain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. *Or* Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. *Or* Filtering function severely compromised.
10 best rating	**8**	**5**	**3**	**1** worst rating

Figure 2. A series of ten habitat features are used in NRCS Stream Visual Assessment Protocol (SVAP). This example shows riparian habitat features and corresponding ratings.

Figure 3. Habitat features such as riparian buffer width are often used to assess stream and watershed condition.

Biotic factors (figure 1), particularly characteristics of stream biota, have been used with great success to evaluate watershed condition and are one of the oldest approaches to assessing water quality. However, biotic indicators have disadvantages in comparison to other indicators. Biotic indicators are not as visible as habitat indicators to resource managers. For example, a stream habitat feature, such as a sloughing bank and the resulting increase in sediment load is more easily documented than the subtler, but equally damaging, effect of sediment on biotic communities in the stream. Likewise, point discharges of sewage effluent may be more readily recognizable than the cumulative effect of nonpoint nutrient enrichment on biotic communities.

Measurements, too, may fail to predict the adverse effects of chemical pollutants on the biotic community of the stream (Figure 4). Figure 4 illustrates this observation by showing the effect on fish communities of chlorine treatment to waste water inflow downstream of a treatment plant in Saline Branch, Illinois, where chlorine was added to sewage effluent to kill microorganisms that cause human disease. Increasing residual chlorine content downstream of wastewater inflow continued to affect biota downstream. Although chlorine content was well within water quality thresholds, stream biota, as measured by a very poor IBI score, declined downstream. The use of chemical and

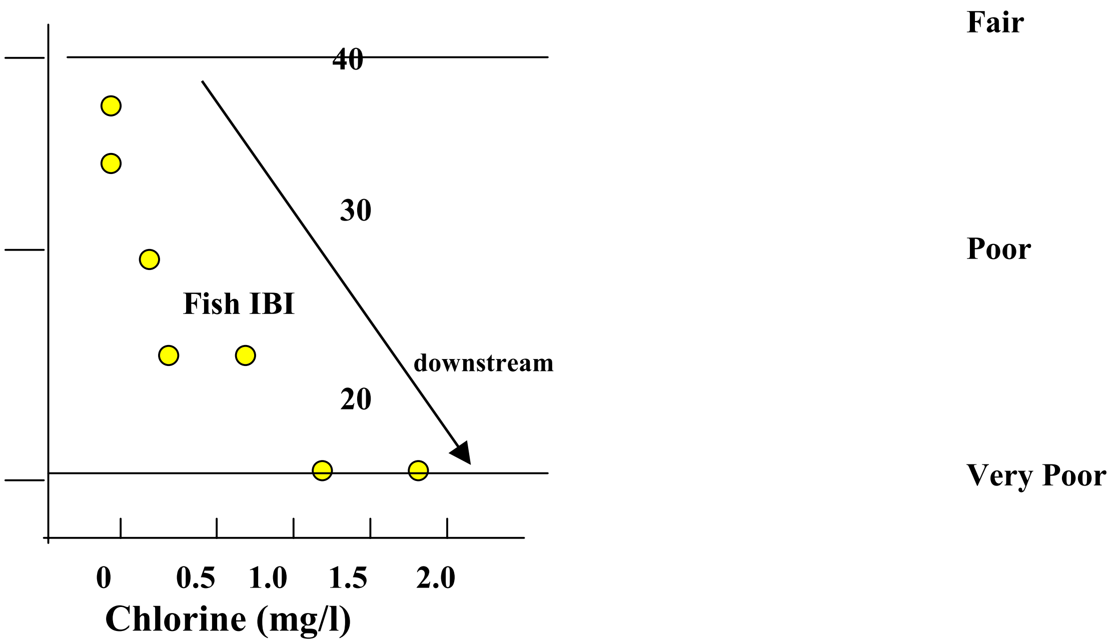


Figure 4. The fish indices of biotic integrity in Saline Branch, Illinois declined downstream in response to increased chlorine content in treated wastewater inflow (modified from Karr and Chu, 1997).

habitat indicators without biotic indicators can lead to unreliable assessments of stream condition. Chemical and habitat indicators are limited in that they reflect ‘a snapshot’ of the conditions that exist at the time the sample is taken. Biotic indicators indicate “a moving picture’ of past as well as current condition and are a more effective means of assessing integrated effects of past and present human activities on the entire watershed.

