Chapter II —Freshwater Benthic Ecology

(Williams & Feltmate, 1992) Pollution is a semi-nebulous term used to describe changes in the physical, chemical or biological characteristics of water, air or soil, that can affect the health, survival, or activities of living entities. Organisms respond to pollution usually in one of two ways, acutely or chronically. Acute effects result in serious injury to, or death of, the organism shortly after exposure to high concentrations of a pollutant. Chronic effects are realized following exposure to low concentrations of a pollutant, the results of which appear over time, often as serious diseases (e.g. cancers).

Contents of Chapter II

Abstract

(Peckarsky *et al,* 1990; Williams & Feltmate, 1992; Hutchinson, 1993; Kellogg, 1994; Rosenberg *et al*, 1997; Mackie, 1998)

In freshwater, benthic macroinvertebrates include the insects, hydrachnidia (true water mites), molluscs (clams, snails and mussels), oligochaetes (worms), leeches & bloodsuckers, crustaceans and others. In most freshwater, the larval insects dominate the macroinvertebrate community. These organisms provide an excellent tool for assessment work.

The most common usage of benthic organisms is as indicators of water quality, especially trophic status of lakes, calcium hardness, alkalinity, pH and conductivity.

I. Benthic macroinvertebrates are common inhabitants of lakes and streams where they are important in moving energy through food webs. The term `benthic' means `bottom-living' and indicates that these organisms usually inhabit bottom substrates for at least part of their life cycle; the prefix `macro' indicates that these organisms are retained by mesh sizes of approx. 200-500 μm (micro-meters). The most diverse group of freshwater benthic macroinvertebrates is the aquatic insects which account for approx. 70% of known species of major groups of aquatic macroinvertebrates in North America. More than 4,000 species of aquatic insects and water mites have been reported from Canada. Thus, benthic macroinvertebrates are a highly diverse group which makes them excellent candidates for studies of changes in biodiversity. It is best to sample either just after ice-out in the spring when late-stage larval forms are present but have not yet begun their final maturation or in late fall after most species have mated and the immatures have had a chance to develop throughout the summer in preparation for over-wintering.

II. Different groups of macroinvertebrates have different tolerances to pollution, which means they can serve as useful indicators of water quality. Biological monitoring provides an effective, easy-to-understand method for determining if a watercourse has been impacted by a pollution source. Macroinvertebrates may live from several weeks to many years and directly depend on adequate habitat and water quality for survival. As a result, macroinvertebrates can indicate pollution impacts from various, cumulative or multiple sources.

III. (Mackie, 1998) The benthic macroinvertebrates are used more commonly than zooplankton and fish in water quality assessments because:

   A. they are larger and more easily examined using low power standard microscopy than are most phytoplankton and zooplankton which require higher power and often specialized microscopy;
   B. most of the species that make up the benthic community are more-or-less confined to a specific area and exhibit little movement out of the area, in contrast to zooplankton whose distribution is greatly affected by currents and wave action;
   C. fish are able to swim away to avoid a stressor (e.g. a contaminant in an outfall), but macroinvertebrates are obliged to stay;
   D. they are good integrators of water and sediment chemistry such that a level of a toxicant that is considered safe may, be sublethal enough to be detected by effects on growth, reproduction, and/or physiology of sensitive of species in the benthic community; and
   E. the benthos cannot avoid even “slugs” or “spills” of effluent and will respond accordingly to the magnitude of the toxic event, which may be missed by chemists if they do not sample the water during the slug or spill event.

IV. *Chemical testing* can also be very important for understanding stream and lake quality, but it often supplies only limited information, equipment can be very expensive and monitoring may be time intensive (sometimes requiring weekly or even hourly sampling).
    A. Williams & Feltmate (1992) reported on a case history where routine sampling of an urban/non-urban stream did not reveal significant differences in chemical characteristics between urban and non-urban sites, and that it probably was because of the sporadic nature of storm sewer runoff. On the other hand, in the case of aquatic insects, they showed higher diversity and richness in the non-urban portion of the stream as compared with the urban portion of the same stream where the biodiversity was severely impacted.
    B. The time required for insect assemblages to return to their natural state, following disturbances such as those of point source industrial pollutants, can be on the order of many years for streams, and decades for lakes.

V. In addition, biological monitoring can provide insight into the nature of stream disturbance through an examination of the predominant feeding patterns (functional feeding groups) of macroinvertebrate groups present (also see Merritt and Cummins, 1996). For example, increased proportions of scrapers may indicate nutrient runoff, while increased numbers of collectors may show organic enrichment. This technique divides stream macroinvertebrates into four main feeding groups: shredders, collectors, scrapers, and predators:
    A. *Shredders* feed on coarse organic material such as leaves, algae and rooted aquatic plants. These organisms play an important role in breaking down leaves or large pieces of organic material to a size that can be used by other macroinvertebrates. Shredders include certain stonefly and caddisfly larvae, sowbugs, scuds and others.
    B. *Collectors* feed on fine pieces of organic material such as leaf fragments, bacteria, stream bed deposits and waste products from other organisms. Collectors are often further divided into filtering collectors like clams or blackfly larvae and gathering collectors like many mayfly and caddisfly larvae and midges.
    C. *Scrapers* graze on algae attached to stones and other surfaces. Many of these organisms are flattened to hold onto surfaces while feeding. Scrapers include water pennies, limpets and snails, netwinged midge larvae, certain mayfly larvae and others.
    D. *Predators* feed directly on other aquatic animals such as fish and invertebrates. Predatory organisms include dobsonfly larvae, fishfly larvae, dragonflies and watersnipe fly larvae.

(Mackie, 1998) The seasonal and spatial variations in diversity of benthic species correspond closely to *__Thienemann's Principles__*. There are three of them:

1. The greater the diversity of conditions in a locality, the larger the number of species that make up the community.
2. The more the conditions deviate from normal, hence from the normal optima of most species, the smaller is the number of species which occur there and the greater the number of individuals of each species which do occur.
3. The longer a locality has been in the same condition, the richer is its biotic community and the more stable it is.

Environmental impact assessment (Williams & Feltmate, 1992)

EIA is defined as, “the process of doing predictive studies on a proposed development, and analysing and evaluating the results of that development”. Although these are admirable goals, EIA, as presently practised, does not make the contribution it might to environmental science.

These problem areas could be addressed by:

(1) placing greater emphasis on long-term, large-scale perturbations of various anthropogenic stresses on aquatic insects, and
(2) focusing more attention on the development of “early-warning”, species response indices to impending stress.

Background

The benthic animals of lakes constitute an extremely diverse assemblage, containing representatives of almost every major group of animals living in fresh water.

In striking contrast to the marine benthos, insects are extremely important and are proportionately more abundant in dilute oligotrophic lakes than in less dilute eutrophic waters. It is possible that this is related to the insects being of terrestrial origin and so less able to take up calcium and other essential substances from fresh water than are soft-bodied and other invertebrates of marine affinities; on this hypothesis, which is clearly not universally valid, insects usually obtain most of what they need by mouth but compete less well with animals having other means of absorption when the needed ions are abundant.

It has been suggested that in the less eutrophic regions, the noninsectan community, ultimately derived directly from the sea, would consist of animals that at some stages depended on dissolved inorganic ions as a source of nutrients, and that such substances would be enriched where such animals lived. The insectan communities being derived from the land would have lost this capacity and, insofar as they have become important members of the fauna of electrolyte-poor water, probably receive their inorganic nutrients from solid food blown or washed into the lake. It was further suggested that the absence of these insects in the noninsectan community is due to the high level of various invertebrates dependent on dissolved nutrients being able to produce large enough populations of predators to limit severely the survival of insect eggs.

“Though this hypothesis to me is very reasonable, it is characteristic of much of benthic ecology, in which the simplest situation depends on a complicated, often hidden, set of interspecific interactions. .... Yet in the simplest form the hypothesis seems unlikely to be true. There is evidence that runs counter to it. All the lower insects- Odonata, Ephemeroptera, and Plecoptera- have salt-absorbing organs on the gills, and there are dragonfly nymphs that do need more electrolytes in solution than might be expected. The dragonfly Libellula as a nymph requires more salt than most other freshwater animals”.

.... G. Evelyn Hutchinson a.k.a. Father of modern Limnology and the modern Darwin (1993)

Types of Benthic Communities (Mackie, 1998)

Benthic organisms may live either within the sediments or upon the sediments.

- The animals that live in the sediments are called **infuanal.** They obtain their food and dissolved oxygen primarily from interstitial water held between the sediment particles. Some even engulf sediment, utilize the food that is taken in with it and then excrete or eliminate the indigestible sand particles.
- Benthic organisms that live on top of the sediments, rocks, logs or plants are called **epibenthos.** The substrate to which the organisms are attached can be identified as a suffix in the term.
    - **Epifauna** are those organisms attached to animals (e.g. zebra mussels often attach to clams, crustaceans, or snails).
    - Organisms that live attached to rocks are called **epilithic.**
    - Those on plants are known as **epiphytic.**
    - Those living upon mud or sand are known as **episammic** organisms.
- The microscopic assemblage of organisms (mostly algae, bacteria, fungi and molds) that grow freely upon or attached to surfaces of submerged objects are called **periphyton.** Since the periphyton include both planktonic and benthic forms, it is sometimes difficult to determine which group they belong. Periphyton are common in both lakes and streams.
- **Lake benthos** is often also classified according to the zone that they live in.
    - **Littoral benthos** and **sublittoral benthos** are characterized by body appendages that allow the organisms to cling to plant stems and leaves.
    - **Profundal benthos** are adapted for gathering or filter feeding the fine organic particles that typify the profundal zone.
        - With the lack of coarse particulate organic matter, shredding invertebrates are absent.
        - Likewise, since there is no light in the profundal zone, grazing (or scraping) animals are absent.
        - In fact, the only functional feeding groups in the profundal zone are:
            - gatherers (e.g. worms),
            - filter feeders (e.g. fingernail clams), and
            - predators (e.g. midge flies).
            - Occasionally a fourth group, the **abyssal benthos,** are present. But the abyssal zone is present only in very deep lakes (>500 m) and many of the benthic species are blind.
- **In streams,** the benthic assemblage in the **riffle areas** (rapids) is very different from that in the **pools,** or back eddies. The benthos of pools is often very similar in form, habits and species composition as that in ponds and lakes. The benthic communities of rivers, in general, are composites of assemblages from their tributaries, truly riverine species and cosmopolitan species that occur virtually everywhere.

Biodiversity and Water Quality (Wetzel, 1983; Williams & Feltmate, 1992; Mackie, 1998)

Indicator Organisms (Mackie, 1998)

"Many species of macroinvertebrates are diagnostic of certain kinds of habitats and their water quality. They are known as ***indicator organisms*, **that is organisms that become numerically dominant only under a specific set of environmental conditions. The most common usage of benthic organisms is as indicators of water quality, especially trophic status of lakes, calcium hardness, alkalinity, pH and conductivity. Stream organisms that exhibit adaptations to life in flowing waters are indicators of stream environments. These organisms exhibit clues that they are from erosional substrates in stream environments. In contrast, organisms that live in depositional substrates (e.g. pools of streams, sediments of lakes) have features characteristic of lentic environments. Some benthic organisms are restricted to temporary ponds and each species has one or more adaptations to survive a period of drought."

Factors Affecting Changes in Biodiversity (Mackie, 1998)

Several biotic factors, such as genetic diversity, can affect biodiversity. Over the short term, e.g. 1-10 years, biodiversity can fluctuate as different gene pools are randomly selected through short term changes in the environment. But over the long term, e.g. decades to centuries, biodiversity has declined due to both direct and indirect factors, such as habitat loss, habitat fragmentation, over-exploitation, pollution and the introduction of exotic species. The effects of natural factors on biodiversity must first be eked out from the anthropogenic factors.

Species are thought to adopt one of three life history strategies in order to live in stable and unstable environments: (i) **r-selection**; (ii) **K-selection**; or (iii) **bet-hedging**. Stable environments are those in climates that are relatively constant and/or predictable, as in tropical climates. Unstable and/or unpredictable environments are characteristic of variable climates, like those in the temperate zone. Stable environments are characterized by species with a K-strategy, while fluctuating environments are characterized by species with an r-strategy. Advocates of r- and K- selection deal with models in which fecundity and mortality schedules fluctuate. Bet-hedging is advocated when fluctuations in these life history traits occur.

- In lotic systems, the variables are variations in stream order and the corresponding changes that occur downstream, as revealed in the river continuum concept. These include substrate types, water velocity, depth and width of streams and sediment loads. All these physical attributes vary in relation to stream order, from coarse substrates (boulders, rocks, etc.) in clear, cold, well oxygenated water and narrow widths and shallow waters of lower order streams to fine sediments (e.g. gravel, sand, silt, etc.) in more turbid, warmer, less oxygenated water and wider and deeper waters of higher stream orders.
- In lentic systems, temporal variations occur due to natural eutrophication processes. Eutrophication is a natural process but eons are required to change an oligotrophic lake into a eutrophic one. While the ecosystem changes, organisms can slowly adapt to the conditions present. But if the rate of change is suddenly increased, only those organisms with life history traits that can accommodate the increasing rate of change, or an unstable environment, will prevail. Species that have incorporated life history traits adapted for a stable environment will succumb. Hence, species that have incorporated K-strategy traits will probably perish before those with r-strategy traits.
- If the magnitude of changes due to natural factors are known, one should be able to determine the magnitude of effects of habitat loss, habitat fragmentation, pollution and the introduction of exotic species.

Table II-1: Some strategies of r- and K-selection traits (Mackie, 1998)

Traits	K-selection	r-selection
Mortality	Density-dependent; high juvenile mortality	Density-independent; high adult mortality
Population size	Constant in time and equilibrium; recolonization rarely needed; at or near carrying capacity	Variable in time, no equilibrium; recolonization frequently needed; usually below carrying capacity
Competition	Usually keen	Often lax
Selection favours:	1. slow development 2. Competitive 3. Delayed reproduction 4. Low resource threshold 5. Large body size 6. Iteroparity 7. Decreased death rate	1. Rapid development 2. High intrinsic rate of increase 3. Early reproduction 4. High resource thresholds 5. Small body size 6. Semelparity 7. Increased birth rate
Life span	Long, >1 year	Short, <1 year
Leads to:	Efficiency	Productivity
Apportionment of energy to reproduction:	Relatively small	Relatively large
1. Mass of young/parent/brood	smaller	Larger
2. Mass of young/parent/lifetime	Smaller	Larger
3. Size of young	Larger	Smaller
4. Parental care	More	Less

Table II-2: Contrasting predictions of r- and K-selection and bet-hedging (Mackie, 1998)

Stable Environments	Fluctuating Environments
Bet-hedging predictions when adult mortality is variable	
Slow development, late maturity	Rapid development, early maturity
Iteroparity	Semelparity
Smaller reproductive effort	Larger reproductive effort
Fewer young	More young
Long life span	Short life span
Bet-hedging predictions when juvenile mortality is variable	
Early maturity	Late maturity
Iteroparity	Semelparity
Larger reproductive effort	Smaller reproductive effort
Fewer broods but more young per blood	More broods but fewer young per brood
Short life span	Long life span

Species Tolerances and Requirements (Mackie, 1998)

The physiological and ecological tolerances and requirements describe the "hardiness" of a species. The more hardy a species is, the greater its ability to adapt to quickly changing environments. "Weed" species are not likely to become endangered or extinct. They are widely distributed and if pollution or intentional destruction by humans eradicates them in one part of the country, other populations will perpetuate the species. If humans alter the rate of change in habitat quality, pollution (or eutrophic) indicator species have less potential to become extinct than do clean water (or oligotrophic) indicator species**.**

- For example, of the fingernail clams, the arctic-alpine clam, *Pisidium conventus,* is more likely to become extinct than the ubiquitous pea clam, *Pisidium casertanum;* or deep water sculpins (*Myoxocephalus quadricornis*) would have a faster extinction rate than the stream- and lake-dwelling slimy sculpin (*Cottus cognatus*). Support for this argument can be seen in many, if not most, of the fish species that are listed as endangered or threatened, which are cold-water species adapted to oligotrophic or pristine conditions.

Urban and Highway Runoff (Mackie, 1998)

Aquatic communities downstream of many municipalities change due to the effects of urban stormwater runoff and solid waste disposal. Stormwater runoff has similar constituents as highway runoff, with road salt, tars, oils, gasoline, metals and rubber tire derivatives entering streams as a broth of contaminants. Runoff from asphalt also has a significantly higher water temperature, often resulting in greater than a 10^{o}C increase in stream temperature immediately below the outfall. Silt loads are also high so that the runoff is hot and turbid. Much of the effluent results in increases in sediment concentrations of total hydrocarbons, aromatic hydrocarbons (both in lubricating oils and fuels), and heavy metals (e.g. lead in fuel, copper in brake linings, zinc and cadmium in tires, and chromium and copper in de-icing salts).

The toxicity of this “broth” of contaminants in the water and sediments is complex, with synergistic and antagonistic effects. Benthic and fish communities respond accordingly, but over the long term, fish may be eliminated and the benthos are dominated by pollution tolerant forms like tubificid worms and chironomid larvae.

In general, the type and size of the receiving water, the potential for dispersion, the size of the surrounding catchment area, and the biological diversity of the ecosystem are some of the factors determining the importance of runoff effects.

(also cf. Maltby *et al,* 1995)

Physical disturbances- Urban land development (Williams & Feltmate, 1992)

Two major effects of urbanization on aquatic systems and insects are, (a) increases in sediment loads during construction phases, and (b) post-storm increases in the discharge of streams and rivers downstream from developments.

- Higher levels of sedimentation can affect aquatic insects by altering biochemical conditions, food resources, respiratory diffusion gradients, and habitat space.
- In a laboratory stream, several species of mayfly, stonefly and caddisfly, when given a choice between sedimented and unsedimented regions, all selected unsedimented substrate.
    - Avoidance of sedimented regions was due to the loss of interstitial space between stones, and behavioural observations revealed that the insects would not excavate fine particles.
- For a 3rd order stream through the city of Edmonton, it was found that although the density of insects was higher within the city (e.g. chironomids and tubificid worms), diversity and richness (number of species and individuals) of the fauna was much lower than that were found in the portion of the same stream upstream of the city.
- In several other cases elsewhere, reductions in densities of aquatic insects in areas of stream exposed to heavy siltation were related to increases in catastrophic and behavioural drift (Rosenberg and Wiens, 1978).

Motor vehicles- Urban areas (Williams & Feltmate, 1992)

Motor vehicles impose an additional urban-related stress on aquatic insects. Higher values of COD in urban surface waters result due to hydrocarbons leaked from automobiles (i.e. oil and gas). Urban runoff also contains significant quantities of lead related to the proportion of catchment area allotted to motor vehicles and to the density of traffic.

Chemical disturbances- Road salt (Williams & Feltmate, 1992; Mackie, 1998)

In many cold weather countries, road salts ($NaCl$, $CaCl_2$, and KCl) are regularly applied in an attempt to de-ice motorways. The fate of these salts is to enter surface water and groundwater supplies, where they have both a proximal impact on stream- and lake-dwelling insects and a distal impact on those species found in groundwater outflows.

