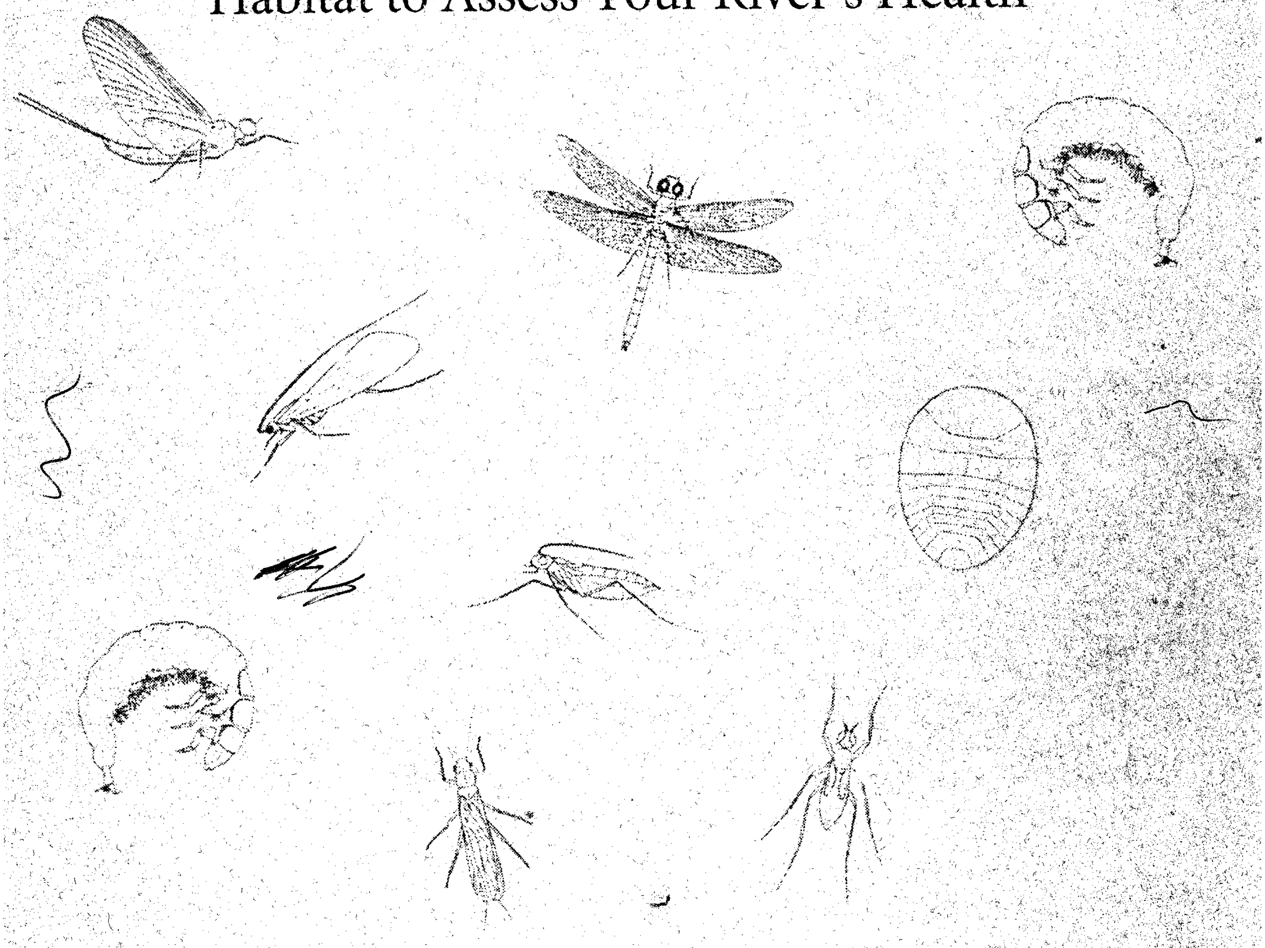
Living Waters

Using Benthic Macroinvertebrates and Habitat to Assess Your River's Health



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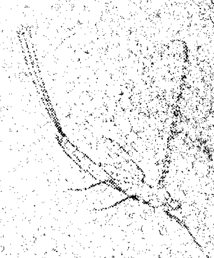