Indices and Indicators

An indicator is a measurement used to derive a score or index. Two or more indicators may be integrated simultaneously to derive an index. Many types of indices are used in the everyday world. Economic indices such as the Dow Jones average and the index of leading economic indicators combines many financial indicators to assess the state of the national economy. Likewise, doctors may simultaneously measure and evaluate many indicators, such as pulse, weight, and cholesterol to assess the state of an individual's health. A biotic index is a score that describes how well a group of organisms are tolerating the surrounding environment (Figure 5).

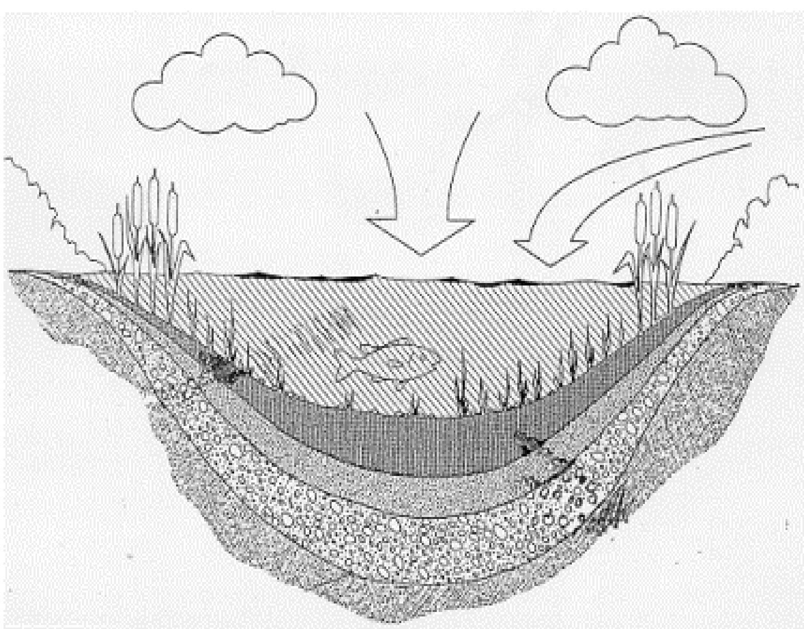


Figure 5. A biotic index is a score that describes how well a group of organisms (such as fish communities) is tolerating the surrounding environment.

History and use of biotic indicators

As early as 1908 water quality specialists developed biotic indicators sensitive to organic effluent and sedimentation. Later approaches (for example, Hilsenhoff, 1982) ranked aquatic insects according to tolerance, i.e., 1 (pollution intolerant) to 10 (pollution tolerant). Sites were then rated according to an average pollution tolerance level and assigned a biotic index value. In the 1960s, diversity indices (e.g., Shannon-Weaver) measured number and abundance of biotic taxa and were widely used by water managers (Pielou, 1975). The current trend is toward multimetric indices, such as the Index of Biotic Integrity that integrates many attributes of the *biota*, such as *species richness*, *guild*, health, etc.

"The most direct and effective measure of the integrity of a water body is the status of its living systems." (Karr, 1997)

The Clean Water Act of 1987 (PL92-500 § 101a) called for "the restoration and maintenance of the physical, chemical, and biotic integrity of the Nation's waters". Before this time (and to some extent today) most agencies were concerned with consumptive and contact uses of water, and chemical water quality measurements were the primary means of assessing water quality rivers.