- NaCl, ranging from 3,735-10,136 mg/l, and KCl, ranging from 204-6,713 mg/l, resulted in 100% mortality of two species (a caddisfly and a midge) within 48 hours. Despite the fact that these concentrations greatly exceed levels in lakes in general, the physiological impact of lower concentrations was still thought to diminish species fitness.
- Further, salt concentrations that exceeded 1000 mg Cl/l induce significant increases in drift rates of benthic macroinvertebrates, decreases in biomass and diversity of algae, and increases in bacterial counts.
- As maximum Cl^{-} concentrations of 1,770 mg/l had been recorded in the field during the summer in a study, it was concluded that road salt applications do have a debilitating effect on stream insects.

Agriculture (Mackie, 1998)

In some watersheds, runoff from agricultural lands accounts for almost all the discharge into major tributaries.

- The direct impact of cattle crossings on survival and diversity of aquatic species is obvious and can account for significant changes observed in benthic and fish community structure.
- Indirect effects of agriculture are also apparent.
  - Direct inputs of manure by cattle results in heavy growths of blue-green surface algae (e.g. *Microcystis, Aphanizomenon*), attached green algae (e.g. *Cladophora*) and submerged macrophytes (e.g. *Myriophyllum*). In some cases, plant biomass is so dense that stream flow is reduced to stagnant pools and eddies, containing soft, black mud that emits a strong hydrogen sulfide odour.
  - Organic enrichment is further enhanced by the spreading of inorganic (e.g. phosphates) and organic (e.g. manure) nutrients on the fields, some of which ends up in the runoff during heavy precipitation events.
  - Compounding the problem of organic enrichment is the input of pesticides from agricultural runoff. herbicides are applied almost annually, after the crops have begun to grow, and enter the stream indirectly as runoff or directly by going too close and accidentally spreading it into the stream.

Chemical disturbances- Pesticides (Williams & Feltmate, 1992)

The ideal pest control agent would:

(1) kill only target species
(2) have no long- or short-term effects on non-target species
(3) break down into harmless chemicals in a short period of time
(4) not select for genetic resistance in the target organisms
(5) not affect predator/prey relationships or competitive interactions
(6) be more economical than not using pest control

Unfortunately, no such pesticide exists. A well known example of a control agent initially thought to be ideal, and later discovered not to be so, is DDT. By means of a circuitous path, aquatic insects can link DDT to the death of higher vertebrates. Further there is a marked paucity of studies that have examined how changes in biotic interactions (predator/prey, competition, etc.) might affect aquatic insect assemblages following exposure to insecticidal sprays.

Physical disturbances- Forestry practices (Williams & Feltmate, 1992)

The impact of logging on aquatic insects is related primarily to two activities, road construction and tree felling.

- To curtail the impact of logging on aquatic insects, it was suggested that a 30 metre wide buffer strip be left along the shorelines. Using several comparisons, no significant differences were detected in macro-invertebrate communities in streams with wide buffers (>30 m), as compared with controlled (unlogged) areas.

Habitat Loss (Mackie, 1998)

Total destruction of many wetlands has resulted in the direct loss of many species of birds and fish, merely by removal of their “homes”. By removing the wetlands, one indirectly affects the quality and, therefore, the diversity of the receiving waters. Only the more resistant of the species survive, the weak are annihilated.

Habitat Fragmentation (Mackie, 1998)

In some cases, only a part of the wetland or aquatic ecosystem is destroyed, resulting in their fragmentation. One example of habitat fragmentation (in some cases, destruction) is the construction of numerous dirt roads and concrete or asphalt highways across rivulets, creeks, streams and rivers within the same watershed.

- For example, numerous stream orders can be crossed by the same highway, such as the Grand River in southern Ontario. Scientific studies have shown that the diversity of native mussels (*Unionidae*) has declined by about 44%, from 32 living species to 18, in the Grand River watershed.

Artificial Impoundments- Dams and reservoirs (Williams & Feltmate, 1992; Mackie, 1998)

- Anthropogenic control over the flow of running water, usually by means of dams and reservoirs, has influenced nearly all of the world’s major river systems. In several cases, it was found that, following the formation of an impoundment, mayflies, caddisflies and stoneflies disappeared almost immediately but were replaced by high densities of midges. (Williams & Feltmate, 1992)
- (Mackie, 1998) The building of dams imposes a lentic habitat within a lotic system. The aquatic communities must suddenly adjust to the changes in physical, chemical and biological attributes of riverine systems to those of lacustrine systems. Some species are adapted to a lotic existence and perish when a lentic system is imposed upon them. Others, mostly highly tolerant forms like chironomids and tubificid worms, exploit the new habitat and explode in biomass. In many cases, the dams were built on streams of stream order 3, 4 or 5. In this scenario, species diversity usually (i.e. it depends on depth and size of impoundment) declines, but if it does not, the species assemblage certainly changes from one dominated by shredders and lotic filter feeders, grazers and predators to herbivores and lentic filter feeders and predators, with corresponding changes in the fish community.

Chemical disturbances- Industrial pollutants (Williams & Feltmate, 1992)

Industrial pollutants are generally point source in origin as they are usually discharged through pipes, ditches and sewers into bodies of water, at specific locations. Upon entering water, the chemical nature and concentration of pollutants will usually change as a result of four natural processes: dilution, biodegradation, biological amplification, and sedimentation. The rates at which these processes occur (particularly dilution and the oxygen-consuming process of biodegradation) vary directly as a function of the turn-over time of water in a system. When streams or lakes are overloaded with contaminants, and sediments become anaerobic and/or laden with heavy metals, the impact on aquatic insect communities can be severe.

- Water bodies that suffer from industrial pollution are generally characterized by high densities of chironomids and an absence of mayflies and stoneflies.
- The time required for insect assemblages to return to their natural state, following disturbances such as those of point source industrial pollutants, can be on the order of many years for streams, and decades for lakes.

Chemical disturbances- Oil spills (Williams & Feltmate, 1992)

Although concerted efforts have been focused on examining the ecological consequences of oil spills in marine systems, only limited consideration has been given to the accidental release of oil in freshwater habitats.

- One group of insects, chironomids of the subfamily Orthocladiinae, has been shown to respond positively to oiled vs. non-oiled artificial substrates. Apparently the oil stimulates algal growth which attracts these largely algivorous larvae.

Chemical disturbances- Mine waste (Williams & Feltmate, 1992)

The harmful effects of mine waste on aquatic insects vary according to the type of mineral extracted, the size of the operation, the type of mine (surface or subsurface, hard or soft rock), and the local topography and climate. Generally, subsurface mining is less damaging to aquatic systems as, for each unit of mineral extracted, only one-tenth as much land is disturbed as would occur by extracting the equivalent unit from a surface mine. The factors that affect aquatic insects most severely are the release of toxic (mostly heavy metals) substances, increased silt loads, and higher levels of acidity.

- A comparison of lentic insects between ponds affected by coal strip-mining and a non-affected control pond revealed that the **diversity** of insects was least in spoil ponds, probably due to higher nitrate and sulphate levels. In contrast, the **density** of insects was highest in the contaminated ponds, which was attributable, again, to high numbers of chironomids.
- The recovery of insect populations following cessation of mining activities, even when combined with terrestrial restoration programmes (e.g. planting vegetation), is very slow.
    - Terrestrial reclamation programmes do not assure aquatic restoration, and it was recommended that water quality criteria be given greater consideration in reclamation procedures for mined lands.

Chemical disturbances- Acid deposition (Williams & Feltmate, 1992)

In western and central Europe, Scandinavia, the northeastern United States, south-eastern Canada, and south-eastern China, acid deposition is a serious problem affecting aquatic and terrestrial systems. Although acid deposition is more commonly referred to as *acid rain*, this is a misnomer, as acids and acid forming substances are also deposited in snow, sleet, fog, dew, and as dry particles and gas.

Precipitation has a natural pH value of approximately 5.1 (5.0-5.6, depending on location), which forms when carbon dioxide, trace amounts of sulphur and nitrogen compounds, and atmospheric organic acids dissolve in atmospheric water. However, elevated levels of acidity result when the primary air pollutants, sulphur dioxide and nitrous oxide, enter the atmosphere at disproportionately high rates (due primarily to the burning of fossil fuels), and react to form secondary air pollutants.

- If the acid deposition lands in regions that contain limestone or other alkaline (basic) substances, then the effects on the ecosystem are neutralised although this buffering capacity does not last *ad infinitum*.
- If, however, the acid deposition lands in regions with little buffering capacity, such as on granite or some types of sandstone, damage to the ecosystem may be significant.
  - If the region contains bedrock with a high aluminium content the effects are further exacerbated, as the aluminium will dissolve and, in ionic form, cause asphyxiation in fishes through the impairment of gill function.
- The effects of acid stress on aquatic life can be extreme in geographical regions characterized by spring snow melts.

The potential impact of global warming on the ecology of aquatic insects (Williams & Feltmate, 1992)

Although a few studies have examined whether the microdistribution of aquatic insects within habitats is influenced by temperature, the collective evidence thus far indicates that such habitat selection does occur.

Mechanisms that aid certain species in withstanding the effects of pollution (Williams & Feltmate, 1992)

- Mechanisms that aid chironomids in withstanding the effects of pollution include a higher oxygen storage capacity because of the presence of haemoglobin (e.g. in *Chironomus anthracinus* and *C. plumosus*), and an ability to avoid heavy metals by burrowing into the sediment.
- Other means of limiting the impact of pollutants include:
  - (1) body and gill movements to enhance oxygen uptake (as in perlid stoneflies and ephemerellid mayflies),
  - (2) breathing at the water surface by means of tracheal tubes (various Hemiptera),
  - (3) adjustment of life-cycle to avoid periods of pollution stress (e.g. as in *Ephemerella ignata*), and
  - (4) having generation times short enough to avoid stressful periods (e.g. as in *Baetis* and *Nemoura*)

(Wetzel, 1983)

Benthic community structure in lakes usually consists of a rich fauna with high oxygen demands in the littoral zone above the metalimnion. Heterogeneity of substrata is great in the littoral; benthic-animal species diversity is greater in the littoral than in the more homogeneous profundal zone. As lakes become more productive, the number of benthic animals adapted to hypolimnetic conditions of reduced oxygen and increased decompositional end-products declines.

- Two maxima in abundance and biomass of benthic animals are often observed; one in the littoral zone, the other in the lower profundal zone.
- As lakes become for fertile, submersed macrovegetation can be eliminated as a result of light attenuation. Maximum abundance and biomass of benthic animals may then shift to the profundal zone.
- With further eutrophication and intensive organic-matter decomposition in the profundal zone, much of the benthic fauna of the profundal zone can be eliminated.
- As lakes become more eutrophic, a shift occurs in the percentage composition of two dominant benthic groups, with a decrease in the dipteran chironomid larvae and an increase in the more tolerant oligochaete worms (e.g., tubificids).
- The dipteran phantom midge *Chaoborus* is another major component of the profundal benthic fauna of lakes. *Chaoborus* larvae migrate into the open water at night and prey heavily on zooplankton. Feeding on limnetic zooplankton by *Chaoborus* is highly selective.

Table II-3: Comparison of the Relative Composition of the Dominant Benthic Macroinvertebrates of Several Lakes of Differing Productivity based on other criteria (Wetzel, 1983)

	Percentages			
Lake	**Chironomidae**	**Oligochaeta**	**Sphaeridae**	**Others**
Oligotrophic				
Convict, Calif.	65.3	30.8	0.4	3.5
Bright Dot, Calif.	77.5	3.1	19.1	0.3
Dorothy, Calif.	69.5	23.3	3.5	3.7
Constance, Calif.	56.9	20.5	20.5	2.1
Cultus, British Columbia	65.0	24.0	---	---
Lake Ontario	1.8	6.4	3.4	88.4
Lake Erie (1929-1930)	10	1	2	87
Eutrophic				
Lake Erie (1958)	27	60	5	8
Glenora Bay, Lake Ontario	42.3	29.4	6.2	22.1
Washington, Wash.	43	51	3	3

Data are only approximately comparable because of different methods employed

Substrate Influence

(Allan, 1995)

Recommendation by a world leader, Prof. Dr. Noel Hynes of the University of Waterloo, Ontario:

(Date: Fri, 20 Mar 1998 10:05:30
From: Noel Hynes
Subject: book
I'm sorry, but I have only my own copy of The Ecology of Running Waters. Many thousands were printed, so it must be available on the second-hand market, but it is very out of date. I think that it was responsible for an enormous advance in our knowledge, during the nearly 30 years since its publication, because people became confident that the field had been reviewed. I worked very hard in order to make that review complete, and I always refused to do a second edition because I knew that it would not be possible to make a complete review and I did not wish to get into the "recent advances" loop. The best current text on running water is J.D. Allen, 1995, Stream ecology. Chapman and Hall ISBN 0 412 29430.
.. Noel Hynes)

Substrate is a complex aspect of the physical environment. What comes to mind first are the cobbles and boulders in the bed of a mountain stream, and silts and sands that are more typical of lowland rivers. Organic detritus is found in conjunction with mineral material, and can strongly influence the organism's response to substrate. Determination of the role of substrate is further complicated by its tendency to interact with other environmental factors. For example, slower currents, finer substrate particle size and (possibly) lower oxygen are often correlated. In addition, the size and amount of organic matter, which affect algal and microbial growth, vary with substrate. This natural covariation of environmental factors makes it very difficult to ascribe causality from field surveys. Substrate ofcourse depends on the parent material available, but there is a general tendency for particle size to decrease as one proceeds downstream.

Inorganic Substrates

Table II-4: The classification of mineral substrates by particle size, according to the Wentworth Scale

Size Category	Particle Diameter (range in mm)
Boulder	>256
Cobble	
Large	128-256
Small	64-128
Pebble	
Large	32-64
Small	16-32
Gravel	
Coarse	8-16
Medium	4-8
Fine	2-4
Sand	
Very coarse	1-2
Coarse	0.5-1
Medium	0.25-0.5
Fine	0.125-0.25
Very fine	0.063-0.125
Silt	<0.063

The influence of substrate on organism abundance and diversity

In general, diversity and abundance increase with substrate stability and the presence of organic detritus. Other factors which appear to play a role include the mean particle size of mineral substrates, the variety of sizes, and surface texture, although it is difficult to generalise about their effects.

Table II-5: Abundance and species diversity of aquatic insects found in five habitats (characterised mainly by their substrates) in a Quebec stream. Values are annual averages.

Habitat	Abundance (no./sq.m.)	No. of species	Diversity =(S-1) / $\log_e N$
Sand	920	61	1.96
Gravel	1,300	82	2.31
Cobbles and pebbles	2,130	76	2.02
Leaves	3,480	92	2.40
Detritus (finely divided leaf material in pools and along stream margins)	5,680	66	1.73

In general, diversity and abundance of benthic invertebrates increase with median particle size (MPS), and some evidence suggests that diversity declines with stones at or above the size of cobbles. The amount of detritus trapped within the crevices is also likely to be important, and substrates of intermediate size are superior in this regard. A variable mix of substrates ought to accommodate more taxa and individuals, and particle size variance usually increases with MPS.

Evidently the amount and type of detritus contained within the sediments is sufficiently dependent on the size and mix of the mineral substrates that it is unwise to measure substrate preference without concurrent study of trapped organic matter.

Silt, in small amounts, benefits at least some taxa. When silt was added to larger mineral substrates in laboratory preference tests, silt enhanced the preference for coarse substrates in the mayfly *Caenis latipennis* and the stonefly *Perlesta placida*. In large amounts, silt generally is detrimental to macroinvertebrates. It causes scour during high flow, fills interstices thus reducing habitat space and the exchange of gases and water, and reduces the algal and microbial food supply.

Substrate texture refers to surface properties such as hardness, roughness, and perhaps ease of burrowing, along with other aspects. Researchers have found that more invertebrates colonized granite and sandstone, which have comparatively rough surfaces, than the smoother quartzite. Other experiments also found diversity and abundance to be greater on irregular than on smooth substrates of the same overall size.

Diversity and Biotic Indices

Benthic macroinvertebrate species are differentially sensitive to many biotic and abiotic factors in their environment. Consequently, macroinvertebrate community structure has commonly been used as an indicator of the condition of an aquatic system (Armitage *et al*, 1983; Ohio Department of Natural Resources, unpublished; Rosenberg and Resh, 1993). Biotic index systems have been developed which give numerical scores to specific "indicator" organisms at a particular taxonomic level (Armitage *et al*, 1983; Ohio Department of Natural Resources, unpublished). Such organisms have specific requirements in terms of physical and chemical conditions. Changes in presence/absence, numbers, morphology, physiology or behaviour of these organisms can indicate that the physical and/or chemical conditions are outside their preferred limits (Rosenberg and Resh, 1993). Presence of numerous families of highly tolerant organisms usually indicates poor water quality (Hynes, 1998).

RBPs—Biotic Indices—Rapid Bioassessment Protocols (Barbour *et al*, 1998; Bode *et al*, 1991; Bode *et al*, 1996; David *et al*, 1998; Hynes, 1998; Klemm *et al*, 1990; Mackie, 1998; Novak & Bode, 1992; Plafkin *et al*, 1989; Reid *et al*, 1995; Rosenberg & Resh, 1993; Rosenberg *et al*, 1997; Somers, 1997a; Somers, 1997b; Somers *et al*, 1998; U.S. Environmental Protection Agency, 1998)

The numbers of indices based on the benthic macroinvertebrate communities is probably about 5 times that of any of the other groups, with about 50 indices currently in existence, and the number is still growing. Some of the benthic indices are based on species identification, the species assemblages being analyzed by a range of mathematical models, from a fairly straightforward species diversity index to more complex multivariate analyses. Bioassessment methods such as these are based on numerous quantitative samples (e.g. with Ekman grabs, T-samplers, Surber samplers, etc.) that require a great deal of time to sort and separate all the invertebrates, and more time and expertise (and money) to identify all the organisms.

So recent trends have been towards more rapid bioassessment techniques, such as using semi-quantitative collecting methods (e.g. kick-and-sweep) and selecting at random and identifying only the first 100 organisms in the sample. To help ensure unbiased selection of organisms, it is recommended that a subsampling procedure be used. This entails evenly distributing the composite sample into a gridded pan with a light coloured bottom. Then all organisms are removed from a set of randomly selected grids until atleast 100 animals are picked. Once identified, the functional feeding behaviour of each species is determined from tables (Barbour *et al,* 1998; Bode *et al*, 1991; Bode *et al*, 1996; Klemm *et al,* 1990; Mackie, 1998; Plafkin *et al,* 1989). A CPOM (coarse particulate organic matter, such as leaf litter) sample is also required from each site. This sample is used for determining the numbers of shredders present.

Some of these rapid bioassessment techniques have been standardized so that water quality comparisons can be made between streams and lakes. These standardized methods are in common use today and are termed **RBPs** (Rapid Bioassessment Protocols). The U.S. EPA has developed 5 RBPs, the first three being based on benthic macroinvertebrates and the fourth and fifth on fish. The complexity of the protocol increases with the RBP number, RBP I being less complex than RBP II and so on. RBP I is used to discriminate obviously impacted and non-impacted areas from potentially affected areas requiring further investigation. It allows rapid screening of a large number of sites. Areas identified for further study can be rigorously evaluated using RBP II, III and V (IV is a questionnaire survey). RBP II is based on family level identification and RBP III on a species level identification.