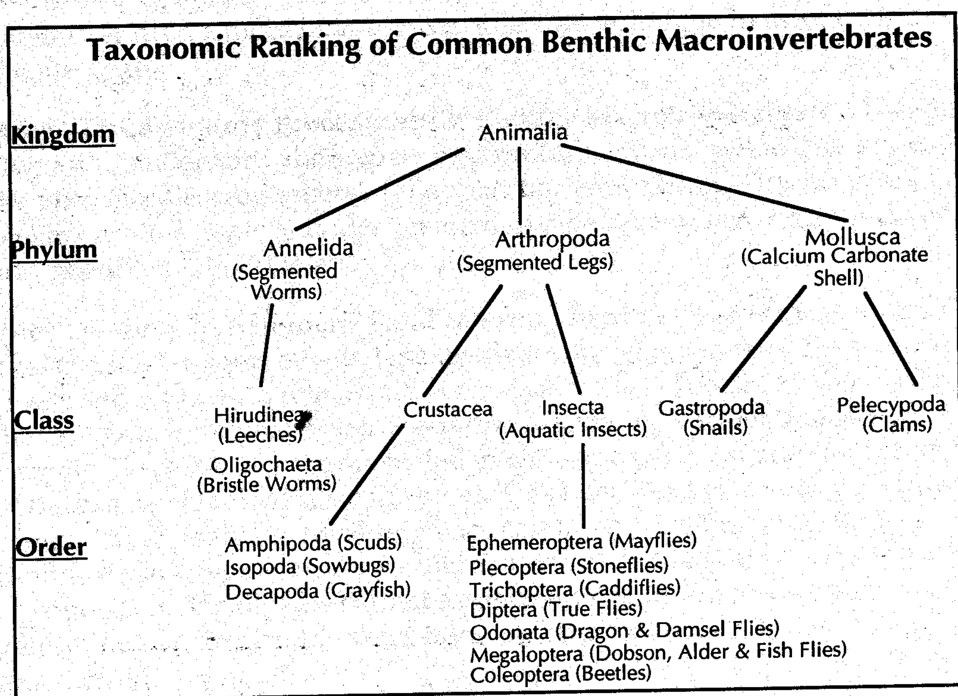
II. A CLOSER LOOK AT BENTHIC MACROINVERTEBRATES: THE ROLE THEY PLAY IN THE STREAM ECOSYSTEM

In Chapter I, we defined benthic macroinvertebrates as animals without backbones that live at least part of their life cycles at the bottom of a body of water. In this chapter, we'll take a closer look at these organisms and describe the role they play in the stream ecosystem.

A. WHERE BENTHIC MACROINVERTEBRATES FIT IN THE ANIMAL KINGDOM

All living things are grouped in a classification system, where they are arranged into groups known as *taxonomic ranks*. Taxonomic ranks include kingdom, phylum, class, order, family, genus, species.

Benthic macroinvertebrates are in the Kingdom Animalia -- the animals. The following diagram illustrates where the commonly-collected benthic macroinvertebrates fit in the classification system for the animal kingdom.



This classification system continues: within orders there are *families*, within families there are *genera*, and within genera there are *species*.