Today the Clean Water Act still challenges us to answer critical questions about the biotic state of the nation's waters. Because biota that live in bodies of water integrate, in themselves, the effects of various *stressors*, they reflect current as well as changes over time and cumulative effects. Biota used as indicators can show problems otherwise missed or underestimated. Biotic indicators are useful for examining the effect of human activities on the land and serve as a 'red flag' to prompt further examination of areas susceptible to degradation. To illustrate these points, some case studies are described which show how biotic indicators were used to evaluate stream water quality and watershed condition for various land use issues. The first example, situated in the Blackout River Watershed, Montana, shows the successful use of biotic indicators to identify areas impacted by overgrazing, clearcutting, and removal of riparian vegetation. The second example examines the role of both benthic macroinvertebrates and fish as indicators of water quality trends in Ohio. The last example shows how citizens (teachers and students) can become involved in monitoring water quality by using biotic indicators.

Example 1

Land use and aquatic biointegrity of the Blackfoot River Watershed, Montana (modified from Rothrock, Barten, and Ingman, 1998)

Introduction

The Blackfoot River, a major tributary to the Upper Clark Fork of the Columbia River, is located in west-central Montana (Figure 6). It is designated as class B-1 by Montana's drinking water standards, indicating its water will support all beneficial uses (drinking water, recreation, and trout fisheries). In the 1990s, however resource managers, environmental groups, and the public had growing concerns about water quality degradation of the Blackfoot River. In the late 1980s, it had become apparent that the numbers and size of sport fish caught in the river had declined in comparison to the 1970s. Fishing pressure was thought to be one reason for fish decline, but bottom-dwelling aquatic insects, the primary food source for trout, had also declined (Ingman, 1990). During the 1970s and 80s, there had been an increase in crop production, grazing, mining, timber harvesting, and road construction in the 2,290-square-mile watershed. The need for information on the apparent linkages between land use, *biotic integrity*, and watershed management prompted this study.

The Blackfoot Watershed

In August 1995, seven subwatersheds of the Blackfoot River were sampled for macroinvertebrates (aquatic insects). The seven subwatersheds were selected to represent agricultural (irrigated alfalfa and hay and livestock grazing), silvicultural (timber harvesting, Figure 7), and wilderness land uses in the watershed. A recently restored stream was also included for comparison to the other sites.[2] Information was also collected on riparian habitat condition, land use, soil types, percentage of roads, slope classes, land ownership, soil erosion, and sediment delivery.

Several metrics were determined from sampling data of benthic macroinverrtebrate communities. Among these were *taxa richness*, *total abundance*, taxomomic group composition and percent dominant taxa, *Hilsenhoff's Biotic Index*, and *EPT* richness and abundance. Each metric is associated with a particular water quality characteristic. For example, Hilsenhoff's Biotic Index is used to detect organic pollution. EPT richness is a measure of those species sensitive to water quality degradation. Taxa richness generally increases with increasing water quality. These metrics and some others were used collectively to derive a composite normalized metric score (CNM):

CNM = (taxa richness) + (total abundance + EPT taxa + EPT abundance + EPT : Chironomidae + percent dominant taxa + 1/Hilsenhoff's Biotic Index + scrapers : total organisms + shredders: filtering collectors.

[2] The restored section of Rock Creek (1.5 mile) was used for trout production from 1977 to 1982. Ten artificial channels were created by diversion of water from the original creek to raise rainbow trout. Restoration involved creating a regionally typical riffle-pool sequence, planting riparian vegetation, adding exclusion fencing, and adding coarse woody debris.

The CNM score was designed to allow the comparison of macroinvertebrate communities between subwatersheds. The seven subwatersheds were ranked by the CNM score and ranged from the best (maximum of 9) to the worst. These rankings including habitat and land use data, are shown in Table 1.