Metrics (Barbour *et al,* 1998)

Metrics (or indices) allow the investigator to use meaningful indicator attributes in assessing the status of assemblages and communities in response to perturbation. For a metric to be useful, it must have the following technical attributes:

(1) ecologically relevant to the biological assemblage or community under study and to the specified program objectives;

(2) sensitive to stressors and provides a response that can be discriminated from natural variation.

The purpose of using multiple metrics to assess biological condition is to aggregate and convey the information available regarding the elements and processes of aquatic communities.

⇒ It is cautioned that all the published metrics inclusive of the ones discussed in this chapter have been developed from moderate to extensive field data from rivers, and not from lakes, hence may or may not be totally applicable in the case of lakes, especially larger and deeper ones. Caution should be exercised and the indiscriminate use of the metrics without supporting chemical and other related field data should be avoided. Further, none of the indices originate from the Atlantic Provinces of Canada, especially from Nova Scotia. The only studies known to us and publicly available (e.g.. local university libraries) are:

- Hynes, K.E. 1998. Benthic Macroinvertebrate Diversity and Biotic Indices for Monitoring of 5 Urban and Urbanizing Lakes within the Halifax Regional Municipality (HRM), Nova Scotia, Canada. Project D-2, Soil & Water Conservation Society of Metro Halifax. xiv, 114p. (Lakes Wrights, Springfield, McGrath, Kearney and Morris) *(available at the Dalhousie University Killam and DalTech libraries).*
- Gaertner, Monica J. 1999. Benthic Macroinvertebrate Diversity and Biotic Indices for Monitoring of Lakes Dollar, Russell, Stillwater, Papermill and Kinsac within the Halifax Regional Municipality (HRM), Nova Scotia, Canada. Project E-2, Soil & Water Conservation Society of Metro Halifax. (includes an educational video) *........ under preparation.......... (will be available at the Dalhousie University Killam and DalTech libraries).*

Because species assemblages differ naturally among different regions (ecoregions) in North America, and even between stream orders in the same ecoregion, many metrics require a reference site for each evaluation. The reference can be an unaffected reach in the same stream or in a neighbouring stream of the same order. Many of the indices in the protocols use **tolerance scores** that were derived from large data bases of both published and unpublished studies of experts for all the major groups of taxa. Colonial taxa, like Porifera (sponges) and Bryozoa (moss animals), are not included in the scoring systems (Mackie, 1998).

Lake and Reservoir Bioassessment and Biocriteria (U.S. Environmental Protection Agency, 1998)

Benthic invertebrate assemblages in lakes correspond to particular habitat types and can be classified according to the three basic habitats of lake bottom: littoral, sublittoral, and profundal.

The littoral habitat of lakes usually supports larger and more diverse populations of benthic invertebrates than do the sublittoral and profundal habitats. The vegetation and substrate heterogeneity of the littoral habitat provide an abundance of microhabitats occupied by a varied fauna, which in turn enhances invertebrate production. The littoral habitat is also highly variable due to seasonal influences, land use patterns, riparian variation, and direct climatic effects producing high-energy areas. *The epifauna species composition, number of individuals, areal extent, and growth form vary with the species composition of the macrophyte beds, making it difficult to determine the benthic status accurately*.

The sublittoral habitat, below the area of dense macrophyte beds, but above typical thermoclines, lacks the heterogeneity of the littoral habitat; However it is also less subject to littoral habitat variables and influences. The sublittoral habitat is rarely exposed to severe hypoxia but might also lack the sensitivity to toxic effects that is found in the profundal habitat. *The sublittoral habitat supports diverse infaunal populations, and standardized sampling is easy to implement because a constant depth and substrate can be selected for sampling. Therefore, the sublittoral habitat is the preferred habitat for surveying the benthic assemblage in most regions*.

The profundal habitat, in the hypolimnium of stratified lakes, is more homogeneous due to a lack of habitat and food heterogeneity, and hypoxia and anoxia in moderately to highly productive lakes are common. The profundal habitat is usually dominated by three main groups of benthic organisms including chironomid larvae, oligochaete worms, and phantom midge larvae (*Chaoborus*). Many species of chironomids and tubificid oligochaetes are tolerant to low dissolved oxygen, such that these become the dominant profundal invertebrates in lakes with hypoxic hypolimnia. As hypoxia becomes more severe tubificids can become dominant over chironomids. In cases of prolonged anoxia, the profundal assemblage might disappear entirely. If hypoxia is rare in reference lakes of the region, and if toxic sediments are suspected to occur in some lakes, then the profundal habitat might be preferred for the region.

Benthic macroinvertebrates are moderately long-lived and are in constant contact with lake sediments. Contamination and toxicity of sediments will therefore affect those benthic organisms which are sensitive to them. Acidification of lakes is accompanied by shifts in the composition of benthic assemblages to dominance by species tolerant of acidic conditions. Effects of rapid sedimentation are less well-known but appear to cause shifts toward lower abundances and oligotrophic species assemblages as well as more motile species.

***Benthic macroinvertebrates are present year-round and are often abundant, yet not very motile. However, the benthos integrate environmental conditions at the sampling point*.**

Reference lakes/sites

The recommended empirical approach is to use a population of reference lakes to establish conditions that will be used to identify and calibrate metrics.

Reference sites must be carefully selected because they will be used as a benchmark against which test sites will be compared. The conditions at reference sites should represent the best range of minimally impaired conditions that can be achieved by similar lakes within the region. The reference sites must be representative of the region, and relatively least impacted compared to other lakes of the regions.

Sites that are undisturbed by human activities are ideal reference sites. However, land use practices and atmospheric pollution have so altered the landscape and quality of water resources nationally that truly undisturbed sites are rarely unavailable.

Stringent criteria might require using park or preserve areas for reference lakes. Criteria for reference lakes will also pertain to the condition of the watershed, as well as the lake itself.

If relatively unimpaired conditions do not occur in the region, the selection process could be modified to be more realistic and reflect attainable goals, such as the following:

- Land use and natural vegetation- Natural vegetation has a positive effect on water quality and hydrological response of streams. Reference lakes should have at least some percentage of the watershed in natural vegetation.
- Riparian zones- Zones of natural vegetation alongside the lakeshore and streams stabilize shorelines from erosion and contribute to the aquatic food source through allochthonous input. They also reduce nonpoint pollution by absorbing and neutralizing nutrients and contaminants. Watersheds of reference lakes should have at least some natural riparian zones regardless of land use.
- Best management practices- Urban, industrial, suburban, and agricultural nonpoint source pollution can be reduced with successful best management practices (BMPs). Watersheds of reference lakes should have BMPs in place provided that the efficacy of the BMPs have been demonstrated.
- Discharges- Absence or minimal level of permitted discharges (NPDES) into surface waters.
- Management- Management actions, such as extreme water level fluctuations for hydropower or flood control, can significantly influence lake biota. Reference lakes should be only minimally impacted by management activities.

Paleolimnology

An alternative to characterizing present-day reference conditions is to estimate historic or prehistoric pristine conditions. In many lakes, presettlement conditions can be inferred from fossil diatoms, chrysophytes, midge head capsules, cladoceran carapaces, and other remains preserved in lake sediments. Fossil diatoms are established indicators of historical lake alkalinity, salinity, and trophic state. Diatom frustules, composed of silica, are typically well preserved in lake sediments and easy to identify. However, remains of other organisms are problematic because of incomplete preservation.

RBP II- U.S. EPA (Plafkin *et al,* 1989)

Rapid Bioassessment Protocol II (RBP II) can detect sites of intermediate impairment with relatively little additional time and effort. This protocol can be used to prioritize sites for more intensive evaluation (i.e., RBP III, replicate sampling, ambient toxicity testing, chemical characterization) or can be used in lieu of RBP I as a screening technique. RBP II is based on RBP III at a reduced level of effort. RBP II incorporates the concept of benthic analysis at the family taxonomic level as advocated by some States (e.g., Virginia, Illinois), and utilizes field sorting and identification.

The data analysis scheme used in RBP II integrates several community, population, and functional parameters into a single evaluation of biotic integrity (Table II-6). Each parameter, or metric, measures a different component of community structure and has a different range of sensitivity to pollution stress (Table II-7). This integrated approach provides more assurance of a valid assessment because a variety of parameters are evaluated. Deficiency of any one metric in a particular situation should not invalidate the entire approach.

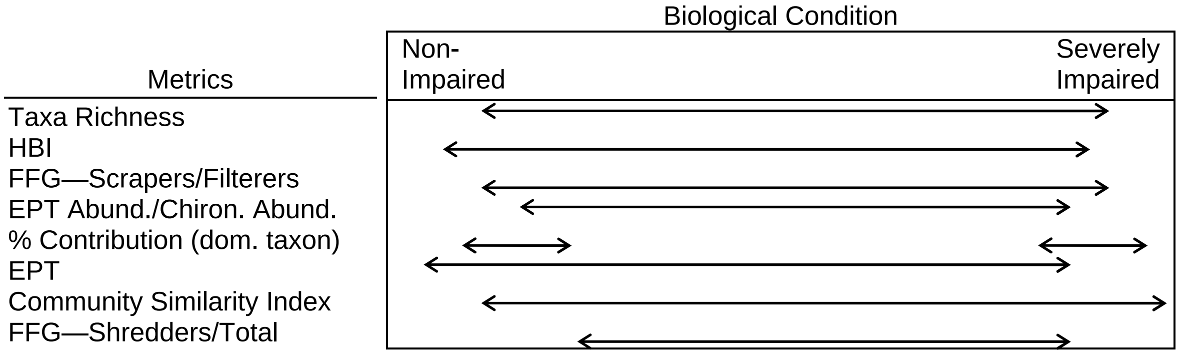
Table II-6: Criteria (a) for characterisation of biological condition for RBP II

Metric	Biological Condition		
	Non-Impaired	**Moderately Impaired**	**Severely Impaired**
1. Taxa Richness	Comparable to the best situation within an ecoregion	Fewer taxa due to loss of most intolerant forms	Few taxa present. If in high densities, then dominated by one or two taxa. Only tolerant organisms present
2. Family Biotic Index (modified)			
3. Ratio of Scrapers/Filtering Collectors (b)			
4. Ratio of EPT and Chironomid Abundance			
5. % Contribution of Dominant Family			
6. EPT Index			
7. Community Similarity Index (c)			
8. Ratio of Shredders/Total (b)			

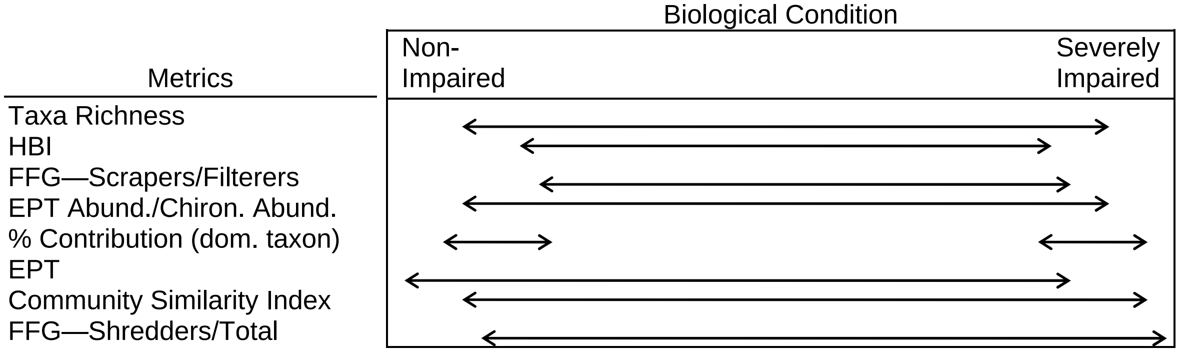
(a) Scoring criteria are generally based on percent comparability to the reference station
(b) Determination of Functional Feeding Group is independant of taxonomic grouping
(c) Community Similarity Indices are used in comparison to a reference station

Table II-7: Range of sensitivities of Rapid Bioassessment Protocol (RBP) II and III benthic metrics in assessing biological condition in response to organics and toxicants (Plafkin *et al,* 1989)

Organics



Toxicants



The eight metrics used in RBP II are the same as those in RBP III, but the scoring criteria used to evaluate the metrics have been modified to accommodate the less rigorous taxonomy (family level identifications) of RBP II. The integrated data analysis (Table II-8) is performed as follows:

- Using the raw benthic data, a numerical value is calculated for each metric. Calculated values are then compared to values derived from either a reference site within the same region, a reference database applicable to the region, or a suitable control station on the same stream. Each metric is then assigned a score according to the comparability (percent similarity) of calculated and reference values.
- Scores for the eight metrics are then totaled and compared to the total metric score for the reference station. The percent comparison between the total scores provides a final evaluation of biological condition.
- Values obtained may sometimes be intermediate to established ranges and require some judgment as to assessment of biological condition. In these instances, habitat assessment, physical characterization, and water quality data may aid in the evaluation process.

Table II-8: Flowchart of bioassessment approach advocated for RBP II (Plafkin *et al,* 1989)

Criteria for characterization of biological condition for Protocol II

Metric	Biological Condition Scoring Criteria		
	6	3	0
1. Taxa richness (a)	>80%	40-80%	<40%
2. Family Biotic Index (modified) (b)	>85%	50-85%	<50%
3. Ratio of Scrapers/Filtering Collectors (a,c)	>50%	25-50%	<25%
4. Ratio of EPT and Chironomid Abundance (a)	>75%	25-75%	<25%
5. % Contribution of Dominant Family (d)	<30%	30-50%	>50%
6. EPT Index (a)	>90%	70-90%	<70%
7. Community Loss Index (e)	<0.5	0.5-4.0	>4.0
8. Ratio of Shredders/Total (a,c)	>50%	25-50%	<25%

(a) Score is a ratio of study site to reference site X 100
(b) Score is a ratio of reference site to study site X 100
(c) Determination of Functional Feeding Group is independant of taxonomic grouping
(d) Scoring criteria evaluate actual percent contribution, not percent comparability to the reference station
(e) Range of values obtained. A comparison to the reference station is incorporated in these indices

BIOASSESSMENT

% Comp. to Ref. Score (a)	Biological Condition Category	Attributes
>79%	Non-impaired	Comparable to the best situation to be expected within an ecoregion. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and habitat quality.
29-72%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<21%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa. Only tolerant organisms present.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and physicochemical data may be necessary to aid in the decision process.

The RBP II metrics used to evaluate the benthic data and their significance are explained below:

Metric 1. Taxa Richness (Plafkin *et al,* 1989)

Reflects health of the community through a measurement of the variety of taxa (total number of families) present. Generally increases with increasing water quality, habitat diversity, and habitat suitability. Sampling of highly similar habitats will reduce the variability in this metric attributable to factors such as current speed and substrate type. Some pristine headwater streams may be naturally unproductive, supporting only a very limited number of taxa. In these situations, organic enrichment may result in an increased number of taxa (including EPT taxa).

Metric 2. Modified Family Biotic Index (Plafkin *et al,* 1989)

Tolerance values range from 0 to 10 for families and increase as water quality decreases. The index was developed by Hilsenhoff (Hilsenhoff, 1988) to summarize the various tolerances of the benthic arthropod community with a single value. The Modified Family Biotic Index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI) of Hilsenhoff. Tolerance values for each family were developed by weighting species according to their relative abundance in the State of Wisconsin.

⇒ In unpolluted streams the FBI was higher than the BI, suggesting lower water quality, and in polluted streams it was lower, suggesting higher water quality. These results occurred because the more intolerant genera and species in each family predominate in clean streams, whereas the more tolerant genera and species predominate in polluted streams. Thus the FBI usually indicates greater pollution of clean streams by overestimating BI values and usually indicates less pollution in polluted streams by underestimating BI values. The FBI is intended only for use as a rapid field procedure. It should not be substituted for the BI; it is less accurate and can more frequently lead to erroneous conclusions about water quality (Hilsenhoff, 1988).

The family-level index has been modified for the RBP II to include organisms other than just arthropods using the genus and species-level biotic index developed by the State of New York (Bode *et al,* 1991; Bode *et al,* 1996). *Although the FBI may be applicable for toxic pollutants, it has only been evaluated for organic pollutants*. The formula for calculating the Family Biotic Index is:

$$FBI = \sum \frac{x_i \ t_i}{n}$$

where
x_i = number of individuals within a taxon
t_i = tolerance value of a taxon
n = total number of organisms in the sample (100)

Table II-9: Evaluation of water quality using the family-level biotic index (Hilsenhoff, 1988)

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4,25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very poor	Severe organic pollution likely

Hilsenhoff’s family-level *tolerance values may require modification for some regions.*

Table II-10: Tolerance Values for Macroinvertebrates for application in the RBP II and other metrics (Bode *et al,* 1996; Hauer & Lamberti, 1996; Hilsenhoff, 1988; Plafkin *et al,* 1989)

Plecoptera	
Capniidae	1
Chloroperlidae	1
Leuctridae	0
Nemouridae	2
Perlidae	1
Perlodidae	2
Pteronarcyidae	0
Taeniopterygidae	2
Ephemeroptera	
Baetidae	4
Baetiscidae	3
Caenidae	7
Ephemerellidae	1
Ephemeridae	4
Heptageniidae	4
Leptophlebiidae	2
Metretopodidae	2
Oligoneuriidae	2
Polymitarcyidae	2
Potomanthidae	4
Siphlonuridae	7
Tricorythidae	4
Odonata	
Aeshnidae	3
Calopterygidae	5
Coenagrionidae	9
Cordulegastridae	3
Corduliidae	5
Gomphidae	1
Lestidae	9
Libellulidae	9
Macromiidae	3
Megaloptera	
Corydalidae	0
Sialidae	4
Lepidoptera	
Pyralidae	5
Neuroptera	
Sisyridae	
Climacia sp.	5

Trichoptera	
Brachycentridae	1
Calamoceratidae	3
Glossosomatidae	0
Helicopsychidae	3
Hydropsychidae	4
Hydroptilidae	4
Lepidostomatidae	1
Leptoceridae	4
Limnephilidae	4
Molannidae	6
Odontoceridae	0
Philpotamidae	3
Phryganeidae	4
Polycentropodidae	6
Psychomyiidae	2
Rhyacophilidae	0
Sericostomatidae	3
Uenoidae	3
Diptera	
Athericidae	2
Blephariceridae	0
Ceratopogonidae	6
Blood-red Chironomidae (Chironomini)	8
Other Chironomidae (including pink)	6
Dolochopodidae	4
Empididae	6
Ephydridae	6
Muscidae	6
Psychodidae	10
Simuliidae	6
Syrphidae	10
Tabanidae	6
Tipulidae	3
Coleoptera	
Dryopidae	5
Elmidae	4
Psephenidae	4
Collembola	
Isotomurus sp.	5

Amphipoda	
Gammaridae	4
Hyalellidae	8
Talitridae	8
Isopoda	
Asellidae	8
Decapoda	6
Acariformes	4
Mollusca	
Lymnaeidae	6
Physidae	8
Sphaeridae	8
Oligochaeta	8
Hirudinea	
Bdellidae	10
Helobdella	10
Polychaeta	
Sabellidae	6
Turbellaria	4
Platyhelminthidae	4
Coelenterata	
Hydridae	
Hydra sp.	5

Metric 3. Ratio of Scraper and Filtering Collector Functional Feeding Groups (Plafkin *et al,* 1989)

This metric reflects the riffle/run community food-base. When compared to a reference site, shifts in the dominance of a particular feeding type indicate a community responding to an overabundance of a particular food source. The predominant feeding strategy reflects the type of impact detected. Assignment of individuals to Functional Feeding Groups is independant of taxonomy, with some families representing several functional groups. A description of the Functional Feeding Group concept can be found in Cummins (1973), and Merritt & Cummins (1996).

