MACROINVERTEBRATE ECOLOGY

MARYLAND STATE ENVIROTHON

Macroinvertebrate Ecology

Invertebrates are animals that do not have an internal skeleton of cartilage or bone.[1] For the Maryland Envirothon Aquatics Issue, we will concern ourselves with only the aquatic macroinvertebrates (can be seen with the naked eye) that are found in Maryland's freshwater streams. The purpose of this document is to give you a brief overview of macroinvertebrate anatomy, behavior, and ecology. You will also learn how to use macroinvertebrates as an indicator of water quality. It is strongly recommended that you visit a nearby stream, collect some insects, and practice identifying them in the field. You should also know what your samples tell you about the quality of water in your stream.

Why are they important?

Macroinvertebrates play an important role in the ecosystem of which they are a part. Not only do they serve as food for fish, amphibians, and water birds, they are also involved in the breakdown of organic matter and nutrients.

Freshwater macroinvertebrates are used to assess the "health" of a stream. Taking samples of *all aquatic life stages* of macroinvertebrates can serve as an indicator of the water quality for several reasons:

- Some are sensitive *(intolerant)* to pollution, habitat changes, and severe natural events, while others are more tolerant;
- Many live in the water for over a year;
- They are generally sessile – they cannot escape pollution like fish and birds;
- They are easy to collect.

The biological evaluation of water quality is linked to the number of pollution-tolerant organisms compared to the number of *pollution intolerant* ones. If a survey of the stream yielded a *higher proportion* of pollution tolerant macroinvertebrates and no sensitive ones, that *could* indicate poor water *or habitat* quality index. A more favorable water quality index would be characterized by finding sensitive organisms as well as tolerant organisms. An index such as this is more useful when data is gathered over the long term and trends can be analyzed. The Macroinvertebrate Assessment Form is one sample of how you might assess the water quality of your stream using macroinvertebrates.

Two methods commonly used for evaluating water quality are *indicator organisms* and *diversity indices*. The *indicator organisms* method is based on the fact that every species has a certain range of physical and chemical conditions in which it can survive. Some organisms can survive in a wide range of conditions and can "tolerate" more pollution. Other organisms are very sensitive to changes in water conditions and cannot tolerate pollution. Examples of intolerant organisms are mayflies, stoneflies, and some caddisflies (members of the Ephemeroptera, Plecoptera, and Trichoptera orders, respectively). Examples of some pollution-tolerant organisms

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[1] Voshell,Jr., J. Reese. *A Guide to Freshwater Invertebrates of North America*. Mc Donald & Woodward Publishing Co. Blacksburg, VA. 2002.

include leeches, aquatic worms, and some midge *(Diptera)* larva. Water quality is evaluated by comparing the number of tolerant organisms to the number of intolerant organisms. A large number of pollution-tolerant organisms and few intolerant organisms may indicate poor water and/or habitat quality. However, remember that pollution-tolerant organisms can also be found in a wide range of conditions, including pollution-free environments.

Diversity refers to the number of different kinds of organisms found in a biological community. In general, communities with a high diversity are more stable. Pollution and/or frequent habitat disturbance can eliminate intolerant species, and therefore reduce diversity. So if an area becomes polluted, the total number of organisms may stay the same, but diversity may decrease.

Macroinvertebrate classification

An astounding 95% of over a million species in the world are invertebrates. About 900,000 insects have been identified, and scientists believe there may be an equivalent number still to be identified.[2] A classification scheme is necessary to keep track of them all. Organisms are classified into groups of similar organisms that can be distinguished from other groups of organisms. The main categories of the groups used for classifying are: kingdom, phylum, class, order, family, genus, and species. These categories are hierarchical. Below is an example of the classification system for the common housefly:

- Kingdom: Animalia (animals)
  - Phylum: Arthropoda (arthropods)
    - Class: Hexapoda (hexapods)
      - Subclass: Insecta (insects)
        - Order: Diptera (true flies)
          - Family: Muscidae (muscid flies)
            - Genus: Musca
              - Species: domestica

Figure 1. Classification scheme for the common housefly.