Highlights of Findings

The composite normalized metric score (CNM) (Table 1) determined for the study was related to land use influences and individual site impacts. Site rankings determined by CNM scores ranged from 1 (best) to 7 (worst):

1. nearly pristine conditions in a wilderness area - Monture Creek
2. public forest management - Chamberlain Creek
3. multiple use; forestry, wildlife, and grazing - Cottonwood Creek
4. industrial forest harvesting - Belmont Creek
5. a restored section of an agricultural subwatershed - Rock Creek
6. privately owned agricultural use; 11% cropland and pasture and 31% herbaceous or shrub/bush rangeland - Nevada Creek
7. privately owned and BLM-owned agricultural use; 9% crop and pasture, 1% shrub/brush rangeland, and remainder in evergreen forest for livestock grazing - Union Creek

The wilderness stream with its nearly pristine conditions had the highest aquatic biotic integrity (indicated by highest CNM score). In contrast, the most impacted sites in the study were the agricultural sites, Nevada and Union Creeks. These subwatersheds were impacted by overgrazing and riparian vegetation removal. Algae mats were present, an indicator of nutrient enrichment linked to inadequate riparian zone protection. These two streams also had the largest estimated erosion and sediment delivery rates, the greatest impairment from nonpoint source pollution, and the most impoverished benthic macroinvertebrate communities (lowest CNM scores and poorest water quality).

The silvicultural watersheds, Belmont and Chamberlain Creeks, had the greatest amount of estimated soil erosion and sediment delivery and lower CNM scores than the wilderness reference site but had better conditions than the agricultural sites. Belmont Creek had steep slopes, higher road density, and recent clearcutting that probably caused more accelerated erosion and subsequent aquatic habitat degradation compared to Chamberlain Creek, and probably account for the lower CNM score for Belmont Creek compared to Chamberlain Creek.

The multiple use watershed (Cottonwood Creek) and the restored section of Rock Creek are ranked between the silvicultural and agricultural sites. Rock Creek was had degraded conditions because of cattle grazing and lack of woody vegetation along the stream banks. Rock Creek was restored by creating a riffle-pool sequence, planting riparian vegetation (willow), fencing to exclude livestock, and adding coarse woody debris. Although Rock Creek had intermediate CNM scores, the CNM scores for six evenly spaced sampling sites downstream from the rangeland became progressively better (increase in CNM score from 5.2 to 7.5 downstream) - the apparent affect of the restoration (Figure 8). The restoration reduced sediment deposition in Rock Creek by more than 50 percent and produced a ninefold increase in the rainbow trout population.

Summary

Pressure on the Blackfoot River, a class I trout river in Montana, is increasing with population growth and development, crop production, irrigation, grazing, and timber harvesting. Biotic indicators (benthic macroinvertebrates) were collected and used to examine the link between land use, water quality, and *aquatic biointegrity*. Results showed that benthic macroinvertebrate populations in the Blackfoot River Watershed correspond to land use. An index derived from macroinvertebrate data (the CNM) was useful in ranking the subwatersheds by land use. The highest score (the best) was determined in a wilderness section of the watershed, and the lowest score (the worst) in the agriculture areas. CNM scores for public forestlands, commercial timber harvesting, and a restored section ranked between those extremes. Biotic indicators used in this study, particularly benthic macroinvertebrates, were useful indicators of land use stress within the watershed. Ranking of the sites by land use enabled managers to assess what practices are degrading the watershed. Policy-makers were able to prioritize activities in the watershed.