The relative abundance of Scrapers and Filtering Collectors in the riffle/run habitat is an indication of the periphyton community composition, availability of suspended Fine Particulate Organic Material (FPOM), and availability of attachment sites for filtering. Scrapers increase with increased diatom abundance and decrease as filamentous algae and aquatic mosses (which scrapers cannot efficiently harvest) increase. However, filamentous algae and aquatic mosses provide good attachment sites for Filtering collectors, and the organic enrichment often responsible for overabundance of filamentous algae can also provide FPOM that is utilized by the Filterers.

Filtering Collectors are also sensitive to toxicants bound to fine particles and should be the first group to decrease when exposed to steady sources of such bound toxicants. This situation is often associated with point-source discharges where certain toxicants adsorb readily to dissolved organic matter (DOM) forming FPOM during flocculation. Toxicants thus become available to Filterers via FPOM.

The Scraper to Filtering Collector ratio may not be a good indicator of organic enrichment if adsorbing toxicants are present. In these instances the FBI and EPT Index may provide additional insight. Qualitative field observations on periphyton abundance may also be helpful in interpreting results.

Metric 4. Ratio of EPT and Chironomidae Abundance (Plafkin *et al,* 1989)

The index uses relative abundance of these indicator groups as a measure of community balance. Good biotic condition is reflected in communities with an even distribution among all four major groups and with substantial representation in the sensitive groups, Ephemeroptera, Plecoptera, and Trichoptera. Skewed populations having a disproportionate number of the Chironomidae relative to the more sensitive insect groups may indicate environmental stress.

Certain species of some genera such as *Cricotopus* are highly tolerant and as opportunists may become numerically dominant in habitats exposed to metal discharges where EPT taxa are not abundant, thereby providing a good indicator of toxicant stress. It was found that mayflies were more sensitive than chironomids to exposure levels of 15 to 32 µg/l of copper. Chironomids tend to become increasingly dominant in terms of percent taxonomic composition and relative abundance along a gradient of increasing enrichment for heavy metals concentration.

An alternative to the ratio of EPT and Chironomidae Abundance metric is the Indicator Assemblage Index (IAI) developed by Shackleford. The IAI integrates the relative abundance of the EPT taxonomic groups and the relative abundance of chironomids and annelids upstream and downstream of a pollutant source to evaluate impairment. The IAI may be a valuable metric in areas where the annelid community may fluctuate substantially in response to pollution stress.

Metric 5. Percent Contribution of Dominant Family (Plafkin *et al,* 1989)

The index uses abundance of the numerically dominant taxon relative to the rest of the population as an indication of community balance at the family-level. A community dominated by relatively few families would indicate environmental stress. This metric may be redundant if the Pinkham and Pearson Similarity Index is used as a community similarity index for metric number 7.

Metric 6. EPT Index (Plafkin *et al,* 1989)

The EPT index generally increases with increasing water quality. The index value summarizes the taxa richness within the insect groups that are generally considered pollution sensitive. This was developed for species-level identifications; however, the concept is valid for use at family-level identifications. Headwater streams which are naturally unproductive may experience an increase in taxa (including EPT taxa) in response to organic enrichment.

Metric 7. Community Similarity Indices (Plafkin *et al,* 1989)

These indices are used in situations where a reference community exists, either through sampling or through prediction for a region. Data sources or ecological data files may be available to predict a reference community to be used for comparison. These indices are designed to be used with either species level identifications or higher taxonomic levels. Three of the many community similarity indices available are discussed below;

(Sample A = reference station [or mean of reference database]
Sample B = station of comparison)

- Community Loss Index- Measures the loss of benthic taxa between a reference station and the station of comparison. This is an index of compositional dissimilarity, with values increasing as the degree of dissimilarity with the reference station increases. Values range from 0 to "infinity". This index seems to provide greater discrimination than either of the following two community similarity indices. The formulae for the Community Loss Index is:

$$Community\ Loss = \frac{d - a}{e}$$

where
a = number of taxa common to both samples
d = total number of taxa present in Sample A
e = total number of taxa present in Sample B

- Jaccard Coefficient of Community Similarity- Measures the degree of similarity in taxonomic composition between two stations in terms of taxon presence of absence. The Jaccard Coefficient discriminates between highly similar collections. Coefficient values, ranging from 0 to 10, increase as the degree of similarity with the reference station increases.
  - The formulae for the Community Loss Index and the Jaccard Coefficient are:

$$Jaccard\ Coefficient = \frac{a}{a + b + c}$$

where
a = number of taxa common to both samples
b = number of taxa present in Sample B but not A
c = number of taxa present in Sample A but not B

- Pinkham and Pearson Community Similariy Index- Incorporates abundance and compositional information and can be calculated with either percentages or numbers. A weighting factor can be added that assigns more significance to dominant taxa. The formula is:

$$S.I._{ab} = \sum \frac{\min(x_{ia}, x_{ib})}{\max(x_{ia}, x_{ib})} \left[\frac{x_{ia}}{x_a} \cdot \frac{x_{ib}}{x_b} \div 2 \right]$$

(weighting factor)

where

x_{ia}, x_{ib} = number of individuals in the ith taxon in Sample A or B

Metric 8. Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected- CPOM Sample (Plafkin *et al,* 1989)

Also based on the Functional Feeding Group Concept, the abundance of the Shredder Functional Group relative to the abundance of all other Functional Groups allows evaluation of potential impairment as indicated by the CPOM-based Shredder community. Shredders are sensitive to riparian zone impacts and are particularly good indicators of toxic effects when the toxicants involved are readily adsorbed to the CPOM and either affect microbial communities colonizing the CPOM or the Shredders directly.

The degree of toxicant effects on Shredders versus Filterers depends on the nature of the toxicants and the organic particle adsorption efficiency. Generally, as the size of the particle decreases, the adsorption efficiency increases as a function of the increased surface to volume ratio. Because water-borne toxicants are readily adsorbed to FPOM, toxicants of a terrestrial source (e.g., pesticides, herbicides) accumulate on CPOM prior to leaf fall thus having a substantial effect on Shredders.

The focus of this approach is on a comparison to the reference community which should have a reasonable representation of Shredders as dictated by seasonality, region, and climate. This allows for an examination of Shredder or Collector “relative” abundance as indicators of toxicity.

RBP III- U.S. EPA (Plafkin *et al,* 1989)

Rapid Bioassessment Protocol III (RBP III) is a more rigorous bioassessment technique than RBP II, involving systematic field collection and subsequent lab analysis in order to allow detection of more subtle degrees of impairment. Discrimination of four levels of impairment should be possible with this assessment. Although Protocol III requires more detailed taxonomy than can ordinarily be accomplished in the field, lab analysis procedures emphasize a minimal level of effort to ensure the protocol's time- and cost-effectiveness. Where differences among stations are subtle, however, more detailed sample analyses (e.g., enumeration of larger subsamples) or processing of a greater number of samples (to define replicability or assess more habitats) may be necessary to resolve such differences.

Data provided by RBP III can be used to prioritize sites for more intensive evaluation (e.g., quantitative biological surveys, ambient toxicity testing, chemical characterization). Besides providing a means of evaluating effects among stations, this protocol provides a basis for monitoring trends in benthic community structure that might be attributable to improvement or worsening of conditions over time.

Table II-11: Criteria [(a)] for characterisation of biological condition for RBP III

Metric	Biological Condition			
	Non-Impaired	Slightly Impaired	Moderately Impaired	Severely Impaired
1. Species Richness	Comparable to the best situation within an ecoregion	Community structure less than expected, loss of some intolerant forms	Fewer species due to loss of most intolerant forms	Few species present. If in high densities, then dominated by one or two taxa. Only tolerant organisms present
2. Hilsenhoff Biotic Index (modified)	↕	↕	↕	↕
3. Ratio of Scrapers/Filtering Collectors [(b)]				
4. Ratio of EPT and Chironomid Abundance				
5. % Contribution of Dominant Taxonomy				
6. EPT Index				
7. Community Similarity Index [(c)]				
8. Ratio of Shredders/Total [(b)]				

(a) Scoring criteria are generally based on percent comparability to the reference station
(b) Determination of Functional Feeding Group is independant of taxonomic grouping
(c) Community Similarity Indices are used in comparison to a reference station

Table II-12: Flowchart of bioassessment approach advocated for RBP III (Plafkin *et al,* 1989)

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
1. Taxa richness (a)	>80%	60-80%	40-60%	<40%
2. Hilsenhoff Biotic Index (modified) (b)	>85%	70-85%	50-70%	<50%
3. Ratio of Scrapers/Filtering Collectors (a,c)	>50%	35-50%	20-35%	<20%
4. Ratio of EPT and Chironomid Abundance (a)	>75%	50-75%	25-50%	<25%
5. % Contribution of Dominant Taxon (d)	<20%	20-30%	30-40%	>40%
6. EPT Index (a)	>90%	80-90%	70-80%	<70%
7. Community Loss Index (e)	<0.5	0.5-1.5	1.5-4.0	>4.0
8. Ratio of Shredders/Total (a,c)	>50%	35-50%	20-35%	<20%

(a) Score is a ratio of study site to reference site X 100
(b) Score is a ratio of reference site to study site X 100
(c) Determination of Functional Feeding Group is independant of taxonomic grouping
(d) Scoring criteria evaluate actual percent contribution, not percent comparability to the reference station
(e) Range of values obtained. A comparison to the reference station is incorporated in these indices

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% Comp. to Ref. Score (a)	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation to be expected within an ecoregion. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Composition (species richness) lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases..
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and physiochemical data may be necessary to aid in the decision process.

The RBP III metrics used to evaluate the benthic data and their significance are explained below:

Metric 1. Species Richness (Plafkin *et al,* 1989)

Same as in RBP II except here the analyses is based on the number of genera and/or species.

Metric 2. Modified Hilsenhoff Biotic Index (Plafkin *et al,* 1989)

Same principle as that in RBP II, except this is based on species level identification of most taxa.

The index has been modified to include non-arthropod species as well on the basis of the biotic index used by the State of New York (Bode *et al,* 1991; Bode *et al,* 1996). The latest tolerance values to species level in most taxa can be found in Bode *et* al (1996). *Although the HBI may be applicable for other types of pollutants, it has only been evaluated for organic pollutants*. The formula for calculating the Biotic Index is:

$$HBI = \sum \frac{x_i \ t_i}{n}$$

where
x_i = number of individuals within a species
t_i = tolerance value of a species
n = total number of organisms in the sample

Hilsenhoff's biotic index (1987) *may require regional modification in some instances.*

Metric 3. Ratio of Scraper and Filtering Collector Functional Feeding Groups (Plafkin *et al,* 1989)

A detailed rationale is available within the RBP II earlier in the Chapter. Identification here is to the genera and/or species levels.

Metric 4. Ratio of EPT and Chironomidae Abundance (Plafkin *et al,* 1989)

Same as that under RBP II except for the lower level of analyses required in RBP III.

Metric 5. Percent Contribution of Dominant Taxon (Plafkin *et al,* 1989)

The index uses abundance of the numerically dominant taxon relative to the rest of the population as an indication of community balance at the lowest positive taxonomic level.

Metric 6. EPT Index (Plafkin *et al,* 1989)

Same as in RBP II except here analyses is to the genera and/or family levels.

Metric 7. Community Similarity Indices (Plafkin *et al,* 1989)

The three indices have been discussed in the RBP II section.

Metric 8. Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected- CPOM Sample (Plafkin *et al,* 1989)

Same as in RBP II except here analyses is to the genera and/or family levels.

New York State Department of Environmental Conservation (Bode *et al,* 1991; Bode *et al,* 1996; Bode *et al,* 1997; Novak & Bode, 1992)

On-site screening procedure-Criteria (Bode *et al,* 1996)

The following five criteria were established for determination of non-impact. Failure of any one criterion establishes possible impact:

a. Mayflies must be present and numerous; at least 3 species must be present.
b. Stoneflies must be present.
c. Caddisflies must be present, but not more abundant than mayflies.
d. Beetles must be present.
e. Aquatic worms must be absent or sparse.

If the five criteria for non-impacted conditions are met, the sample may be returned to the stream. Organisms may be archived for tissue analysis. If any of the five criteria is not met, the sample is preserved for laboratory processing, and a water sample may be taken for toxicity testing, or a sediment sample for chemical analysis.

It should be recognized that this procedure is designed to answer only the question of impact vs. no impact, and its use is normally limited to sites considered likely to be nonimpacted. The inherent shortcoming of this method is that the assessment lacks any quantitative documentation. If the on-site determination is questionable, the sample should be preserved for laboratory processing. The method should not be used at headwater sites or sites affected by lake outlets, as these faunas are usually already reduced by natural processes.

Macroinvertebrate Community Indices (Bode *et al,* 1996)

Seven water quality indices are currently used as measures of macroinvertebrate community health. Different combinations of these indices are used for kick samples from riffles, net samples from slower, sandy streams, multiplate samples from navigable waters, and Ponar samples from lakes and rivers.

⇒ 1. Species richness

This is the total number of species or taxa found in the sample. Higher species richness values are mostly associated with clean water conditions.

⇒ 2. EPT richness

This index denotes the total number of species of mayflies, stoneflies, and caddisflies. These are considered to be mostly clean-water organisms, and their presence generally is correlated with good water quality.

⇒ 3. Biotic Index

The Hilsenhoff Biotic Index is calculated by multiplying the number of individuals of each species by its assigned tolerance value, summing these products, and dividing by the total number of individuals. On a 0-10 scale, tolerance values range from intolerant (0) to tolerant (10). Tolerance values, listed in the species list (Bode *et al,* 1996) are mostly from Hilsenhoff (1987). High HBI values are indicative of organic (sewage) pollution, while low values are indicative of clean-water conditions.

⇒ 4. Percent Model Affinity

This is a measure of similarity to a model non-impacted community based on percent abundance in 7 major groups (Novak & Bode, 1992). Percentage similarity is used to measure similarity to::

- For kick samples, the model community of 40% Ephemeroptera, 5% Plecoptera, 10% Trichoptera, 10% Coleoptera, 20% Chironomidae, 5% Oligochaeta, and 10% Other.

  - For Ponar samples, the model is 20% Oligochaeta, 15% Mollusca, 15% Crustacea, 20% Non-Chironomidae Insecta, and 20% Chironomidae, and 10% Other.

◊ Procedure for calculating Percent Model Affinity:
  - ◊ Determine the percent contribution for each of the 7 major groups: Oligochaeta, Ephemeroptera, Plecoptera, Coleoptera, Trichoptera, Chironomidae, and Other. These must add up to 100.
  - ◊ For each group, compare the actual percent contribution with that in the model; find the lesser of the two values, and add up these values.
  - ◊ The sum of the lesser values for the seven groups is the Percent Model Affinity value.

⇒ 5. Species diversity

Species diversity is a value that combines species richness and community balance (evenness). Shannon-Wiener diversity values are calculated using the formula in Weber (1973). High species diversity values usually indicate diverse, well-balanced communities, while low values indicate stress or impact.

⇒ 6. Dominance

Dominance is a simple measure of community balance, or evenness of the distribution of individuals among the species. Simple dominance is the percent contribution of the most numerous species. Dominance-3 is the combined percent contribution of three most numerous species. High dominance values indicate unbalanced communities strongly dominated by one or more of the very numerous species.

⇒ 7. NCO richness

NCO denotes the total number of species of organisms other than those in the groups Chironomidae and Oligochaeta. Since Chironomidae and Oligochaeta are generally the most abundant groups in impacted communities, NCO taxa are considered to be less pollution tolerant, and their presence would be expected to be more indicative of good water quality. This measure is the Ponar counterpart of EPT richness.

Table II-13: Biological Assessment Profile of Index Values for Riffle Habitats (Bode *et al,* 1996)

(SPP= Species richness, EPT= EPT richness; HBI= Hilsenhoff Biotic Index; PMA= Percent Model Affinity)

Water Quality Scale	SPP	EPT	HBI	PMA	Water Quality Impact
10.0	35	15	2.00	90	↑
		14	2.50	85	
9.0		13	3.00	80	
					None
	30	12	3.50	75	
8.0		11	4.00	70	
			4.50	65	↓
		10			↑
7.0	25				
		9	5.00	60	
		8			Slight
			5,.0		
6.0		7		55	
	20		6.00		
		6			
5.0			6.50	50	↓
		5			↑
			7.00	45	
		4			
4.0	15				
			7.50		
		3			Moderate
				40	
3.0		2	8.00		
				35	
			8.50		↓
	10				
2.0					↑
			9.00	30	
		1			Severe
1.0					
			9.50	25	
0.0	5	0	10.00	20	↓

Methods for Impact Source Determination (Bode *et al,* 1996)

Impact Source Determination (ISD) is the procedure for identifying types of impacts that exert deleterious effects on a waterbody. While the analysis of benthic macroinvertebrate communities has been shown to be an effective means of determining severity of water quality impacts, it has been less effective in determining what kind of pollution is causing the impact. Impact Source Determination uses community types or models to ascertain the primary factor influencing the fauna.

The method found to be most useful in differentiating impacts in New York State streams was the use of community types, based on composition by family and genus. It may be seen as an elaboration of Percent Model Affinity (Novak & Bode, 1992), which is based on class and order. A large database of macroinvertebrate data was required to develop ISD methods. These methods were developed for data derived from 100-organism subsamples of traveling kick samples from riffles of New York State streams. Application of the methods for data derived from other sampling methods, habitats, or geographical areas would likely require modification of the models.

The database included several sites known or presumed to be impacted by specific impact types. The impact types were mostly known by chemical data or land use. These sites were grouped into the following general categories: agricultural nonpoint, toxic-stressed. sewage (domestic municipal), sewage/toxic. siltation, impoundment, and natural. Each group initially contained 20 sites. Cluster analysis was then performed within each group, using percent similarity at the family or genus level. Within each group four clusters were identified, each cluster usually composed of 4-5 sites with high biological similarity. From each cluster a hypothetical model was then formed to represent a model cluster community type; sites within the cluster had at least 50 percent similarity to this model. These community type models formed the basis for Impact Source Determination (Tables II-14a to 14d). The method was tested by calculating percent similarity to all the models, and determining which model was the most similar to the test site. Some models were initially adjusted to achieve maximum representation of the impact type. New models are developed when similar communities are recognized from several streams.

Use of the ISD methods: ISD is based on similarity to existing models of community types (Tables II-14a to 14d). The model that exhibits the highest similarity to the test data denotes the likely impact source type, or may indicate “natural”, lacking an impact. In the graphical representation of ISD, only the highest similarity of each source type is identified. If no model exhibits a similarity to the test data of greater than 50%, the determination is inconclusive. The determination of impact source type is used in conjunction with assessment of severity of water quality impact to proved an overall assessment of water quality.