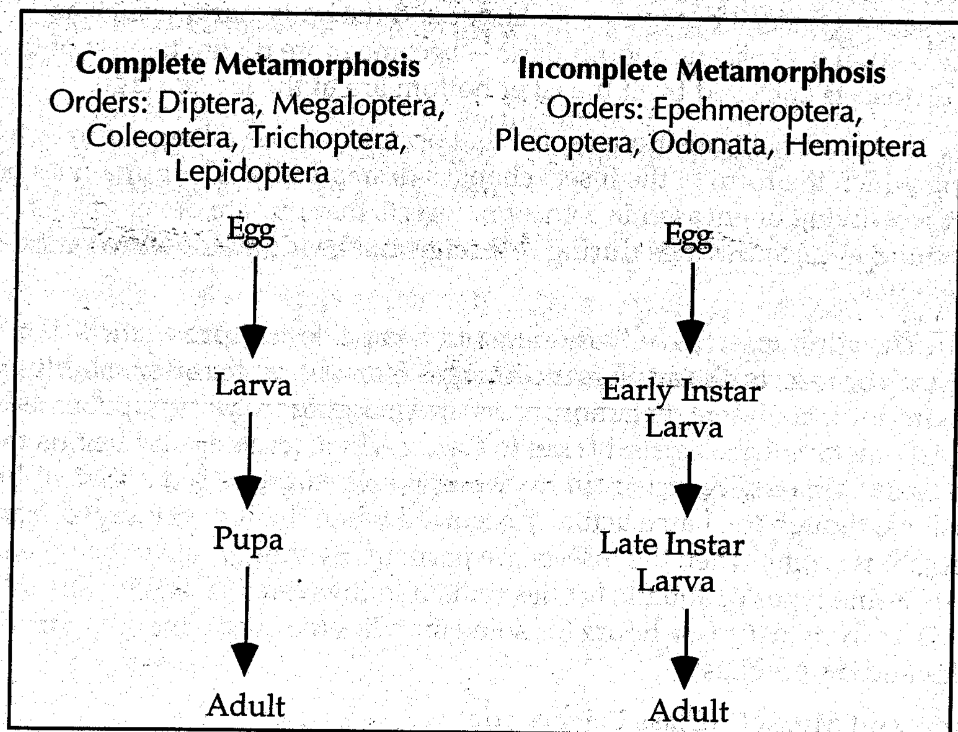
B. LIFE CYCLES OF BENTHIC MACROINVERTEBRATES

All living things go through a series of changes as they mature from birth to adulthood, when they are able to reproduce. This series of developmental stages from birth to sexual maturity is known as the *life cycle.*

Benthic macroinvertebrates include a wide range of organisms with different life cycles. In this section, the life cycles are described for the aquatic insects, clams and mussels, snails and limpets, segmented worms, and crustaceans.

<u>The Aquatic Insects (Class Insecta)</u>

Aquatic insects go through a series of changes in form -- from egg to adult -- known as *metamorphosis.* There are two kinds of metamorphosis: *complete* and *incomplete.* The stages in each are shown below:



The length of this cycle ranges from less than 2 weeks for some midges and mosquitoes to 4-5 years for some dobsonflies and dragonflies. Here's what happens during each stage:

1) **Egg:** The cycle begins when an adult female deposits her eggs in or on the water, on aquatic or overhanging vegetation, or even on other animals. The number of eggs laid varies from hundreds to thousands per female. The scientific term for the egg laying process is *oviposition.* This occurs in a variety of ingenious ways such as walking into the water and "gluing" them to rocks, dragging her abdomen in the water while in flight so the eggs are "washed" off, landing on vegetation and depositing the eggs, "injecting" the eggs into

soft wood or plant material, and others. The insect remains in the egg for a period of time that ranges from as short as a week to as long as a year, depending on the type of insect, and the temperature of the water.

2) **Larva:** The insect hatches from the egg as a tiny *larva* the first mobile life stage of the insect. At this point, it seeks out food and shelter. The larvae[1] have an outer covering called an *exoskeleton* . As the larva grows, the exoskeleton is shed and a new one reformed. The shed exoskeleton is known as a *cast skin.* You can sometimes find them on rocks, floating in the water, or in the samples you collect. The larval stage between sheddings of the exoskeleton is known as an *instar*. There may be as few as 3 or 4 or as many as 40 instars during the larval stage. The larval stage may last only a week (for small organisms such as some mosquitoes, biting midges, and black flies) or as long as 3 years for larger organisms such as dobsonflies and dragonflies. As the larva grows, it becomes both larger and the body parts -- such as wings, sexual organs, and mouth parts -- become more distinct. Most of the aquatic insects collected from the river bottom are in the larval stage.

3) **Pupa:** This is a brief transitional stage that occurs in more advanced insects, during which the form of the insect changes dramatically. The pupa may be either free-living or encased in a cocoon. Insects that pupate develop legs, compound eyes, and wings during this stage and bear little or no resemblance to the larvae.