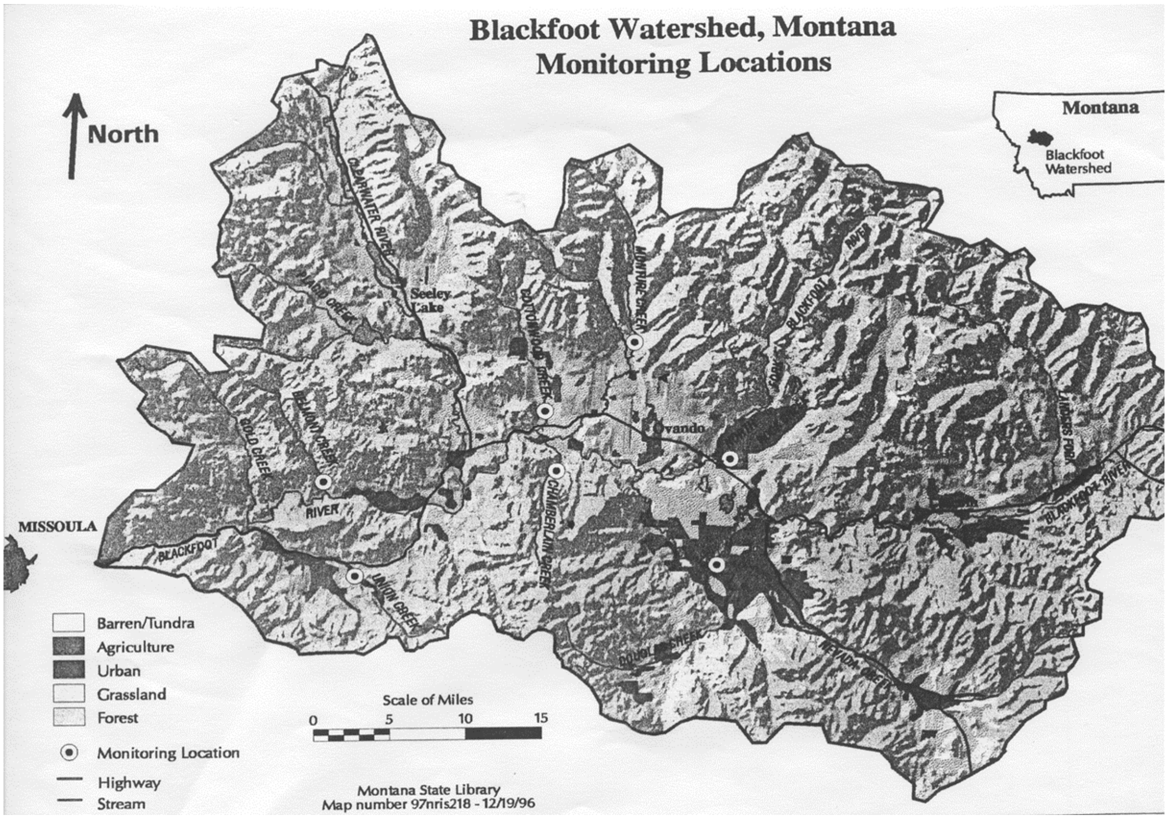


Figure 6. The location of the Blackfoot Watershed, Montana.

Figure 7. Clearcutting of timber on steep slopes led to decline in IBI scores (photo by Paul K. Barten).

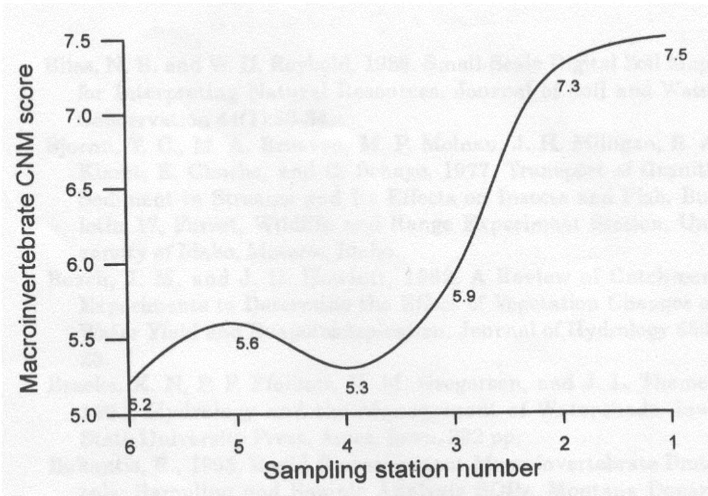


Figure 8. Macroinvertebrate scores at six sampling points proceeding downstream in the Rock Creek Restoration project, a tributary of the North Forl of the Blackfoot River, Montana.

Table 1. Characteristics estimated for the seven subwatersheds of the Blackfoot watershed.