Table II-14a: Community Types for Impact Source Determination (Bode *et al,* 1996)

	NATURAL											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	-	-	5	-	5	-	5	5	-	-	-	5
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeriidae	-	-	-	-	-	-	-	-	-	-	-	-
Asellidae	-	-	-	-	-	-	-	-	-	-	-	-
Gammaridae	-	-	-	-	-	-	-	-	-	-	-	-
Isonychia	5	5	-	5	20	-	-	-	-	-	-	-
Baetidae	20	10	10	10	10	5	10	10	10	10	5	15
Heptageniidae	5	10	5	20	10	5	5	5	5	10	10	5
Leptophlebiidae	5	5	-	-	-	-	-	-	5	-	-	25
Ephemerellidae	5	5	5	10	-	10	10	30	-	5	-	10
Caenis/Tricorythodes		-	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	5	5	-	5	5	15	5	5	5
Psephenus	5	-	-	-	-	-	-	-	-	-	-	-
Optioservus	5	-	20	5	5	-	5	5	5	5	-	-
Promoresia	5	-	-	-	-	-	25	-	-	-	-	-
Stenelmis	10	5	10	10	5	-	-	-	10	-	-	-
Philopotamidae	5	20	5	5	5	5	5	-	5	5	5	5
Hydropsychidae	10	5	15	15	10	10	5	5	10	15	5	5
Helicopsychidae/ Brachycentridae												
Rhyacophilidae	5	5	-	-	-	20	-	5	5	5	5	5
Simuliidae	-	-	-	5	5	-	-	-	-	5	-	-
Simulium vittatum	-	-	-	-	-	-	-	-	-	-	-	-
Empididae	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	5	-	-	-
Chironomidae												
Tanypodinae	-	5	-	-	-	-	-	-	5	-	-	-
Diamesinae	-	-	-	-	-	-	5	-	-	-	-	-
Cardiocladius	-	5	-	-	-	-	-	-	-	-	-	-
Cricotopus/Orthocladius	5	5	-	-	10	-	-	5	-	-	5	5
Eukiefferiella/Tvetenia	5	5	10	-	-	5	5	5	-	5	-	5
Parametriocnemus	-	-	-	-	-	-	-	5	-	-	-	-
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	20	-	-	10	20	20	5
Polypedilum (all others)	5	5	5	5	5	-	5	5	-	-	-	-
Tanytarsini	-	5	10	5	5	20	10	10	10	10	40	5
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100

Table II-14b: Community Types for Impact Source Determination (Bode *et al,* 1996)

	NUTRIENT ADDITIONS, NONPOINT SOURCES								TOXIC				
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**A**	**B**	**C**	**D**	**E**
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	5
Oligochaeta	-	-	-	5	-	-	-	-	-	10	20	5	5
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	5	-	-	-
Sphaeriidae	-	-	-	5	-	-	-	-	-	-	-	-	-
Asellidae	-	-	-	-	-	-	-	-	10	10	-	20	10
Gammaridae	-	-	-	5	-	-	-	-	5	-	-	-	5
Isonychia	-	-	-	-	-	-	-	5	-	-	-	-	-
Baetidae	5	15	20	5	20	10	10	5	15	10	20	-	-
Heptageniidae	-	-	-	-	5	5	5	5	-	-	-	-	-
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	5	-	-	-	-	-
Caenis/Tricorythodes	-	-	-	-	5	-	-	5	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	5	-	-	5	-	5	5	-	-	-	-	-	-
Optioservus	10	-	10	5	-	-	15	5	-	-	-	-	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	15	15	-	10	15	5	25	5	10	15	-	40	35
Philopotamidae	15	5	-	5	-	25	5	-	10	-	-	-	-
Hydropsychidae	15	15	15	25	10	35	20	45	20	10	15	10	35
Helicopsychidae/ Brachycentridae													
Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	5	-	15	5	5	-	-	-	-	-	-	-	-
Simulium vittatum	-	-	-	-	-	-	-	-	-	20	-	-	-
Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae													
Tanypodinae	-	-	-	-	-	-	5	-	5	10	-	-	-
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/ Orthocladius	10	15	10	5	-	-	-	-	15	10	25	10	5
Eukiefferiella/ Tvetenia	-	15	10	5	-	-	-	-	-	-	20	10	-
Parametriocnemus	-	-	-	-	-	-	-	-	-	-	-	5	-
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	10	20	10	5	10	10	-	-	-	-
Tanytarsini	10	10	10	5	20	5	5	10	-	-	-	-	-
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100

Table II-14c: Community Types for Impact Source Determination (Bode *et al*, 1996)

	SEWAGE EFFLUENT, ANIMAL WASTES									**MUNICIPAL/INDUSTRIAL**					
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**A**	**B**	**C**	**D**	**E**	**F**
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	40	-	-	-	5
Oligochaeta	5	35	15	10	10	35	40	10	20	20	20	70	10	-	20
Hirudinea	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Sphaeriidae	-	-	-	10	-	-	-	-	-	-	5	-	-	-	-
Asellidae	5	10	-	10	10	10	10	50	-	10	5	10	10	15	5
Gammaridae	-	-	-	-	-	10	-	10	-	40	-	-	-	15	-
Isonychia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Baetidae	-	10	10	5	-	-	-	-	10	5	-	-	-	5	-
Heptageniidae	10	10	10	-	-	-	-	-	-	5	-	-	-	-	-
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Caenis/ Tricorythodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Optioservus	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	15	-	10	10	-	-	-	-	-	5	-	-	10	5	-
Philopotamidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsychidae	45	-	10	10	10	-	-	10	10	10	-	-	50	20	-
Helicopsychidae / Brachycentridae Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simulium vittatum	-	-	-	25	10	35	-	-	5	-	-	-	-	-	-
Empididae	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
Chironomidae															
Tanypodinae	-	5	-	-	-	-	-	-	-	-	10	-	-	5	15
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/ Orthocladius	-	10	15	-	-	10	10	-	5	5	10	20	-	5	10
Eukiefferiella/ Tvetenia	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-
Parametriocnemus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomus	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	10	60	-	30	10	10	-	-	-	10	20	40
Tanytarsini	10	10	10	10	-	-	-	10	20	-	-	-	10	10	-
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table II-14d: Community Types for Impact Source Determination (Bode *et al,* 1996)

	SILTATION					IMPOUNDMENT									
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Platyhelminthes	-	-	-	-	-	-	10	-	10	-	5	-	50	10	-
Oligochaeta	5	-	20	10	5	5	-	40	5	10	5	10	5	5	-
Hirudinea	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	10	-	5	5	-	-	-	-
Sphaeriidae	-	-	-	5	-	-	-	-	-	-	-	-	5	25	-
Asellidae	-	-	-	-	-	-	5	5	-	10	5	5	5	-	-
Gammaridae	-	-	-	10	-	-	-	10	-	10	50	-	5	10	-
Isonychia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Baetidae	-	10	20	5	-	-	5	-	5	-	-	5	-	-	5
Heptageniidae	5	10	-	20	5	5	5	-	5	5	5	5	-	5	5
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caenis/ Tricorythodes	5	20	10	5	15	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Optioservus	5	10	-	-	-	-	-	-	-	-	-	-	-	5	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	5	10	10	5	20	5	5	10	10	-	5	35	-	5	10
Philopotamidae	-	-	-	-	-	5	-	-	5	-	-	-	-	-	30
Hydropsychidae	25	10	-	20	30	50	15	10	10	10	10	20	5	15	20
Helicopsychidae/ Brachycentridae Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-
Simuliidae	5	10	-	-	5	5	-	5	-	35	10	5	-	-	15
Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae															
Tanypodinae	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/ Orthocladius	25	-	10	5	5	5	25	5	-	10	-	5	10	-	-
Eukiefferiella/ Tvetenia	-	-	10	-	5	5	15	-	-	-	-	-	-	-	-
Parametriocnemus	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	5	5	5	-	-	20	-	-	5	5	5	5
Tanytarsini	10	10	10	10	5	5	10	5	30	-	-	5	10	10	5
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Ontario Ministry of the Environment and Energy-Streams and small lakes (David *et al,* 1998; Reid *et al,* 1995; Somers *et al,* 1998)

Recommendations from Somers *et al,* 1998:

1) "Subsampling 100 animals is sufficient for rapid bioassessments. The results of the ANOVAs and associated power calculations revealed only modest gains in our ability to distinguish lakes using subsamples of 200 or 300 animals. The only exceptions to this conclusion are studies that use indices based on richness measures and rare taxa, where larger counts are necessary to adequately census rare individuals.
2) Multivariate indices should be used in addition to simple indices to interpret rapid bioassessment data. Two simple metrics (% amphipods and % insects) and a multivariate metric (CA axis 1) were the best indices for distinguishing our 5 lakes.
3) Variance components (i.e., r_i) and MDCs should be used in comparative studies to provide guidance for making unbiased decisions. Intraclass correlations and power calculations complement simple ANOVAs and provide useful tools to evaluate competing methods. Without objective criteria, these types of comparative studies often produce inconclusive results".

Some of the simple rapid bioassessment indices to consider are:

- Number of taxonomic groups
- % oligochaetes
- % amphipods
- % EPT
- % non-dipteran insects
- % insects
- % dipterans
- % gastropods
- % pelecypods
- EPT/chironomids
- % dominants

Other miscellaneous indices:

Simpson's diversity index (Krebs, 1994)

The Simpson's diversity index (D) is calculated using the following equation:

$$D = 1 - \sum_{i=1}^{s} (p_i)^2$$

where "p_i" is the proportion of individuals of the "i^{th}" taxon in the community. Simpson's index gives relatively little weight to the rare species and more weight to the common species. It ranges in value from 0 (low diversity) to a maximum of (1-1/s), where "s" is the number of taxa.

Shannon-Wiener Index (Williams & Feltmate, 1992)

This is a widely used method of calculating biotic diversity in aquatic and terrestrial ecosystems, and is expressed as:

$$H = -\sum_{i}^{s} (p_i)(\log_2 p_i)$$

where
H= index of species diversity
s= number of species
p_i= proportion of total sample belonging to the i'th species.

A large H value indicates greater diversity, as influenced by a greater number and/or a more equitable distribution of species.

ETO Metric (U.S. Environmental Protection Agency, 1998)

Number of ETO taxa (Ephemeroptera, Trichoptera, Odonata).

Wilhm and Doris Species Diversity Index (Mackie, 1998)

$$\text{mean diversity, d} = -\sum \left({n_i}/{N} \right) \log_2 \left({n_i}/{N} \right)$$

where n_i is the number of individuals in species "i" and N is the total number of individuals in a sample.

Water quality is assessed as:

Mean diversity, d	Water Quality
<1	Polluted
1-3	Subpolluted
>3	Clean

- The species diversity index has several advantages. It is a good objective, numerical approach that is easily reported. It takes into account all the species present and their relative abundance but it is not necessary to actually name the species. One needs only to distinguish species A from species B, C, D and so on. In fact, identification to genus is sufficient because the diversity value changes only slightly at that generic level.
- However the species diversity index becomes increasingly less reliable with higher taxonomic levels (e.g. family, order, class).
- A major disadvantage of the diversity index is it ignores the "quality" of the species, that is whether it is a tolerant or sensitive species. Also, the index is affected by factors other than pollution, such as habitat quality. Indeed, diversity values less than 3 are often obtained in the

most pristine headwater streams because few species are adapted to cold water and a shredding feeding behaviour.
- The diversity index is somewhat sensitive to sample size as well. Studies have shown that atleast 0.5 m^2 of bottom needs to be sampled, but above this value he species diversity index remains relatively constant.

Saprobic Index (Mackie, 1998)

The benthic saprobic index was developed to elucidate conditions in slowly moving rivers with organic enrichment. The index tends to break down in streams where slow reaches are separated by riffle areas and in short turbulent stretches of streams. The index only works if the organisms are identified to species, or to genus in some cases.

Trent Index (Mackie, 1998)

Woodiwiss (1964), while working for the Trent River Authority in England, devised a scheme in which the number of groups within defined taxa was related to the presence of six key organisms within the faunal assemblage. This index was also adapted by the Tennessee Stream Pollution Board in the U.S., and with modifications by several countries. The index can be calculated on samples collected either quantitatively or qualitatively, but enumeration of individuals is not required. The Trent index can be used to assess organic or mixed pollution.

The Trent index is a great improvement over the Saprobien system in that the index values are within a defined range (0 for extreme pollution to 10 for pristine conditions), and the sample sorting time is greatly reduced.

Some criticisms of the index are; (i) it is insensitive to determining improved water quality; (ii) it can only be used to assess streams with riffle areas, and grossly underestimates water quality in non-riffle areas; and (iii) it is not applicable to all geographical areas, which applies to nearly all indices. However, several elements of the Trent index have been used in the development of other indices, such as the Chandler index.

Chandler Index (Mackie, 1998)

Chandler (1970) working on the River North Esk and other Lothian rivers in Britain, used many elements of the Trent index. This index can be used only for organic pollution. Differences of diversity and abundance between clean and polluted parts of a river are immediately obvious. The index has a continuous gradation from polluted to clean conditions. The highest index values are obtained in a headwater area with several species of stoneflies, mayflies and caddisflies.

BMWP Biotic Index (Armitage *et al,* 1983; Friedrich *et al,* 1996; Hynes, 1998; Mackie, 1998)

In order to limit the taxonomic requirement of earlier biotic indices to identify organisms to species level, some alternative indices have been developed which use only the family level of identification. An example is the Biological Monitoring Working Party-score (BMWP) which has been published as a standard method by an international panel (ISO-BMWP, 1979). This score was devised in the UK but was not specific to any single river catchment or geographical area. The new BMWP score attempted to take the advantages of earlier biotic indices. The Biological Monitoring Working Party (BMWP) score is calculated by adding the individual scores of all indicator organisms present (family level, except order Oligochaeta) (Friedrich *et al*, 1996).

The organisms are identified to the family level and then each family is allocated a score between 1 and 10. The score values (Table II-15) for individual families reflect their pollution tolerance; pollution intolerant families have high scores and pollution tolerant families have low scores. Mayfly nymphs score 10, molluscs score 3 and the least sensitive worms score 1. The number of taxa gives an indication of the diversity of the community (high diversity usually indicates a healthy environment, Friedrich *et al*, 1996).

Table II-15: Pollution sensitivity grades for families (higher levels in a few cases) of river macroinvertebrates for SIGNAL (S) and BMWP (B) scores. Families not occurring in North America have been omitted. N represents families found in N. America and are graded according to the inverse of Bode *et al* (1991) and Plafkin *et al (1989)* tolerance values to correspond to SIGNAL and BMWP scores (modified from Mackie, 1998)

Family	Grade			Family	Grade			Family	Grade		
	N	B	S		N	B	S		N	B	S
Acariformes	6	-	-	Gammaridae	4	6	6	Peltoperlidae	9	-	-
Aeolosomatidae	2	-	-	Gerridae	5	5	4	Perlidae	8	10	10
Aeshnidae	6	8	6	Glossiphoniidae	3	3	3	Perlodidae	8	10	-
Agrionidae	4	8	-	Glossosomatidae	10	-	8	Philopotamidae	7	8	10
Ancylidae	4	6	6	Gomphidae	6	8	7	Phryganeidae	7	-	-
Anthomyiidae	4	-	-	Gordiidae	8	10	7	Physidae	2	3	3
Anthuridae	4	-	-	Gyrinidae	5	5	5	Piscicolidae	5	4	-
Asellidae	2	3	-	Haliplidae	5	5	5	Planariidae	4	5	3
Arctiidae	5	-	-	Haplotaxidae	1	1	5	Planorbidae	3	3	3
Arrenuridae	4	-	-	Helicopsychidae	7	-	10	Platyhelminthidae	6	-	-
Astacidae	4	8	-	Helodidae	5	5	-	Pleidae	5	5	-
Athericidae	6	-	7	Heptageniidae	7	10	-	Pleuroceridae	4	-	-
Atractideidae	4	-	-	Hirudinea	0	-	-	Polycentropodidae	4	7	8
Baetidae	5	4	5	Hyalellidae	2	-	-	Polychaeta	4?	-	-
Baetiscidae	6	-	-	Hydridae	5	-	4	Polymetarcyidae	8	-	-
Belostomatidae	5	-	5	Hydrobiidae	4	3	5	Potamanthidae	6	10	-
Blephariceridae	10	-	10	Hydrometridae	5	5	5	Psephenidae	6	-	5
Branchiobdellidae	4	-	-	Hydrophilidae	5	5	5	Psychodidae	8	8	2
Brachycentridae	9	10	-	Hydropsychidae	6	5	5	Psychomyiidae	8	8	-
Caenidae	5	7	-	Hydroptilidae	5	6	6	Pteronarcidae	10	-	-
Calopterygidae	4	-	-	Hygrobiidae	5	5	5	Ptychopteridae	1	-	-
Capniidae	8	10	-	Idoteidae	5	-	-	Pyralidae	5	-	6
Ceratopogonidae	4	-	6	Isotomidae	5	-	-	Rhyacophilidae	9	-	7
Chaoboridae	2	-	-	Lebertiidae	4	-	-	Sabellidae	4	-	-
Chironomidae	1	2	1	Lepidostomatidae	10	10	-	Scirtidae	5	5	8
Chloroperlidae	10	10	-	Leptoceridae	6	10	7	Sialidae	6	4	4
Chrysomelidae	5	5	-	Leptophlebiidae	7	10	10	Simuliidae	5	-	5
Coenagrionidae	2	6	7	Lestidae	1	-	7	Siphlonuridae	8	10	-
Collembola	5?	-	-	Leuctridae	10	10	-	Sphaeriidae	4	3	6
Corbiculidae	4	-	6	Libellulidae	8	8	8	Spurchonidae	4	-	-
Corduliidae	7	8	7	Limnephilidae	7	7	8	Sisyridae	5	-	-
Cordulegasteridae	7	8	-	Limnesidae	4	-	-	Tabanidae	5	-	5
Corixidae	5	5	5	Limnocharidae	4	-	-	Taeniopterygidae	8	10	-
Corydalidae	6	-	4	Lumbriculidae	2	1	1	Talitridae	2	-	-
Culicidae	1	-	2	Lymnaeidae	4	3	-	Thiaridae	6	-	7
Dixidae	10	-	8	Mesoveliidae	5	5	4	Tipulidae	7	5	5
Dolichopodidae	6	-	-	Mideopsidae	4	-	-	Tricorythidae	6	-	-
Dreissenidae	2	-	-	Molannidae	4	10	-	Tubificidae	1	1	1
Dryopidae	5	5	-	Muscidae	4	-	3	Tyrellidae	4	-	-
Dytiscidae	5	5	5	Naididae	3	1	1	Unionidae	4	6	-
Elmidae	5	5	7	Nemouridae	8	7	-	Unionicolidae	4	-	-
Empididae	4	-	4	Nepidae	5	5	-	Valvatidae	2	3	-
Enchytreidae	1	1	-	Nepticulidae	5	-	-	Veliidae	5	-	4
Ephemerellidae	10	10	-	Notonectidae	5	5	4	Viviparidae	4	6	-
Ephemeridae	8	10	-	Odontoceridae	10	10	8				
Ephydridae	4	-	2	Oedicerotidae	4	-	-				
Erpobdellidae	3	3	3	Oligochaeta	2	-	-				

Note: The grades under (N) above should be used in the said indices (there is some question as regards the grades of the taxa which have been noted along with a `?')