4) **Adult:** The adult insect is fully formed and is capable of reproduction. For most aquatic insects, the adult form emerges from the water after shedding its last skin (for incomplete metamorphosis) or emerging from its pupal case (for complete metamorphosis) and takes to the air where it mates and begins the cycle again. This emergence from the water is sometimes called a "hatch" by fly fishers, though the hatch actually occurred when the larva emerged from the egg. It is a time when the insects are particularly vulnerable to being eaten by fish. Some types of aquatic beetles remain in the water as adults. The adult stage lasts from just a few hours for some mayflies to several months for some beetles and dragonflies.

<u>The Clams and Mussels (Class Pelecypoda)</u>

Clams and mussels also undergo a series of changes in form from egg to adult.

Fingernail Clams: The simplest transition is in the Fingernail Clams. These clams are self-fertilizing and the eggs are hatched inside the clam. The young are brooded there as well. They are released into the water as young free-living clams. Adults live 1 - 2 years.

Asian Clams: As the name implies, these organisms are not native to the U.S. These clams produce an intermediate form of larva, called a *veliger*, which is free-swimming and matures into an adult. Adults live 2 - 3 years.

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[1] The plural form of larva.

Pearly Mussels: The eggs are fertilized when the female draws in sperm-laden water through her siphon. She carries the eggs for a period of months and the larvae, called *glochidia*, are released into the water where they attach to fish or amphibians as parasites. They mature to adults while attached to the host. They drop off and live as adults for quite a long time, many for 20 years or more.

The Snails and Limpets (Class Gastropoda)

Snails and limpets hatch from eggs as small, fully-formed adults.

The Segmented Worms (Phylum Annelida)

Aquatic Earthworms (Class Oligochaeta) reproduce by fertilization (self-fertilization or exchanging sperm) or by budding. When fertilization occurs, the worm constructs a cocoon containing embryos and deposits them on rocks, vegetation or debris. The worms mature and emerge to live for 1 - 2 years. In budding, a part of the worm forms a bud, which grows into a new worm, which separates from the original.

Leeches (Class Hirudinea) reproduce by fertilization. A cocoon containing the embryos is deposited on the river bottom or along the shoreline. The worms mature and emerge to live for 2 - 15 years.

The Crustaceans (Class Crustacea)

Crayfish, scuds, and sowbugs hatch from eggs as small, fully formed organisms. However, their "skins" called *cuticles* do not stretch, so they go through a shedding process similar to aquatic insect larvae. As with the insects, the animal between sheddings is called an instar.

C. WHERE THEY LIVE: PHYSICAL HABITAT NICHES IN RIFFLES, RUNS, AND POOLS

Benthic macroinvertebrates need places to hang onto, places from which to collect food, and places that provide shelter. These places are known as *physical habitats.* This section describes the different habitats in rivers.

Rivers are high energy ecosystems. The flowing water is constantly changing the landscape carrying materials away from places where then current is fast (erosion) and depositing it in places where the current is slow.

Benthic macroinvertebrates exist in a wide range of locations in the river:

* Shallow, fast moving, rocky bottom areas known as *riffles.*
* Deeper, slower moving sandy and gravely bottom areas known as *runs.*
* And deep, slow moving muddy-bottom areas known as *pools.*

However, the number and diversity of organisms present varies considerably among these habitats.

Riffle areas contain a wide variety of current velocities -- fast rushing water, slower areas along the margin, *eddies* behind rocks, etc. For the most part, the water is flowing relatively rapidly and carries smaller particles (like silt, sand and small gravel) downstream. This leaves behind a bottom consisting primarily of larger particles (rocks and gravel), though smaller particles like coarse sand and small gravel may be left in the slower sections of the riffle. The larger particles provide a variety of living spaces, stable conditions (since they don't move) and large surface areas to hang onto. Food is carried in by the current in the water column, deposited on the bottom, and grows on the rocks. Since riffles contain a wide variety of surfaces for macroinvertebrates to hang onto, current conditions, food sources, and living spaces, the contain a wide variety of macroinvertebrates.