Subwatershed and Land Use

Metric	**Belmont** **silviculture**	**Chamberlain** **silviculture**	**Cottonwood** **multiple use**	**Monture** **wilderness**	**Nevada** **agriculture**	**Rock** **restored**	**Union** **agriculture**
Land Area (km2)	74	37	185	161	915	102	269
Composite Normalized Metric (CNM) Score	5.0	6.2	5.2	7.1	3.4	4.7	3.2
Rank by CNM	4	2	3	1	6	5	7
Stream physical habitat assessment Score	78	87	86	90	58	89	69
Forest Land (%)	99	95	84	90	57	73	90
Agricultural Land **(%)**	1	5	15	0	42	22	10
Roads (%)	3.5	1.2	1.8	1.2	2.2	2	2.3
Est. Avg. Soil Erosion Rate (t/ac)/yr	1.6	0.2	0.3	0.4	1.8	0.3	0.8
Est. Avg. Sediment Delivery Rate (t/ac)/yr	0.3	<0.1	<0.1	<0.1	0.3	<0.1	0.2
Avg. Slope (%)	11-20	11-20	0-5	11-20	0-5	0-5	0-5

Example Two

Using Biological Data -Trends in the Health of Ohio Waters

When evaluating the water quality of a water body, we often want to know trends- whether its condition is improving, holding steady, or declining. Historical records are studied to determine trends in water quality over time. Biotic indicators can provide a good measure of the trend in water condition. In some areas, these data have only been collected for a short period of time. In Ohio, the use of biotic indicators to assess the effectiveness of water quality programs has been in place for 20 years[3]. In 1990, Ohio adopted numerical biological criteria as a formal component of its water quality standards. Figures 9 and 10 show how benthic macroinvertebrate and fish assemblages, integrated into an Index of Biotic Integrity, are used to track changes in water quality in Ohio.

The most common use of biotic assessment is the determination of aquatic life use attainment status. Individual water body locations are assessed as in "full, "partial," or nonattainment," using a combination of fish and macroinvertebrate indicators. These biological data results are used for reporting the status of the water resource relative to biological integrity or reference conditions, and can be used to track whether water quality is being maintained or needs to be restored (Table 2).

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[3] from http://www.epa.gov/owow/monitoring/

Other uses of Ohio biomonitoring and assessment results are the following:

- The Ohio Water Resource Inventory (CWA Section 305b report),
- Nonpoint pollution assessment and management,
- Dredge and fill 9401 Certifications),
- The National Pollution Discharge Elimination System (NPDES) Permit program, and
- Risk assessment to aquatic life from hazardous waste sites.

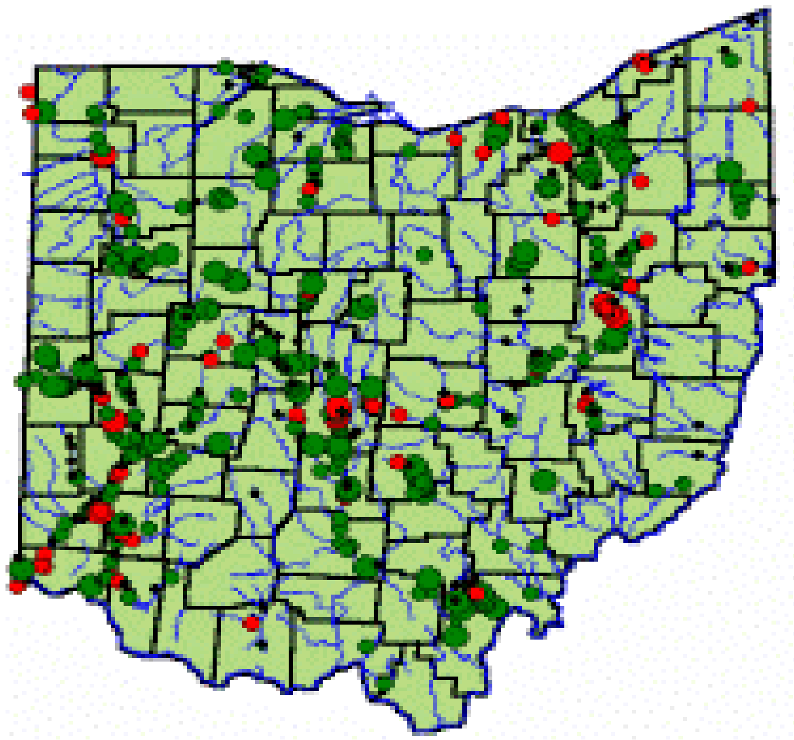

Figure 9. Trends in macroinvertebrate assemblages in Ohio. The red indicates a decline and green indicates improvement in water quality.