Adaptations for Aquatic Habitats

Most insects that land on water are trapped by the water surface tension, and tiny ones can even drown inside a water droplet, unable to break out of the bubble surface. Aquatic insects cope by having waterproofed skin so large amounts of fresh water do not diffuse into the body. Many are covered with a water-repellent waxy layer. They also usually have hairy or waxy legs, which repel water so they don't get trapped by the water surface tension. Many of these insects are strong swimmers or crawlers as nymphs or larvae and as adults can also fly, although the degree to which they use their

[2] Ibid.

ability to fly varies quite a bit. Water Boatmen are the only aquatic beetles that can take off from the water - without having to crawl out of the water first.

Aquatic insects have some other useful adaptations to help them live in aquatic environments:

<u>Life cycles</u>

Insects either go through complete metamorphosis or incomplete metamorphosis. Incomplete metamorphosis has three main stages: egg, nymph, and adult.

- Egg - A female insect lays eggs. These eggs are often covered by an egg case, which protects the eggs and holds them together.
- Nymph - The eggs hatch into nymphs. Nymphs looks like small adults, but usually don't have wings. Nymphs shed or molt their exoskeletons (outer casings made up of a hard substance called chitin) and replace them with larger ones several times as they grow. Most nymphs molt 4-8 times.
- Adult - The insects stop molting when they reach their adult size. By this time, they have also grown wings.

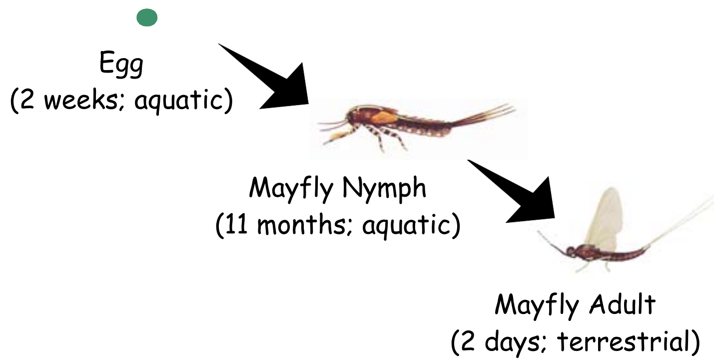

Figure 2. Incomplete metamorphosis.

Most insects go through complete metamorphosis. Complete metamorphosis has 4 stages:

- Egg - A female insects lays eggs.
- Larva - Larvae hatch from the eggs. They do not look like adult insects. They usually have a worm-like shape, but many have legs in the larval form. Caterpillars, maggots, and grubs are all just the larval stages of insects. Larvae molt their skin several times as they grow slightly larger.
- Pupa - Larvae make cocoons around themselves. Larvae don't eat while they're inside their cocoons. Their bodies develop into an adult shape with wings, legs, internal organs, etc. This change takes anywhere from 4 days to many months.
- Adult - Inside the cocoon, the larvae change into adults. After a period of time, the adult breaks out of the cocoon.