Run areas generally are deeper and slower moving. This leaves smaller particles (like sand and gravel) on the river bottom, creating a more uniform habitat. This does not provide the same diversity of living spaces and surfaces to hang onto as in riffle areas. Nor is the habitat as stable: higher flows in the spring and after storm events may be capable of moving the sand and gravel, and any organisms living there, downstream. Food is carried in by the current in the water column, deposited on the bottom, and may also grows on the bottom if the water is shallow enough so sunlight can penetrate to the river bottom. Since runs are not as stable and do not contain the variety of surfaces to hang onto, current conditions, food sources, and living spaces as riffles, they contain a smaller variety of macroinvertebrates.

Pool areas are deep and slow-moving. This makes for a uniform bottom of smaller particle sizes like sands and silts. These materials provide very limited living spaces and surfaces for macroinvertebrates to hang onto. Further, sand

and silt, and the organisms living there, are easily swept downstream by runoff events. So these habitats get periodically scoured, and then deposition fills them in again. This shifting habitat limits the types of organisms that can live there. Food may be limited to that deposited on the river bottom or suspended in the water column. In deeper pools, light may not penetrate to the river bottom, so plants (a food source and living surface) don't grow there. Pools support a very limited variety of organisms compared to riffles.

D. PHYSICAL ADAPTATIONS OF BENTHIC MACROINVERTEBRATES

The focus of this manual is the collection of benthic macroinvertebrates in relatively fast-moving water. Living in this environment is a challenge. So benthic macroinvertebrates have developed certain body characteristics that enable them to thrive in this challenging environment. Here are some examples:

Flattened Bodies: Some organisms have developed a flattened profile. This allows them to live in the small crevices as well as the relatively still boundary layer close to the surface of rocks and the bottom. Examples are water pennies and mayflies in the family Heptageniidae.

Hooks and Grapples: Well developed claws on the legs and on posterior prolegs enable these organisms to strongly attach to surfaces both to maintain position and as an aid in moving around. Examples include the leg claws on the insects and the well-developed posterior proleg claws on the net-spinning and free-living caddisflies.

Small Size: As with flattened bodies, small size enables organisms to live in the relatively still boundary layer close to the surface of rocks and the bottom.

Sticky Secretions: Many bottom-dwelling critters use sticky secretions to attach themselves to the bottom. Examples include black flies, caddisflies, and midges.

Streamlining: Streamlined bodies offer the least resistance to moving water and, like fish, a few benthic macroinvertebrates have adopted this shape and are good swimmers. An example are mayflies in the family Baetidae.

Other adaptations include reduction in body projections, friction pads and suckers, and the use of large sand grains and small stones for ballast.

E. BEHAVIORAL ADAPTATIONS OF BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrate behavior has also been adapted to life in moving water. This behavior relates to the way they move about or maintain themselves in the current:

Clingers hold themselves to the bottom in strong flowing water by using claws, attachment disks or flattened profiles.

Sprawlers crawl about on river bottoms of rocks, sand, woody debris, or leaf packs.

Climbers commonly live on aquatic plant stems, roots, filamentous algae, or mosses in slower water.

Burrowers dig into soft sand or silt bottoms or live in spaces between larger sand grains and gravel.

Floaters can live at or near the water surface or at various depths in slower water.

Swimmers have streamlined bodies and often possess oar-like legs and swimming hairs.

Skaters do not break the surface film of the water.

Jumpers use a spring-like structure on their abdomen to jump off the water.

Riffle habitats tend to contain clingers, sprawlers, burrowers, and swimmers. The other behavior groups tend to occur in pool habitats.

F. River Characteristics That Affect the Benthic Macroinvertebrate Community

The previous two sections have described how benthic macroinvertebrates meet the challenge of living in moving water and getting food in rivers. This section will briefly describe the physical, chemical, and biological characteristics of the river ecosystem and describe how these change upstream to downstream.

Physical River Characteristics That Affect Benthic Macroinvertebrates

The physical characteristics of the river form the foundation for the benthic macroinvertebrate community. These characteristics combine to determine the riffle, run and pool habitat types described above. Some of the important physical characteristics that affect benthic macroinvertebrates are:

Current Velocity: This refers to how fast, in feet per second, the water is moving at the collection site. Riffle areas with current velocities between 0.5 and 2.5 feet per second support the most diverse communities.