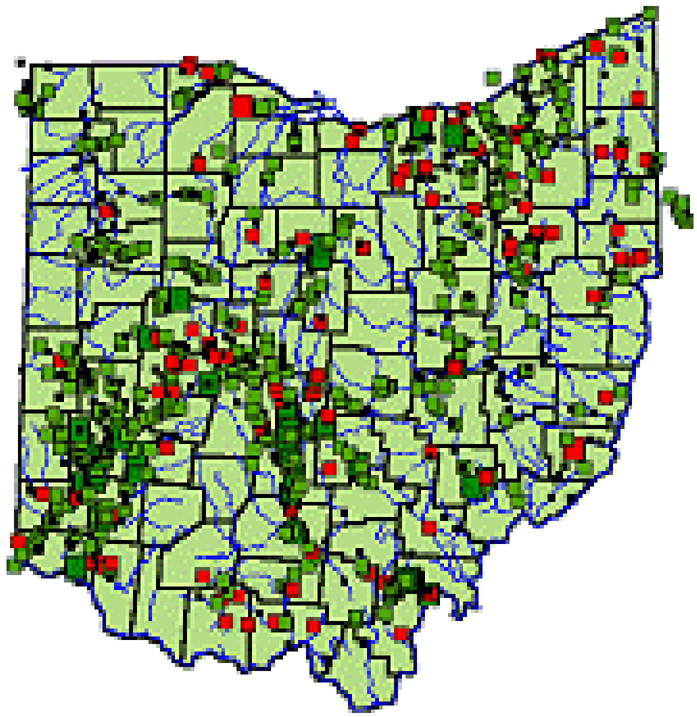

Figure 10. This map shows the trends in the Index of Biotic Integrity, an indicator of fish species diversity and health. Red indicates decline and green indicates improvement in water quality.

Table 2. Example of Index of Biotic Integrity scores for some warm water habitat reference sites in Ohio. Water resource biological data are compared to reference sites to track whether water quality is being maintained or needs to be restored.

Ecoregion*	HELP	IP	EOLP	ECBP	WAP
IBI Score	32	40	38	40	44

*HELP= Huron/Erie Lake Plain, IP= Interior Plateau, EOLP= Erie/Ontario Lake Plain, ECBP= Eastern Corn Belt Plains, WAP= Western Alleghany Plateau

Example Three

The Student watershed Research Project -Saturday Academy

Biological indictors are commonly used to teach students about water quality. An example of this is the Student Watershed Research Project (SWRP) sponsored by the Saturday Academy of the Oregon Graduate Institute.[4] Since 1991, the SWRP has trained 91 teachers and 6,000 students using over 90 local stream sites in Oregon. The students learn about a local watershed and ways of enhancing and maintaining the resources in the watershed. As part of the SWRP study, students learn how to collect macroinvertebrate samples. The students can collect benthic macroinvertebrates after some field training. Quality control guidelines ensure reproducible results and allow students to provide high quality baseline data for resource managers and scientists. Students feel a sense of stewardship because they are working toward tangible goals in their local watersheds. Figure 11 shows a student collecting macroinvertebrate samples for use in a watershed water quality study.

Figure 11. A student from Tualatin High School stirs up debris in order to catch macroinvertebrates in a D-net.