Average Score Per Taxon (ASPT) (Armitage *et al,* 1983; Friedrich *et al,* 1996; Hynes, 1998; Mackie, 1998)

The Average Score Per Taxon (ASPT) is calculated by dividing the BMWP score by the number of indicator families present in the sample (Friedrich *et al*, 1996). Armitage *et al* then assessed the performance of both systems in relation to physical and chemical features of the study sites and found that the ASTP score system explained a higher proportion of the variance in the environmental data.

Armitage *et al* (1983) sampled the benthos using a 3-minute kick-and-sweep method (900 µm mesh size) at each site, 3 times/year (spring, summer, fall). All animals were sorted and identified to species where possible, but identification to family is all that is needed for the BMWP and the ASPT. Site scores are obtained by summing the individual scores of all families present (if several species are present in a family, the family is scored only once). Criteria for water quality assessment were not provided, but are probably similar to the SIGNAL biotic index, an Australian method that is based on ASTP. These criteria are:

ASTP value	Water Quality Assessment
>6	Clean Water
5-6	Doubtful quality
4-5	Probable moderate pollution
<4	Probable severe pollution

Stream Invertebrate Grade Number- Average Level (SIGNAL) (Mackie, 1998)

SIGNAL is a modification of the British BMWP score system adapted for use in Australian rivers. All specimens were identified to family level only. The assessment of water quality is based on the same criteria listed earlier for the ASTP index. The criteria are based on samples taken from unpolluted reference sites, and sites with mild to severe pollution by municipal effluent and urban water runoff.

Beak Biotic Index (Mackie, 1998)

A plethora of biotic indices have been developed to assess water quality of North American rivers. The Beak Index is a bioassessment technique that utilizes groups of taxa and species to assess not only water quality, like most other indices, but also the fisheries potential of the North American rivers. The index ranges from 0 for severe pollution (usually toxic) to 6 for an unpolluted stream. It can be derived from samples taken by any method that permits a reasonably accurate estimate to be made of population densities. It is recommended that control samples from an unpolluted area be taken for comparison.

Identification to species is essential for a rigorous assessment but an approximate result can be obtained by sorting and counting to families. To use the index to its fullest potential, the investigator needs to know the relative abundances of species with different functional feeding behaviours (i.e. grazers, filter feeders, predators, etc.) and their ecological tolerances and requirements.

The Beak index is an advance over the Diversity index in that species are also considered for their sensitivity to pollution. Nevertheless, much of the tolerances and requirements are a matter of opinion and the index value assigned often “assumes” that the type of community listed in Table II-16 is present.

Table II-16: Calculation of the Beak Index (Mackie, 1998)

Sensitive groups: Odonata Trichoptera Megaloptera Ephemeroptera Plecoptera	A normal complement scores 3 points. If only part of the group is found, score 1 or 2 points., e.g. if only one order is present, score 1 point, if two orders, score 2 points.
Facultative groups: **(in clean or polluted water)** Chironomidae Amphipoda Isopoda Gastropoda Bivalvia	A normal complement scores 2 points. If most are missing, e.g. if only one or two groups are present, score 1 point.
Pollution-tolerant groups: Tubificidae Lumbriculidae *Procladius culiciformis* (Chironomidae)	A normal or supranormal complement scores 1 point.

Table II-17: Interpretation of the Beak Index (Mackie, 1998)

Pollution Status	Biotic Index	Type of Macroinvertebrate community	Fisheries potential
Unpolluted	6	Sensitive, facultative and tolerant predators, herbivores, filter and detritus feeders all represented, but no species in excessively large numbers	All normal fisheries for type of water well developed
Slight to moderate pollution	5 or 4	Sensitive predators and herbivores reduced in population density or absent. Facultative predators, herbivores and possibly filter and detritus feeders well developed and increasing in numbers as index decreases	Most sensitive fish species reduced in numbers or missing
Moderate pollution	3	All sensitive species absent and facultative predators (Hirudinea) absent or scarce. Predators of Pelopiinae and herbivores of Chironomidae present in fairly large numbers	Only coarse fisheries maintained
Moderate to heavy pollution	2	Facultative and tolerant species reduced in numbers if pollution toxic; if organic few species insensitive to low oxygen levels present in large numbers	If fish present, only those with high toleration of pollution
Heavy pollution	1	Only most tolerant detritus feeders (Tubificidae) present in large numbers	Very little, if any, fisheries potential
Severe pollution, usually toxic	0	No macroinvertebrates present	No fish

Sequential Comparison Index (SCI) (Mackie, 1998)

This index was developed for people who have no experience at identifying organisms. In fact, the accuracy of the index decreases with increasing benthological experience of the user. It does not work for experienced benthologists because they would classify different larval stages of a single species as one taxon, whereas an inexperienced person would call them different taxa, or two organisms of different size may be classified as the same by the benthologist but differently by the novice. It is essential that the sorting be done randomly. For example, if all the large animals are sorted first and then all the small ones, the sample would probably be biased in the ordering of taxa, resulting in fewer runs and a smaller index value. The index would probably work well for inexperienced cottagers, sport fishermen, etc., with the above caveats in mind.

The index is based on the "sign test" and the "theory of runs". That is, it relies on the innate ability of the user to recognize differences in size, shape and colour (signs) of organisms. It is an expression of community structure since it depends upon both the species richness of the community and on the distribution of individuals among the species. Only two individuals are compared at a time. The current individual need only be compared to the previous one. If it looks similar it is part of the same "run"; if not, it is part of a new run. The greater the number of runs, the greater the diversity. Organisms of the same appearance are assigned to the same taxon. The number of different looking "signs" represents the number of different taxa.

$$SCI = \frac{no.of\ runs\ x\ no.of\ taxa}{total\ no.of\ individuals}$$

where
a run is a set of organisms that looks similar
a taxon is a different looking organism

The criteria for assessing water quality with the SCI is as follows:

SCI Value	Water Quality
≤8.0	Polluted
8.1-12	Moderately polluted
>12	Clean

Sample:

Organism #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	☺	☻	☻	◘	◙	◙	◙	◙	☺	☹	☹	☹	◘	☻	◙
Run	1	2	2	3	4	4	4	4	5	6	6	6	7	8	9
Taxon	1	2		3			4		1		5		3	2	4

The SCI for this particular sample is: (9x5)/15=3, a value that ranks it from polluted water.

Hynes (1998), Project D-2, Soil & Water Conservation Society of Metro Halifax

Hynes (1998) investigated the applicability of a handful of the above indices to 5 lakes, Wrights, Springfield, McGrath, Kearney, and Morris within the Halifax Regional Municipality (HRM). All lakes were located in urban or urbanizing areas, and it was hoped that the indices could be used for future monitoring of these and other lakes for signs of pollution/degradation.

Gaertner (1999), Project E-2, Soil & Water Conservation Society of Metro Halifax

Gaertner (1999) carried out a relatively extensive investigation of the applicability of several of the indices to 5 more lakes, Dollar, Russell, Stillwater, Papermill, and Kinsac within the Halifax Regional Municipality (HRM), Nova Scotia. All lakes except for Dollar were located in urban or urbanizing areas. An educational vidoe for public education also accrued from this project and is available from the univeristy libraries.

Freshwater Zoobenthos with indicator value

Only significant taxon groups where reliable literature exists as regards their indicator values are noted below. For biodiversity indices, all (or most) benthic groups have relevance, and the individual chapters that follow this chapter address some basic aspects.

Superphylum Arthropoda (Williams & Feltmate, 1992; Thorp & Covich, 1991)

The most successful terrestrial phylum and one of the most prominent freshwater taxa is Arthropoda. Its three subphyla with freshwater members- Uniramia (aquatic insects), Chelicerata (water mites and aquatic spiders) and Crustacea (crayfish, fairy shrimp, copepods, etc.)- are all diverse and important components of lakes and streams. Arthropods occupy every heterotrophic niche in benthic and pelagic habitats of most permanent and temporary aquatic systems. These metameric coelomates are characterized by a chitinous exoskeleton and stiff, jointed appendages modified as legs, mouthparts, and antennae (except in water mites).

Subphylum Uniramia

Class Insecta (Mackie, 1998)

The greatest diversity in form and habit is exhibited by the insects. They occupy every kind of freshwater habitat imaginable, including temporary streams and ponds, the shallowest and deepest areas of lakes, the most pristine and polluted rivers, roadside ditches, eaves troughs, moss, within and on macrophytes and all ranges of water chemistry, from acidified to alkaline bodies of water. They also represent all the functional feeding groups, including predators, shredders, grazers, (or scrapers), filter feeders, gatherers, piercers and parasites.

Insects can be separated immediately from other arthropod classes by the presence of: 1) one pair of antennae; 2) three pairs of segmented legs in adults and most larvae (only the larvae of true flies lack segmented legs); and 3) one to two pair of wings on the adults.

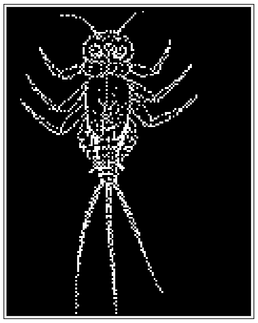
They are conveniently divided into three taxonomic groups based on the type of wings that develop from the larval or nymphal stages and on the type of life stages present

- Those without wings are *apterous* (Greek: a=without; pterous=wings), and they have no change in body form after hatching from the egg. This type of development is called *ametabolous* (Greek:a=without; metabolous=change) metamorphosis. Only the springtails of the order, **Collembola** have ametabolous development in aquatic environments.
- The remaining two groups have winged adults. The wings develop externally in the *exopterous* (Greek: exo=outside; pterous=wings) forms, and internally in the *endopterous* (Greek: endo=inside; pterous=wings) forms.
  - The development stages of the exopterous forms are called nymphs or naiads and they closely resemble the adults in appearance. The nymphs undergo several molts, or instars, before transforming into an adult. The act of shredding or casting the old skin is called ecdysis and the cast skin is called an exuvium (plural=exuviae), commonly referred to as the “shuck”. The adult is called the imago and it differs from the last instar in having fully developed wings and sexual organs. The entire process, from egg through several nymphal instars, is called hemimetabolous (Greek: hemi=incomplete or inseparable; metabolous=change) development.
    - Only three orders of insects have hemimetabolous development, the **Odonata** (dragonflies and damselflies), **Ephemeroptera** (mayflies) and **Plecoptera** (stoneflies).

- Very similar to the hemimetabolous forms are the paurometabolous (Greek: pauros=little, small; metabolous=change) forms in which wings develop externally on the nymphs but the nymphs and adults are often difficult to distinguish and both live in the same habitat and feed similarly. Development is gradual and the changes between instars are subtle and barely noticeable in most instances.
    - Only one order, the **Hemiptera** (true bugs) have paurometabolous development. Aquatic **Orthoptera** (crickets) also have this type of development but they are rare.
- The endopterous forms have a holometabolous (Greek: holo=complete, metabolous=change) type of development in which the egg develops into a worm-like larva. The larvae have no external evidence of wings. Segmented legs and antennae are usually present but may be missing in a few orders. Once the larva is fully grown, it transforms into a resting stage, called the pupa, during which it metamorphoses into an imago. The wings, legs, antennae and compound eyes develop in the pupal stage.
    - Most species of aquatic insects have holometabolous development, including all the **Megaloptera** (dobsonflies, alderflies, hellgrammites), **Neuroptera** (spongeflies), **Lepidoptera** (aquatic butterflies), **Trichoptera** (caddisflies), **Coleoptera** (beetles) and **Diptera** (true flies).
        - Note that “true flies” is two words; only flies of the order Diptera are spelled with two words, for example, crane flies, black flies, midge flies, etc.; all other “false flies” are spelled with one word, e.g. mayflies, caddisflies, etc.

The Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) and Diptera (true flies) are commonly, or perhaps always, the four orders used in environmental impact assessments. For this reason, more emphasis is placed on these orders than on other orders of insects. (Mackie, 1998)

Order Ephemeroptera (Mayflies)



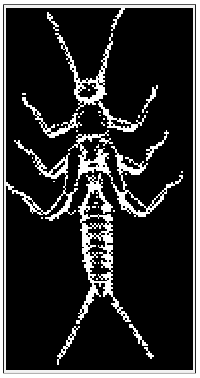
(cf. Chapter III):

These insects of inland waters are aquatic only in their juvenile stages. In general, mayfly nymphs tend to live mostly in unpolluted lakes, ponds, streams and rivers where, with densities of up to 10,000/sq.metre, they contribute substantially to secondary production. However, very small amounts of organic pollution can sometimes, initially, increase the numbers and production of certain species while others are exterminated. Species of ***Baetis*** (Family Baetidae) seem the most tolerant to pollution and these and others are often used as indicators of water quality. Burrowing nymphs such as *Hexagenia bilineata* (Family Ephemeridae) do particularly well in silted impoundments and the problems associated with their mass emergence from the Mississippi River are notorious- e.g. accumulation of adult bodies on road bridges create slippery surfaces for motorists. (Williams & Feltmate, 1992)

Table II-18: Some physiological and ecological tolerances and requirements of common mayfly nymphs. (Mackie, 1998)

Species	General habitat	Feeding	pH	Oxygen %	Trophic level
Baetis vagans	gravel, streams	scraper	≥ 7	100	Oligo
Epeorus vitreus	gravel, streams	shredder	> 7	100	Oligo
Ephemera simulans	sand, gravel, lakes, streams	predator, gatherer, shredder	≥ 7	50-100	Meso-Oligo
Ephemerella subvaria	gravel, streams	scraper	~ 7	100	Oligo
Ephemerella cornuta	gravel, streams	scraper	~ 7	100	Oligo
Heptagenia flavescens	wood, rock, streams	shredder, gatherer	?	50-100	Meso-Eutro
Hexagenia limbata	mud, lakes	predator	> 7	~ 100	Meso-Oligo
Hexagenia recurvata	mud, cold streams	predator	≥ 7	100	Oligo
Isonychia bicolor	swimmer, streams	filter feeder	≥ 7	100	Oligo
Paraleptophlebia debilis	gravel, rocks, streams	gatherer, shredder	> 7	100	Dyst-Oligo
Rhithrogena undulata	gravel, rocks, streams	gatherer	≥ 7	100	Oligo
Stenacron interpunctatum	rocks, lakes, streams, ponds	gatherer, scraper	<7 – >7	25-100	all levels
Stenonema tripunctatum	rocks, streams	gatherer, scraper	≥ 7 - >7	50-100	all levels
Stenonema femoratum	rocks, streams	gatherer, scraper	> 7	100	Oligo
Tricorythodes minutus	indifferent, streams only	gatherer	> 7	25-100	Meso, Dyst

Order Plecoptera (Stoneflies)



(cf. Chapter V):

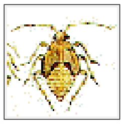
Plecopteran nymphs are restricted to cool, clean streams with high dissolved oxygen content. some species, however, may be found along the wave-swept shores of large oligotrophic lakes. When subjected to low dissolved oxygen concentration, the nymphs of many species exhibit a characteristic "push-up" behaviour that increases the rate of movement past the gills. The gills are variously placed among species on the neck, thorax and abdomen. However, some species have no gills and respiration in these is assumed to be across the cuticle surface.

The high water quality requirements of the nymphs bars all but a very few species from habitats subject to low oxygen levels, siltation, high temperatures and organic enrichment, and this has led to their effective use as biological indicators of environmental degradation. (Williams & Feltmate, 1992)

Table II-19: Some physiological and ecological tolerances and requirements of common stonefly nymphs. (Mackie, 1998)

Species	General habitat	Feeding	pH	Oxygen %
Acroneuria lycorias	rocks, streams	predator of insects	<7 - >7	~ 100
Allocapnia spp.	rocks, streams	shredder	> 7	~ 100
Amphinemura delosa	gravel, rocks, streams	gatherer, shredder	<7 - >7	100
Isoperla bilineata	plants, rocks, streams	predator of insects, gatherer	> 7	100
Isoperla clio	plants, streams	predator of insects	> 7	100
Isoperla fulva	plants, rocks, streams	predator of insects, scraper, gatherer	≥ 7	50-100
Nemoura trispinosa	plants, rocks, streams	shredder	<7 - >7	100
Peltoperla maria	leaf litter, streams	shredder	≥ 7	~ 100
Perlesta placida	rocks, leaves, streams	predator of insects, gatherer	> 7	~ 100
Pteronarcys spp.	rocks, logs, leaves, streams	predator, scraper, shredder	≥ 7	~ 100
Taeniopteryx maura	rocks, logs, leaves, streams	gatherer, shredder	<7 – >7	~ 100

Order Hemiptera (Water Bugs)



(cf. Chapter VI):

The ecology of the aquatic Hemiptera is much better known, and it is probable that they are limnologically more significant than the beetles. (Hutchinson, 1993)

Most hemipterans are either lentic or slow water lotic forms. They are all air breathers and as such are more tolerant of environmental extremes than most other insects. The water boatman, *Hesperocorixa,* and the water strider, *Gerris,* are among the few insects that can tolerate pH values less than 4.5 and are among the last to disappear when lakes and streams acidify.

Of all aquatic organisms, the giant water bug, *Belostoma fluminea,* is considered by many to be among the most tolerant of extreme conditions, high chloride, high BOD, low oxygen, low pH, etc. However, it like all hemipterans, has little or no indicator value because their life does not depend entirely on water quality. (Mackie, 1998)

Order Trichoptera (Caddisflies)

(cf. Chapter VII):

Like mayflies and stoneflies, caddisflies probably evolved in cold, fast-flowing streams, since families with more primitive characteristics (e.g., Rhyacophilidae) are restricted to those habitats. It has been hypothesised that the use of silk for case construction enabled the Trichoptera to become more diverse ecologically, providing a respiratory mechanism whereby habitats with higher temperatures and lower dissolved oxygen levels could be exploited.

At present, caddisflies inhabit a wide range of habitats from the ancestral cool streams to warm streams, permanent lakes and marshes, and permanent and temporary ponds. One species has been found in tide pools off the coast of New Zealand; the females oviposit through the papillar pores of starfishes.

Although caddisfly larvae are found in a wide range of aquatic habitats, the greatest diversity occurs in cool running waters. Furthermore, in families represented in both lotic and lentic habitats, the genera exhibiting more ancestral characters tend to be found in cool streams whereas those showing more derived characters tend to occur in warm, lentic waters. These two findings point to cool, running waters as the most likely primordial caddisfly habitat, the one in which the ancestors of the Trichoptera first became aquatic and the one in which differentiation into the basic groups (superfamilies) took place (Williams & Feltmate, 1992).

Mass emergences of some species from large rivers are considered a nuisance by residents, since the insects are attracted to outdoor lights; human allergies to the scales on their wings have also been reported. The larvae of some leptocerids are reported to damage the young shoots of rice plants in paddy fields. The larvae of a few species are known to eat fish eggs. On the beneficial side, many hydropsychids prey on black fly larvae.