Bottom Composition: The river bottom is made up of different materials: bedrock, boulder (>10″), rubble (2 - 10″), gravel (0.1 - 2″), sand (<0.1″), silt, and organic debris (logs, sticks, leaves, etc.). These materials provide space for the critters to attach to, feed from, or crawl on. In riffle habitats, the material providing the best habitat for macroinvertebrates is a combination of rubble and gravel, with cobble predominating.

Elevation: The height above sea level determines how far the river drops from source to mouth. This affects a number of other characteristics such as gradient, temperature, and shading.

Gradient: The slope of the river determines the current velocity and bottom composition.

Flow: The amount of water in the river channel determines the amount of the bottom covered with water.

Depth: The depth of the river affects whether light can penetrate to the river bottom and cause plants to grow.

Water Clarity: The clarity of the water affects the depth to which light can penetrate and stimulate biological activity.

Shading: The shade provided by trees and other vegetation helps moderate stream temperatures in the summer and provides food for stream animals.

Temperature: Some macroinvertebrates are very sensitive to temperature levels and fluctuations. It also affects the amount of oxygen that the water can hold (cold water can hold more than warm water) and make available to macroinvertebrates and fish.

The Watershed: The river's watershed is like a long, skinny sink, that tilts toward the ocean. The sides of the sink form the watershed. Unlike a sink, however, the watershed is made up of soil and vegetation. Water falling in the watershed travels a complex route through soils, underground, and over the surface. As it travels over the surface, it can pick up soil particles, debris and other materials that can wind up in the river, affecting water clarity and water chemistry. The river channel is the trough that holds the water. It's made up of soil and rock tha the water flows over and around. Vegetation along the river helps hold soil in place, provide shade which moderates the temperature of the water in the summer, and is a food source for aquatic organisms. Changes in the character of the watershed (paving large areas, for example) and river channel (dams and rip rap, for example) will affect the river. The watershed and the river channel are the physical foundation for the river system.

Chemical River Characteristics That Affect Benthic Macroinvertebrates

The river is also a very complex chemical "soup" within which life exists in the river. Water chemistry is affected by the chemistry of rain and snow falling in the watershed and by the geology of the watershed itself. It's also affected by the organisms in the water and by human activities in the water and in the watershed. A few of the river's chemical characteristics that affect benthic macroinvertebrates are:

pH: The acidity of the water is measured on a scale from 0 - 14 pH units. Acidity determines the rate of many bio-chemical reactions in the river. Extreme conditions can be toxic to aquatic life.

Alkalinity: The river can neutralize acid from precipitation or discharges. Rivers with low alkalinity are subject to dramatic fluctuations in pH, which disrupt aquatic life.

Dissolved Oxygen (DO): Water contains oxygen in dissolved form. Oxygen is added to the water through turbulence, through gas exchange at the water's surface, and as a by-product of plant photosynthesis. Oxygen is removed from the water by chemical oxidation, respiration by aquatic animals, and decomposition. Also, cold water can hold more oxygen than warm water, so temperature is a factor. The balance between these factors determines the DO level in the water. Some aquatic life requires high and stable levels in order to flourish. Low DO levels can indicate pollution.

Nutrients: (phosphorus and nitrogen Phosphorus and nitrogen are essential plant and animal nutrients that, in excess amounts, can cause rapid increases in biological activity of certain organisms. This may disrupt the ecological integrity of the stream. It's also an indicator of sewage, animal manure, fertilizer, and other types of contamination. In most streams, phosphorus is the nutrient in short supply, so that relatively small amounts can cause impacts.

Biological River Characteristics That Affect Benthic Macroinvertebrates

The river is a living community of organisms in a complex web of interrelationships that are focused on getting food, getting oxygen or getting sunlight. Food comes from river side vegetation, smaller living organisms, or dead and decaying organic material flowing downstream. Oxygen comes from the water mixing with the air and from plants that produce oxygen as a by-product of photosynthesis. Sunlight comes from above. The amount that reaches the organisms that need it depends on the shading provided by river side vegetation, and the depth and clarity of the water through which the light must travel.