[4] from http://ogi.edu/satacad/swrp

Summary

Since the 1960s, many resource managers have recognized the importance of biological assessments for managing and protecting watershed condition and improving water quality. Stream biota such as fish and benthic macroinvertebrates are sensitive indicators of stream integrity because they

- integrate the effects of natural processes and human induced activities in the watershed
- reflect current conditions as well as changes over time and cumulative effects
- serve as a 'red flag' to prompt further examination of areas susceptible to degradation
- show problems otherwise missed or underestimated by other chemical or habitat indicators

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The status of living systems provides the most direct and effective measure of the "integrity of water," the resource on which all life depends. (Karr and Chu, 1997)

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Glossary

Benthic macroinvertebrates. Small stream-inhabiting creatures that lack backbones, are small enough to be seen with the naked eye (larger than 0.05mm) and spend at least part of their life cycle in or on stream bottoms.

Biotic indicators. Biota or organisms such as fish or benthic macroinvertebrates that have a wide pollution response and are helpful in describing what type of pollution is impacting water quality.

Biotic integrity or aquatic biointegrity. The condition of aquatic communities in unimpaired waterbodies as measured by community structure and function (role)

Caddisflies. A group of stream invertebrates that in general are characterized by 6 hooked legs in the upper third of the body, and 2 hooks at the back end; may be in a stick, rock, or leaf case with its head sticking out; may have fluffy gills tufts on the underside.

Composite Normalized Metric (CNM) is used to compare aquatic biointegrity among watersheds. It is derived from the summation of taxa richness + total abundance + EPT taxa + EPT abundance + EPT: Chironomidae + percent dominant taxa + 1/Hilsenhoff's Biotic Index + scrapers:total organisms + shredders: filtering collectors. CNM scores range from 9 (the best water quality) to 1 (the worst).

EPT Index. First developed as a rapid sampling technique to assess relative differences in water quality, it is based on measurement of pollution-intolerant benthic aquatic insects in the families of Ephemeroptera (E), Plecoptera (P), and Tricoptera (T) .

EPT: Chironomidae. Ratio of pollution-sensitive to more pollution-tolerant macroinvertebrates. An imbalance in the ratio is used to identify stressed systems.

Filtering collectors. Organisms that feed by straining small organic material out of the water column. Some filterers have large fanlike appendages they use to strain organic matter out of the water, while others actually build underwater nets

Guild. A group of similar aquatic organisms, such as a group of predatory or herbivorous fish.

Hilsenhoff's Biotic- a biotic index developed by Hilsenhoff in mid to late 1970s to detect organic stream pollution in Wisconsin streams

Index of Biotic Integrity. First developed by Dr. James Karr in 1981 for use in assessing water quality of small warmwater streams in central Illinois and Indiana, it is based on the combination of twelve measurements used to describe fish community structure and diversity.

Indicators. Anything used as a measurement, directly measured or inferred, to point out changes or status of something such as water quality.

Indices (plural of index). A numerical score usually derived from a series of indicators used to rate quality. A higher index score, such as in the evaluation of water quality, generally denotes higher quality.

Mayflies. A group of stream invertebrates that (in general) are ¼ to 1 inch in length and are brown.. They have gills on the sides of the lower body, 6 hooked legs, antennae, and 2 or 3 hairlike tails. Tails may be webbed together.

Scrappers. Macroinvertebrates that feed on diatoms and algae that are attached to underwater surfaces

Shredders. Macroinvertebrates that feed on larger organic matter such as leaves and twigs, in turn creating finer organic matter that can be fed on by other collector-gather groups of macroinverterbrates

Species richness. The total number of different taxa of aquatic organisms, such as fish or benthic macroinvertebrates in a sample, generally increases with increasing water quality;
taxa richness + total abundance

Stoneflies. A group of stream invertebrates that (in general) are about ½ to 1 ½ inches in length and have 6 legs with hooked tips, antennae, and 2 hair-line tails. They are smooth (no gills) on the lower half of the body.

Stressors. Natural or human processes that affect the environment, e.g. stream discharges.

Taxa (plural of taxon). A group of organisms systematically classified according to their natural relationship, such as a group of macroinvertebrates, which is used to represent the diversity within a sample; a taxonomic group or entity. Taxa are used as a key metric in some biotic condition indices, for example, the Index of Biotic Integrity