Table II-20: Some physiological and ecological tolerances and requirements of common caddisfly larvae. (Mackie, 1998)

Species	General habitat	Feeding	pH	Oxygen %	Trophic level
Agapetus spp.	turtle case, streams	scraper	≥ 7	~ 100	Oligo
Agraylea spp.	silk purse, streams, lakes	piercer, gatherer	≤7 - >7	~ 100	upper Meso
Banksiola spp.	tapered cylinder of leaves in spiral; slow streams, lakes	shredder, piercer (last 2 instars)	<7 - >7	> 50	upper Meso
Brachycentrus americanus	tapered square tube of plant material; on logs & plants in streams	filter feeder, scraper	≥ 7	> 50	upper Meso
Cheumatopsyche spp.	silk net, warmer streams	filter feeder	<6 - >7	25 - 100	lower Meso
Chimarra spp.	sac-like nets, warmer streams	filter feeder	≥ 7	≥ 50	Meso
Frenesia spp.	tube of mineral, wood; cool springs	shredder	> 7	~ 100	Oligo
Glossosoma nigrior	turtle case, streams	scraper	≥ 7	~ 100	Oligo
Helicopsyche borealis	spiral case, streams	scraper	<7 - >7	> 50	upper Meso
Hydropsyche spp.	silk net, streams	filter feeder	≥ 7	> 50	upper Meso
Hydroptila spp.	silk purse, streams	piercer, scraper	≤7 - >7	~ 100	Oligo
Lepidostoma spp.	tapered tube of sand, headwater streams	shredder	~ 7	> 50	upper Meso
Leptocerus americanus	silk tube, lakes	shredder	<7 - >7	> 50	upper Meso
Limnephilus spp.	case variable, omnipresent, lakes, streams	omnivorous	≤7 - >7	25 - 100	None
Molanna blenda	tube case with lateral flanges, lakes, streams	shredder, gatherer, piercer	≤ 7	> 50	lower Oligo
Mystacides sepulchralis	tube of sand, plant material, streams, lakes	gatherer, shredder	≤7 - >7	~ 100	Oligo
Neophylax spp.	tapered tube of sand, streams	scraper	> 7	~ 100	Oligo
Neureclipsis crespuscularis	trumpet-like net, streams	filter feeder, shredder, piercer	≤7 - >7	~ 100	Oligo
Oecetis spp.	tapered, curved tube, streams, lakes	piercer	≤7 - >7	> 50	lower Oligo
Phryganea cinerea	tapered cylinder of leaves in spiral, streams, lakes	shredder, piercer	≤7 - >7	> 50	lower Meso
Phylocentropus placidus	silk tube, headwater streams	filter feeder	~ 7	~ 100	Oligo
Polycentropus cinereus	silk tube, streams	piercer, filter feeder, shredder	5 - >7	> 50	upper Meso
Psychomyia flavida	sac-like nets, streams	gatherer, scraper	<7 - >7	~ 100	Oligo
Rhyacophila spp.	free-living, streams	piercer, gatherer, shredder	<7 - >7	~ 100	Oligo

Order Lepidoptera (Aquatic butterflies and moths)

(cf. Chapter VIII):

Lepidoptera (butterflies and moths) are closely related to Trichoptera, having diverged from the Trichoptera probably in the early Mesozoic. Like their terrestrial counterparts, aquatic caterpillars are strictly herbivorous.

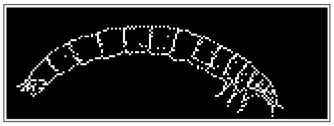
One species, *Petrophila jaliscalis,* is considered an indicator of eutrophic conditions; it can tolerate low oxygen conditions, moderately high temperatures, reduced water flows and enrichment (Mackie, 1998).

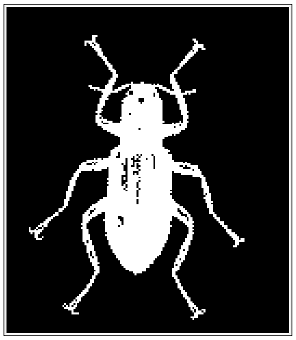
Order Coleoptera (Beetles)

(cf. Chapter IX):

Most larval and adult beetles are tolerant of wide changes in pH and dissolved oxygen concentration. Many adults cannot use dissolved oxygen and must rise to the surface to respire atmospheric oxygen. Few beetles, if any, are recognized as indicator organisms of environmental health. Their main indicator value is in the physical type of habitat they utilize. (Mackie, 1998)

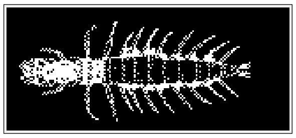
Family Elmidae (Riffle Beetle)





- Both adults and larvae are commonly encountered. Adults are considered better indicators of water quality because they have been subjected to water quality conditions over a longer period. (Kellogg, 1994)

Order Megaloptera (Hellgrammites, Alderflies, Dobsonflies, Fishflies)



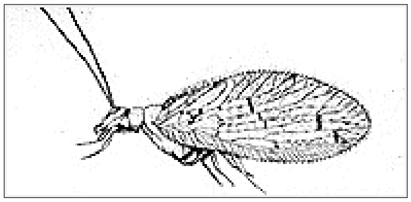
(cf. Chapter X):

Larvae of all species of Megaloptera are aquatic and attain the largest size of all aquatic insects. Larval Corydalidae are sometimes called **hellgrammites** or toe biters. The adult Corydalidae are large, having a wing span of up to 16 cm (Megaloptera = “large wing”). Corydalids (fishflies and dobsonflies) are found in well-oxygenated streams and lakes, as well as in productive ponds or swamps where dissolved oxygen may be very low. Sialids (alderflies) occur in the same broad habitat categories, but usually require muddy or silty deposits and accumulated detritus. (Williams & Feltmate, 1992; Kellogg, 1994)

All are intolerant of pollution. Although they do commonly occur in waters with pH levels near 5.5, circumneutral or alkaline waters seem to have the largest populations. *Sialis* is considered to be more tolerant than the corydalids but cannot tolerate extreme conditions either. No species are recognized as good indicator organisms. (Mackie, 1998)

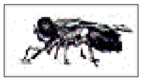
Order Aquatic Neuroptera (Spongillaflies, lace wings)

(cf. Chapter XI):



Sisyrid larvae live exclusively in association with freshwater sponges, either on the surface or in the body cavities of their hosts. They are classified as climbers, clingers, or burrowers. While the habitat of freshwater sponges and, thus, of sisyrids, ranges from cool, clean lakes and streams to relatively polluted ponds, the former is more typical. (Pennak, 1978)

Only 2 genera occur, *Climacia* and *Sisyra*. Their life cycle is similar to the megalopterans. Neither has indicator value. (Mackie, 1998)

Order Diptera (Two-winged or true flies) 

(cf. Chapter XII):

Dipteran larvae occur in almost every conceivable aquatic habitat, from the bracts of pitcher plants (Culicidae: *Wyeomyia*), tree holes (e.g., Chironomidae and Culicidae), saturated soil, and mud puddles, to streams, ponds, large lakes, rivers, and even the marine rocky intertidal zone. Some 32 families of Diptera contain species whose larvae are either aquatic or semiaquatic. Aquatic dipterans represent some of the best known insect forms, including mosquitoes, black flies, midges, crane flies and horse flies, many of which are the most troublesome of all insect pests, particularly in terms of human health and economics. Despite this, many groups of aquatic Diptera play pivotal roles in the processing of food energy in aquatic environments and in supporting populations of fishes and waterfowl.

Family Chironomidae (midges 

(Williams & Feltmate, 1992; Hutchinson, 1993; Wetzel, 1983)
(cf. Chapter XIII):

- The separation of the Diptera, as potential or actual inhabitants of deep water, from the other orders of immature aquatic insects is justified by the fact that an elaborate classification of lake types has been built upon the ecology of the deep-water Chironomidae (true midges) and their associated organisms. The question as to why, among all the aquatic insects with gills, this family of Diptera has alone significantly exploited the depths of lakes is of considerable interest. The generally small size, at least in the lacustrine Diptera, is doubtless important in this invasion.
- The midge larvae found on the shelf and in the deep water of a lake differ in appearance to their smaller pale coloured cousins found in the shallow water. These are generally large larvae (>1/2 inch) that are red coloured, hence the term **“blood worm”.** The red colour is due to the presence of hemoglobin that stores oxygen. This allows them to live in areas that have limited oxygen conditions such as lake bottoms or areas of high organic pollution. The oxygen is exchanged across the cuticle and some forms have tubular gills extending ventrally near the caudal end. These tube makers create a current in their tubes by undulating the body so that water passes through the tube. Lakes that have higher oxygen levels in the hypolimnion (oligotrophic-mesotrophic lakes) often contain large populations of midge larvae.
  - The benthos of the deep water (= hypolimnion) is dictated by the presence and duration of oxygen. The bottom fauna will be reduced or absent in lakes where the deep water looses oxygen for the duration of summer stagnation, or in winter.
  - A mesotrophic system with a stable thermocline in the summer months looses most of its oxygen for a time during stagnation but not for the entire period. The bottom fauna may be limited to a few non-biting midge larvae (*Chironomus* sp.), a biting midge (*Palpomyia* sp.) and a phantom midge (*Chaoboruss punctipennis*).

Family Chaoboridae (phantom midge)

(cf. Chapter XVII):

- In addition to the chironomid larvae, oligochaetes, and the small clam *Pisidium*, another major component of the profundal zone of lakes is the phantom midge *Chaoborus*.

Table II-21: Some physiological and ecological tolerances and requirements of common dipteran larvae. (Mackie, 1998)

Species	General Habitat	Feeding	pH	Oxygen %	Trophic Level
Family Deuterophlebiidae *Deuterophlebia* spp.	clingers on rocks in mountain streams	scraper	<7 - >7	100	Oligo
Family Blephariceridae Blepharicera *spp.*	clingers in streams	scraper	<7 - >7	100	Oligo
Family Tipulidae *Antocha saxicola*	clingers in silk tubes in streams	scraper	> 7	~ 100	Oligo
Family Psychodidae *Psychoda alternata*	burrowers in lakes, streams	gatherer	5.5 - ~7	50-100	Meso
Family Athericidae *Atherix variegata*	erosional streams	piercer	6 - >7	~ 100	lower Oligo
Family Syrphidae *Eristalis tenax*	burrow in organic bottoms of streams, lakes	gatherer	<7 - >7	< 25	Eutro
Family Scathophagidae *Spaziphora* spp.	sewage ponds	scraper	<7 - >7	< 25	Eutro
Family Simuliidae *Simulium* spp.	erosional streams or wave swept shore of lakes	filter feeder	<7 - >7	~ 100	Oligo
Prosimulium spp.	erosional streams	filter feeder	<7 - >7	~ 100	Oligo
Family Chironomidae *Ablabesmyia* spp.	streams, lakes	piercer	<7 - >7	25-100	Eutro
Chironomus plumosus attenuatus, riparius	burrowers in tubes in streams, lakes	gatherer, shredder	<7 - >7	25-100	Eutro
Cricotopus exilis	on rocks in streams	piercer	> 8	25-100	Eutro
Cricotopus bicinctus	streams, lakes	shredder	> 7	25-100	Eutro
Cryptochironomus fulvus	burrower, streams, lakes	piercer	<7 - >7	25-100	Eutro
Dicrotendipes spp.	burrowers, lakes, streams	gatherer, filter feeder, scraper	> 7	25-100	Eutro
Polypedilum fallax	clinger, streams	shredder, gatherer, piercer	≥ 7	25-100	Eutro
Procladius culiciformis	streams, lakes	piercer		25-100	Eutro
Rheocricotopus robacki	erosional streams	gatherer, shredder, piercer	<7 - >7	25-100	Indifferent
Rheopelopia	erosional streams	piercer	<7 - >7	100	Oligo
Rheotanytarsus exiguus	in tube or net, fast streams	filter feeder	<7 - >7	< 50	Eutro
Tanypus punctipennis	lakes	piercer	> 7	25-100	Eutro

Superphylum Arthropoda, Phylum Entoma, Subphylum Chelicerata (Williams & Feltmate, 1992; Thorp & Covich, 1991)

Class Arachnida, Subclass Acari (Peckarsky et al., 1990)

Order Acariformes, Suborder Prostigmata (=suborder Trombidiformes, =suborder Actinedida)

Subcohort Hydrachnidia (=Hydrachnida, =Hydracarina, =Hydrachnellae)-(True water mites)

(cf. Chapter XXI):

Water mites are among the most abundant and diverse benthic arthropods in many habitats. One square metre of substratum from littoral weed beds in eutrophic lakes may contain as many as 2000 deutonymphs and adults representing up to 75 species in 25 or more genera. Comparable samples from an equivalent area of substratum in rocky riffles of streams often yield over 5000 individuals of more than 50 species in over 30 genera (including both benthic and hyporheic forms). Mites have coevolved with some of the dominant insect groups in freshwater ecosystems, especially nematocerous Diptera, and interact intimately with these insects at all stages of their life histories. (Smith & Cook in Thorp & Covich, 1991).

Species of water mites are specialized to exploit narrow ranges of physical and chemical regimes, as well as the particular biologic attributes of the organisms they parasitize and prey upon. Preliminary studies of physicochemical and pollution ecology of the relatively well-known fauna of Europe have demonstrated that water mites are excellent indicators of habitat quality. The results of these studies, along with observations in sampling a wide variety of habitats in North America and elsewhere, lead to the conclusion that water mite diversity is dramatically reduced in habitats that have been degraded by chemical pollution or physical disturbance. (Smith & Cook in Thorp & Covich, 1991).

Superphylum Arthropoda, Phylum Entoma, Subphylum Crustacea (Williams & Feltmate, 1992; Thorp & Covich, 1991)

(cf. Chapter XXII):

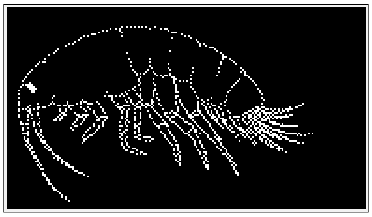
(Thorp & Covich, 1991) Nearly 4000 species of crustaceans inhabit freshwaters around the world, occupying a great diversity of habitats and feeding niches. Within pelagic and littoral zones, water fleas and copepods are the principal macrozooplankton, and benthic littoral areas shelter vast numbers of seed shrimps, scuds, and other crustaceans. An omnivorous feeding habit is typical of crustaceans, although there are many strict herbivores, carnivores, and detritivores. Members of the subphylum Crustacea are characterized by a head with paired mandibular jaws, a pair of maxillae, and two pairs of antennae. Their appendages are often biramous.

Class Malacostraca

Representatives of four groups of malocostracean crustaceans can form major components of the benthic fauna of some fresh waters.

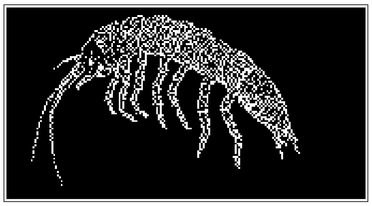
Subclass Eumalacostraca, Superorder Peracarida

Order Amphipoda (Scuds or side swimmers)



- Scuds are most commonly found associated with aquatic vegetation. Scuds are sometimes confused with sowbugs, but scuds are higher than they are wide and swim rapidly on their sides, while sowbugs have flattened, oblong shaped bodies and crawl slowly along surfaces. (Kellogg, 1994)
- Hyalella Azteca is so ubiquitous and abundant that their absence in considered a reliable indicator of lake acidification. They can tolerate pH’s down to 6.5, at which point they begin to disappear. Diporeia hoyi is found only in deep, cold, oligotrophic lakes. However, their preference for deep waters appears to depend upon their requirement for cold water because they have been found in profundal zones with less than 7% oxygen saturation. (Mackie, 1998)

Order Isopoda (Aquatic Sowbugs)



- Large numbers of sowbugs (also known as pillbugs) are often an indication of organic enrichment. Sowbugs are sometimes confused with scuds, but sowbugs are wider than they are high and walk slowly along surfaces. (Kellogg, 1994)
- Although the order is often considered an indicator of moderate enrichment or subpollution, only certain species, such as *C. communis* and *C. racovitzai,* can be considered such. (Mackie, 1998)

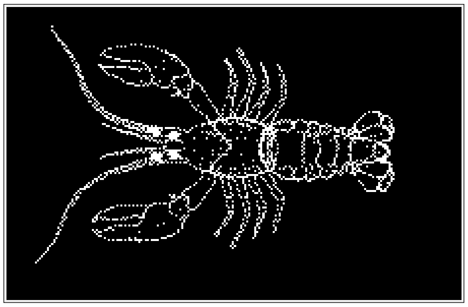
Order Mysidacea (Opossum Shrimps) (Mackie, 1998)

- They are almost exclusively marine except for a few species that are native to deep, cold oligotrophic lakes, such as the Great Lakes and the Finger Lakes of New York State.
- When lake productivity is high, the mysid life cycle is 1 to 2 years in duration; when productivity or temperature are low, mysids may require up to 4 years to complete their life cycle.

Subclass Eumalacostraca, Superorder Eucarida (Williams & Feltmate, 1992, and Thorp & Covich, 1991)

Order Decapoda (Shrimps, Crabs, etc.)

Family Cambaridae (Crayfish)



- Most species live for approximately 2 years although certain species may live up to 6 or 7 years. (Kellogg, 1994)

Family Palaemonidae (Freshwater Shrimp)

- Although infrequently encountered in riffle areas of streams, freshwater shrimp may be common in slow moving brackish or freshwater streams coastal or lowland areas. (Kellogg, 1994)

Class Branchiopoda, Order Cladocera (Water Fleas) (Mackie, 1998)

Holopedium gibberum is characteristic of acidifying lakes and waters low in calcium.

Class Ostracoda (Wetzel, 1983)

The ostracods are small, bivalved crustaceans usually less than 1 mm in size, which are widespread in nearly all aquatic habitats. Ostracod densities increase in more productive lakes (to >50,000/sq.metre).

Phylum Mollusca (Mackie, 1998)

The molluscs are represented in freshwater by only two classes, Gastropoda (the snails and limpets) and Bivalvia (the clams and mussels). All freshwater molluscs have a shell made of calcium carbonate. The shell is secreted by a mantel. All freshwater molluscs move by a muscular foot. The foot extends out of the shell by blood rushing into the foot and filling the numerous spaces within. It is a creeping organ in gastropods but a burrowing organ in bivalves.

The snails and limpets are exclusively grazers, feeding on attached algae, or herbivores feeding on leaf and stem tissues of macrophytes. The clams and mussels are exclusively filter feeders. The clams and mussels are exclusively filter feeders. Some bivalves also deposit feed, that is use cilia on their foot to take up detritus, algae, bacteria and other food deposited on the sediments.

Class Gastropoda (Snails and Limpets)

(cf. Chapter XXIII):

(Hutchinson, 1993; Kellogg, 1994)

Snails possess a single shell that is usually coiled, although sometimes flattened and cone shaped. It is important to distinguish whether the snail is gilled (prosobranch) or has lungs (pulmonate) for respiration. Gilled snails have a hard plate-like cover over the shell opening (operculum), and identification may be assisted by the position of the shell opening. It is important to make sure the snail is alive (someone is at home) before counting it on a survey form. The life cycle is long, 1 to 4 years and productivity is relatively low.

Because prosobranchs depend on oxygen dissolved in the water for respiration, they are intolerant of sites where dissolved oxygen is scarce, such as sites of organic pollution. They also are absent from temporary waters. Gilled snail characteristics include:

- An operculum or plate-like door that protects the opening of the shell and can be quickly closed to avoid predators.
- Coiled shells that usually open on the right-hand side (dextral).