A few of the river's biological characteristics that affect benthic macroinvertebrates are:

In-stream Versus Riparian Food Production: The amount of living plant material produced in the stream versus that which drops in from the area along the stream. In stream production is partly dependent on the availability of sunlight and partly on the availability of nutrients. Some types of food produced in the stream, like algae, are important food and habitat sources for some benthic macroinvertebrates. Other benthic macroinvertebrates feed primarily on leaves and other food that drops into the stream.

Respiration: The amount of oxygen consumed by animals breathing in the stream. In rivers with a high density of aquatic animals, respiration can deplete the dissolved oxygen in the water.

Food Source:

CPOM: Coarse particulate organic material consisting of organic particles greater than 1 mm in diameter. Examples: leaf litter & dead animals

FPOM: Fine particulate organic material consisting of organic particles less than 1 mm in diameter. Examples: decomposed leaf litter & animal tissue.

G. CHARACTERISTICS OF THE BENTHIC MACROINVERTEBRATE COMMUNITY

Benthic macroinvertebrate surveys measure a number of characteristics of the community. Each of these tells us something about the condition of the river:

Abundance: the number of organisms present. Nutrient and food enriched streams will usually have a greater abundance of benthic macroinvertebrates. Both toxicity and physical habitat degradation (silt or sand erosion) will usually decrease the abundance.

Diversity the number of different types of organisms present. Usually the greater the number of types, the healthier the stream. However, some pristine headwater streams may be naturally low in diversity, due to a relative lack of food (quantity and different types) and the small habitat areas. In these areas, an increase in diversity may mean pollution from organic material (from failing septic systems, for example).

Composition: the types of organisms that make up the community. In general, the mayflies, stoneflies, and caddisflies should be well-represented. If any of these groups are absent, it indicates that there may be a problem. As a group, stoneflies are the most sensitive to pollution from sewage and other organic material. They usually make up a relatively small percentage of the sample (5-10%) and are usually the first to disappear from the stream. If they are not present, stream quality may be moderately degraded. Mayflies contain many taxa that are sensitive to pollution. They usually make up a significant percent of the sample (20-40%) and are usually the next to disappear. If neither mayflies nor stoneflies are present, the stream is probably moderately to seriously degraded. Caddisflies contain many taxa that are sensitive to pollution, but also one common taxon (certain genera within the family Hydropsychidae) which is tolerant to pollution. It is very rare to find a sample with no caddisflies -- usually the Hydopshycidae caddisflies will be present even in seriously degraded streams. If the sample is dominated (>50%) by worms or midges, the stream is probably seriously degraded.

Functional Feeding Groups: groups of organisms that share a common feeding strategy and food source.

Shredders feed on large pieces of organic matter such as leaves and other plant parts that fall into the river,

Collectors feed on small bits of organic matter (less than 1 mm in size) either by filtering them from the passing water (*filtering collectors*) or gathering from the stream bottom (*gathering collectors*),

Scrapers/grazers remove and feed on algae attached to rocks or log surfaces in the current,

Predators capture and feed on other animals in the river.

Functional feeding groups are useful in determining the food sources in a river. Since human activities affect these food sources, the functional feeding groups present can indicate impacts. For example, if all functional feeding groups are well-represented this indicates a diversity of food sources -- fine particulate organic matter in the water column, growth of small algal communities on rocks, coarse particulate organic on the bottom, etc. If collectors dominate, it may indicate an overload of organic material in the water column or settled on the river bottom. If filtering collectors dominate, it means that this material is fine particles -- well decomposed sewage, manure, or processed coarser material from upstream. If Gathering collectors dominate, it could mean that poorly decomposed sewage or animal manure or other organic material from upstream is deposited on the bottom.

Pollution Tolerance: the tolerance of organisms to organic matter and nutrients. With increases in pollution from sources of organic material like sewage or animal manure, the types of organisms in the stream usually shift from intolerant taxa (like stoneflies) to tolerant taxa (like worms and midges).