In many pulmonates the mantle cavity may be filled either with air or with water, so that the mantle wall can work either as a lung or as a gill**.** The general greater abundance of pulmonates in eutrophic water is probably connected with productive waters being more susceptible to high respiratory loss of oxygen and the resulting low oxygen concentrations in the water. Traits that determine pouch, pond or other groups of snails (pulmonate) include:

- No plate-like covering over the shell opening.
- Has shell that spirals with opening usually on your left side (if tip is pointed upward and opening is facing you), or shell that is coiled in one plane, or shell that is dome or hat shaped with no coils.

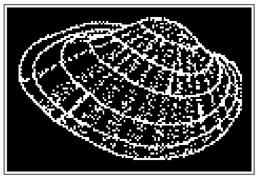
(Mackie, 1998) Considerable research has been done on the ecological and physiological tolerances and requirements of gastropods. Pulmonates tend to be more tolerant than prosobranchs of enrichment because pulmonates can rise to the surface to obtain oxygen when the dissolved oxygen supply is depleted. Most physids are known to tolerate anoxia for a short period of time but they, like all gastropods, need water well saturated with oxygen for proper development of eggs. Similarly, many prosobranchs, like some pleurocerids and viviparids, can tolerate near-anoxia, but only for short periods of time.

⇒ Few, if any, gastropods are good trophic indicators because most prevail in the littoral and sublittoral zones. In these zones conditions can range from barely tolerable to optimal. For example, oxygen concentrations, nutrient levels, pH, alkalinity, light penetration, water currents and other chemical and physical factors vary hourly, daily, and seasonally, as well as with depth and distance from shore. (Mackie, 1998)

⇒ The best trophic indicators tend to be those in the deeper waters, like the profundal zone, where conditions are somewhat predictable before and after thermal stratification occurs. (Mackie, 1998)

⇒ *Bythinia tentaculata,* or faucet snail, is an introduced species and in Europe it is commonly associated with enriched waters, clogging pipelines, some often coming through taps, hence its common name. But in North America it seems to prefer clean, sandy sediments. (Mackie, 1998)

Class Bivalvia (Pelecypoda) (Clams and Mussels)



(cf. Chapter XXIV)

(Mackie, 1998) There are two families of bivalves native to North America, the **Sphaeriidae** (fingernail clams) and the **Unionidae** (freshwater pearly mussels), and two families that were introduced from Europe, the **Corbiculidae** (Asian clams) and the **Dreissenidae** (zebra and quagga mussels). All bivalves are filter-feeding organisms.

- The Asian clam is a warm water species and cannot survive waters that freeze. They are common in enriched waters and can tolerate water with as little as 50% oxygen saturation, but not for prolonged periods. (Mackie, 1998)
- Fingernail clams are closely related to the Asian clams. There are four genera, but only three, *Sphaerium, Musculium and Pisidium,* are common. Most species of *Musculium* can be found in temporary aquatic habitats. Most *Sphaerium* species are large, about 8 to 20 mm; *Pisidium* species are the smallest, most ranging in shell length from about 2 to 6 mm; and most *Musculium* species are intermediate in size, about 8 to 10 mm in shell length, and the shells are thin and fragile. (Mackie, 1998)
    - One species, *Musculium transversum,* is an enrichment indicator, reaching its largest densities in organically enriched waters that may have as little as 25% oxygen saturation. (Mackie, 1998)
    - Most other fingernail clams require clean water with high oxygen tensions. In fact, some fingernail clams are oligotrophic indicators. While most fingernail clams are not assigned to any indicator group, they seem to be most abundant in sandy bottoms and waters with atleast 75% oxygen saturation. (Mackie, 1998)
    - *Sphaerium nitidum* and *Pisidium conventus* reach their greatest densities in the profundal zones of oligotrophic lakes or in the shallow waters of lakes in high northern latitudes. (Mackie 1998)
    - Some, like *Sphaerium simile, Sphaerium striatinum, Pisidium casertanum, Pisidium compressum,* and *Pisidium adamsi* are abundant in organic sediments but the waters are usually well saturated with oxygen, as in many river and stream environments. (Mackie 1998)
- The most familiar bivalves are the freshwater pearly mussels. Most species are large (30-150 mm), but some may grow to nearly 250 mm in shell length.
- Zebra mussels were first discovered in 1988 in Lake St. Clair but probably first arrived in 1985. Quagga mussels were first discovered in 1990 in Lake Ontario but probably first arrived in 1988 or 1989. (Mackie 1998)

- Because of the quagga mussels' ability to reproduce in cooler waters and survive in soft substrates, they will be found in deeper, colder waters of deep lakes and occur further north than zebra mussels. (Mackie 1998)
- Conversely, zebra mussels will probably prevail on hard substrates in the shallow waters of lakes and will be the main species in the southern United States where water temperatures are warmer than found at higher latitudes. (Mackie 1998)
- But both species will cause the same kinds of problems. Because zebra mussels are so prolific in numbers and are so efficient at filtering the water, there has been a noticeable increase in the clarity of water in the Great Lakes since their arrival in 1985. For example, the Secchi depth in Lake Erie had increased from about 1.5 m to about 3.5 m in the eight years that the mussels have been in the Great Lakes. The water clarity is suspected to have a profound impact on larval species of fish that feed upon the plankton. This includes several zooplankton species, larval species of fish that feed upon the zooplankton, and planktivorous adult fish. (Mackie 1998)

This group includes clams and mussels which typically occur in most freshwater habitats and may be particularly abundant in certain streams. Although the clams and mussels have a wide range of tolerances to pollution with some species being very sensitive to water quality, habitat and biological conditions, a number of species of this group (especially clams) can tolerate somewhat degraded conditions. (Peckarsky et al., 1990)

Mussels have larval stages that are parasitic on specific fish species and are dependent on this host fish species for dispersal within aquatic systems. As a result, problems such as barriers to fish movement, or the reactions of mussels or host fish species to environmental conditions may cause complex and variable responses in mussel populations. Because of their long life span and sensitivity to environmental change, most species of mussels are good indicators of water quality.

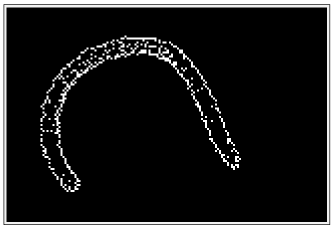
"Dead" clams or mussels (empty shells) do not accurately reflect water quality because shells can persist for long periods regardless of water conditions. The life is long, 1 to 15 years in clams, and productivity is relatively low. (Kellogg, 1994)

Phylum Annelida (The True Worms) (Mackie, 1998)

Freshwaters have five classes of annelids. The most primitive of these are the tube worms of the class Polychaeta with only a few species present in fresh waters. The class Oligochaeta (Chapter XXV), or aquatic earthworms, is well represented in freshwater systems. The leeches and blood suckers of the class Hirudinea (Chapter XXVI) are entirely freshwater in habit. The remaining two classes are specialized in habitats and not discussed here. All annelids have internal segmentation where each segment is isolated from the other. The first segment, called the prostomium, may or may not bear eyes and tentacles. Some classes (e.g. Hirudinea) lack setae and move by using suckers or by swimming.

Class Oligochaeta (Aquatic Worms)

(cf. Chapter XXV)



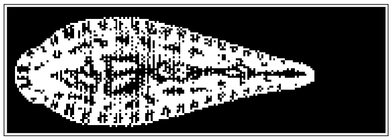
Of the freshwater annelids, the oligochaetes display the greatest diversity and have the greatest indicator value. The two families, Naididae and Tubificidae form 80 to 100% of the annelid communities in the benthos of most streams and lakes at all trophic levels. (Mackie, 1998).

Oligochaetes are common in most freshwater habitats, but they are often ignored by freshwater biologists because they are thought to be extraordinarily difficult to identify. The extensive taxonomic work done since 1960 by Brinkhurst and others, however, has enabled routine identification of most of our freshwater oligochaetes from simple whole mounts. Some aquatic worms closely resemble terrestrial earthworms while others can be much narrower or thread-like. (Peckarsky et al., 1990)

- Oligochaete worms are diverse, and occur in a spectrum of fresh waters, from unproductive to extremely eutrophic lakes and rivers.
- As lakes become organically polluted and dissolved oxygen concentrations become reduced or are eliminated, an abundance of tubificid oligochaetes is commonly found concomitant with a precipitous reduction and exclusion of most other benthic animals. As long as some oxygen is periodically available, and toxic products of anaerobic sedimentary metabolism do not accumulate, the rich food supply and freedom from competing benthic animals and predators permit rapid growth.
- Oligochaete densities can be very large (many thousands per sq.m.). Productivity can vary greatly from year to year because of changes in mortality associated with population dynamics of major long-lived predators (e.g. chironomid midge larvae).

- The tubificids are gatherers, feeding on detritus in the sediments. They are the only worms present in the deepest regions of lakes and are represented by several indicator species. (Mackie, 1998).
    - ⇒ The classical “pollution indicators” are *Tubifex tubifex* and *Limnodrilus hoffmeisteri.* Both species are able to survive periods of anoxia, such as occurs in the hypolimnia of eutrophic lakes during the summer and winter months. Most tubificids have erythrocruorin, a red blood pigment, that effectively extracts oxygen dissolved in the water. The densities of *T. tubifex* and *L. hoffmeisteri* in sewage lagoons may be so high that the bottom appears pink. (Mackie, 1998)
    - ⇒ Though, not all tubificids are pollution indicators. Some species, such as *Tubifex kessleri* and *Peloscolex variegatum,* require well oxygenated waters and reach their greatest densities in oligotrophic lakes. (Mackie, 1998)

Class Hirudinea (Leeches and Bloodsuckers)



(cf. Chapter XXVI)

Leeches are most common in warm, protected shallows where there is little disturbance from currents. Free-living leeches avoid light and generally hide and are active or inactive under stones or other inanimate objects, among aquatic plants, or in detritus. Some species are most active at night. Very rarely are leeches which attach to humans encountered in fast moving water or riffle areas. Many are scavengers or feed on other invertebrates. They are carnivorous, feeding mostly on insects, molluscs and oligochaetes, or scavengers, feeding on dead animal matter.

- Silted substrates are unsuitable for leeches because they cannot attach. Leeches are usually rare in calcium-poor waters. The cannot tolerate high turbidity loading as well. Some species can tolerate mild pollution. (Kellogg, 1994; Mackie, 1998)
- The suckers located at both ends are used for attachment, feeding and locomotion.
- Leech abundance is highly variable, but generally increases in more productive fresh waters.
- Most species are found in waters with $pH>7.0$ and a total alkalinity >60 mg $CaCO_3$/L. Only the highly tolerant indicator species, such as *H. stagnalis* and *C. complanata,* are found in waters with $pH<6.0$.

⇒ Indeed, the tolerance of leeches to many chemicals makes it difficult to discourage their presence by bathers. (Mackie, 1998)

Class Polychaeta (Freshwater Tube Worms) (Mackie, 1998)

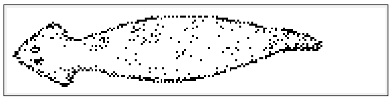
The polychaetes are commonly represented in freshwaters mainly by a single species, *Manayunkia speciosa.* This species is found mainly in fine silty or sandy sediments in oligotrophic and mesotrophic lakes and large rivers. Little is known of its ecological tolerances and requirements, although Mackie and Quadri found it only in water that was atleast 60% saturated with oxygen and the sediments contained silt and sand with little or no organic material. The species is a filter feeder.

Phylum Platyhelminthes (The Flatworms)

The turbellarian flatworms are the only important free-living and truly benthic members of the Platyhelminthes in freshwaters.

Class Turbellaria (Flatworms or Planarians/Dugesia) (Mackie, 1998)

(cf. Chapter XXVII)



Most turbellarians are detritivores, feeding on dead particulate organic material, or zoophagous, feeding on small living or moribund invertebrates (protists, rotifers, nematodes).

  - They tend to be associated more with mesotrophic and eutrophic bodies of water where detritus and decaying animal matter is abundant.
  - Many species are diagnostic of peculiar types of habitats. *Pseudophaenocora sulfophila* is found only in sulphur springs where oxygen saturation rarely exceeds 5 to 40% whereas *Polycelis coronata* is found only in cold, well oxygenated streams.
  - Most turbellarians require atleast 70% oxygen saturation.
  - Even the diversity of parasitic flatworms has some value in assessing environmental quality.

Phylum Nematoda (Roundworms) (Mackie, 1998)

The nematodes have a greater degree of body organization than do the flatworms in that round-worms have a body cavity and a complete digestive system. Nematode worms are mainly a parasitic group, with only a few free living forms. Most are 0.5-1.0 cm long, less than 0.1 mm diameter.

Free-living nematodes are widely distributed in fresh waters and can constitute a significant component of the benthic fauna. Highest densities are commonly found in littoral substrata of productive lakes. (Wetzel, 1983)

- (Mackie, 1998)
  - Little is known about the relationship between the abundance and diversity of free-living forms of roundworms and the trophic status or health of the aquatic environment.
  - However, the diversity of parasitic forms can be an index of environmental quality. The parasitic forms are found in many host species at most trophic levels of an aquatic community.
  - Many studies, particularly in the Great Lakes, have shown that acceleration of pollution, such as eutrophication, by man decreases the diversity of intermediate and final hosts of parasites, as well as the diversity of the parasites themselves. The species of intermediate hosts which do survive increase in abundance, and the parasites respond with increases in both incidence (percentage of individuals that are parasitized) and intensity (number of parasites in each host). Some parasite species disappear altogether.
    - With these concepts in mind, two occurrence scenarios are possible:
      - parasites are absent;
      - parasites are present but they are either less abundant or more abundant than prior to environmental degradation.

      ⇒ The absence of parasites usually indicates situations where lowered environmental quality has already occurred. Four examples are:
        - ∗ exploitation, environmental changes and introductions of new species of fish in Lake Erie resulted in the removal or de-

crease in abundance of whitefish which was followed by a decrease in fish parasite diversity;

        - ∗ waters polluted by acid mine wastes have a low diversity of benthic invertebrates and the low numbers of mollusc, crustacean and insect larvae resulted in the loss of larval sustenance, transfer and host contact of nematode parasites;
        - ∗ high pesticide levels in aquatic habitats eliminated many species of invertebrates and the parasites dependent upon them; and
        - ∗ when the mayfly, *Hexagenia limbata,* was eliminated from Lake Erie, species of nematode parasite, *Lanciomermis,* and digean trematodes dependent upon the mayfly as intermediate host, were also eliminated.
    - ⇒ An increase in abundance of parasites occurs when there are fewer host species remaining, but the survivors exhibit a huge increase in numbers. Pollution tolerant species of invertebrate and vertebrate host species have reduced competition and are allowed to increase in numbers. This increases the efficiency of transfer of parasites that utilize the same trophic relationship.
        - ∗ During the eutrophication process in Lake Erie, the increase in the cyclopoid copepod populations were followed by increases in planktivorous fishes, such as spot tail shiner, emerald shiner, as well as gizzard shad, alewife and rainbow trout. The latter three fish species were introduced during the eutrophication process. Two species of the nematode, *Philometra*, which uses cyclopoids as intermediate hosts, increased in prevalence during the same period. Other parasites also increased in prevalence.

Phylum Nematomorpha (The Horsehair Worms or Gordian Worms) (Mackie, 1998)

Because adult horsehair worms do not feed, they play a minor role in the ecology of benthic communities and are not considered of great importance in assessing water quality.

Phylum Bryozoa (Moss Animals) (Mackie, 1998; Wetzel, 1983)

The freshwater colonial bryozoan members of the primarily marine Ectoprocta are rarely of quantitative importance. These sessile forms, however, occasionally form massive colonies that can become conspicuous members of shallow eutrophic lakes and open areas of swamps for brief periods. (Wetzel, 1983)

No bryozoans are capable of tolerating pollution and their presence usually indicates good water quality with at least 50% oxygen saturation. Most are photonegative and develop best in shaded parts of the aquatic habitat. (Mackie, 1998)

Phylum Porifera (Freshwater sponges) (Mackie, 1998; Wetzel, 1983)

Freshwater sponges usually occur only in relatively clear, unproductive waters. They are rarely abundant, and their contribution to total benthic productivity is usually minor. (Wetzel, 1983)

Sponges are primarily a marine group. There is only one family of freshwater sponges, the Spongillidae, with about 30 species in North America. Sponges are mainly epibenthic. They lack a distinct body form but can be recognized immediately by their “garlic” odour. (Mackie, 1998)

- Most sponges are very sensitive to enrichment and pollution and their presence in large biomasses usually indicates good water quality.

- Two of the most common species are *Spongilla lacustris* and *Ephydatia fluviatilis* but, unfortunately, both grow in all kinds of habitats and are among the more tolerant species.
- *Ephydatia muelleri* and *Eunapius fragilis* are alkaline species occurring in clean waters with pH greater than 7.5.
- *Heteromeyenia tubisperma* is restricted to clean, running waters.

Phylum Protozoa (Wetzel, 1983)

Most freshwater Protozoa are attached to benthic substrata. Few protozoans tolerate low dissolved oxygen concentrations; most inhabit surficial sediments and migrate to shallower water when dissolved oxygen of deeper strata declines in stratified productive lakes. Many protozoan populations exhibit summer maxima. Little is known of natural protozoan productivity in fresh waters.

Profundal Lake Benthos

Quantitative Aspects

Benthologists have found that many lakes have a **concentration zone.** This is the depth at which the peak abundance and biomass of benthos occur. Usually the peak abundance occurs between the 2 and 4 metre depths but can go as deep as 7 metres. (Mackie, 1998)

Table II-22: Profundal macroinvertebrates with trophic status indicator value.

(Species are listed from primitive to most highly evolved forms in different phyla. The nomenclature for some phyla has been updated.)

Genus/species name	Common name	Taxon group	Function; Indicator value
Manayunkia speciosa	freshwater polychaete	Phylum Annelida Class Polychaeta	Filterer, gatherer; Oligotrophic indicator
Limnodrilus hoffmeisteri	sludge worm	Class Oligochaeta	Gatherer; Eutrophic indicator
Tubifex tubifex	sludge worm	Class Oligochaeta	Gatherer; Eutrophic indicator
Peloscolex variegatum	oligochaete	Class Oligochaeta	Gatherer; Oligotrophic indicator
Tubifex kessleri	oligochaete	Class Oligochaeta	Gatherer; Oligotrophic indicator
Sphaerium corneum	European fingernail clam	Phylum Mollusca Class Bivalvia	Filterer: Mesotrophic indicator
Sphaerium nitidum	Arctic-Alpine fingernail clam	Class Bivalvia	Filterer; Oligotrophic indicator
Pisidium conventus	Arctic-Alpine pea clam	Class Bivalvia	Filterer; Oligotrophic indicator
Caecodotea (Asellus) spp.	isopod	Superphylum Arthropoda Subphylum Crustacea Order Isopoda	Gatherer; Mesotrophic indicator
Diporeia hoyi	deep water amphipod	Order Amphipoda	Gatherer; Oligotrophic indicator
Mysis relicta	relict mysid	Order Mysidacea	Predator; Oligotrophic indicator
Chironomus plumosus (also ca. Table II-6)	blood worm	Superphylum Arthropoda Class Insecta Order Diptera Family Chironomidae	Gatherer; Eutrophic indicator
Hexagenia limbata	mayfly	Order Ephemeroptera	Predator; Oligotrophic indicator

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