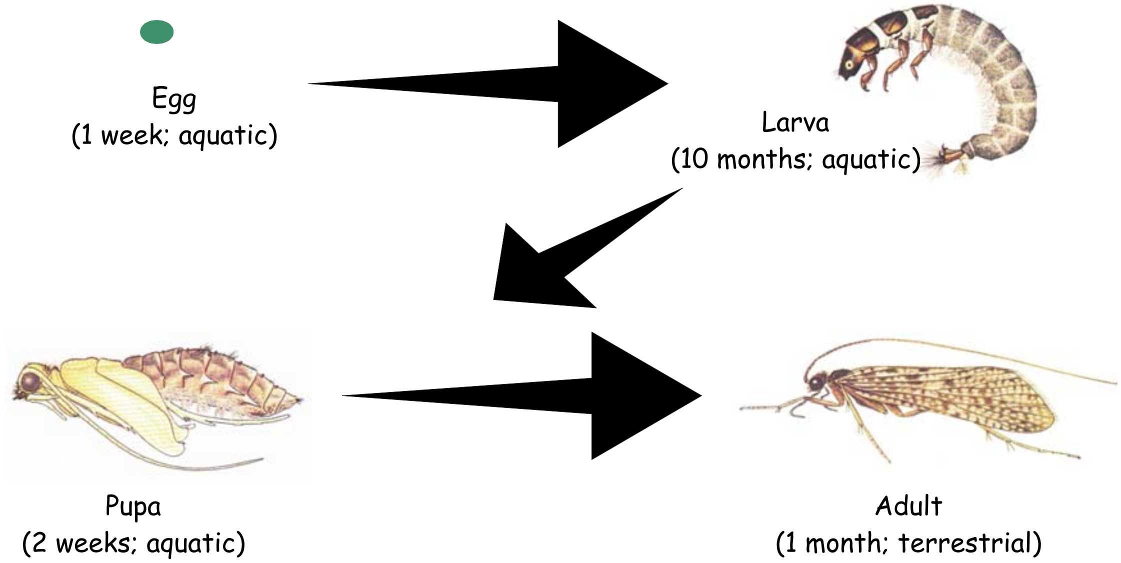

Figure 3. Complete life cycle of a caddisfly

Life cycles for aquatic insects may be very short or very long. For example, a mosquito has a life cycle of two weeks, while some hellgrammites take 4 or 5 years to complete one life cycle. There are three types of life cycles in a temperate stream:

Slow season life cycle. This may occur in cooler streams. The insects grow during fall and winter while feeding on leaf detritus. Pupae and adults will emerge from late winter to early summer. Examples of slow season life cycle insects include some mayflies, stoneflies, and caddisflies.

Fast season life cycle. A fast season life cycle is where the growth of the immature is fast after a long egg or larval diapause. They may stay in the egg stage from August to March, the larvae stage from March to May/June, and become an adult in June or July. An example of a fast season life cycle insect includes some caddisflies.

Nonseasonal life cycle. These are individuals where several stage or sizes are present in all seasons. An example would be hellgrammites.

<u>Breathing underwater</u>

Water is much heavier than air and there is much more oxygen in air (20%) than in the water. So, in order to extract oxygen from water, an insect will have to process a lot of water to get a sufficient amount of oxygen. That is probably one reason why adult aquatic insects continue to breathe air instead of developing gills. Usually only aquatic insect larvae develop gills to absorb oxygen from the water.

Aquatic insects have some fascinating adaptations for breathing under water:

Snorkel with a breathing tube. Mosquito larva and water scorpions use breathing tubes. The end of the tube usually has bristles to break the water surface tension and keep the tube open. This method, however, doesn't allow the insect to travel far from the water surface.

Scuba tank. Some aquatic insects create an "air tank" for greater freedom of movement underwater. There are two types of air tanks: One type, used by a water beetle, uses a **skin of air** that is trapped by hairs on the body or under the wing covers. The insect breathes the air in the bubble through the holes in its abdomen (spiracles) just like other insects. A second type, called a **diving bell** is used by the water spider. The Water Spider (*Argyroneta aquatica*) is not an insect, but is adapted very well to aquatic conditions. It lives underwater by creating an underwater air chamber. It gathers a small bubble of air from the surface on its hairy hind legs, then releases it into a silken web woven among water weeds. The bubble allows the insect to absorb oxygen directly from the water. As the insect uses up the oxygen in the bubble, dissolved oxygen in the water diffuses into the bubble so the insect can actually get more oxygen than was originally in the bubble. However, nitrogen must be present for this to happen. The nitrogen provides stability to the bubble (it diffuses more slowly into water than other gases). The spider goes back to the surface to replenish nitrogen rather than to get fresh oxygen. The spider mates and lays eggs inside this chamber. Baby spiders leave the chamber and find new ponds by ballooning--trailing silken strands in the wind, which allows it to fly!

Figure 4. Water Spider

<u>Walking on water</u>

Skates. Some aquatic insects skate on the water surface by distributing their body weight over long, thin, waterproof legs. They paddle with the middle pair of legs, steer with the hind legs and use the short front legs to attack and hold prey.

Jet skis. The Camphor Beetle (*Stenus*) also skates on the water surface. When alarmed, it releases a chemical from its back legs that reduces the water surface tension. In this way, the water surface tension on the front pulls it forwards. It shoots forwards on its front feet which are held out like skis, and steers itself by flexing its abdomen. This tiny beetle is the size of a rice grain but can travel nearly 1m a second this way! It doesn't hunt on water, but at the water's edge, and saves this trick to escape predators.

<u>Other aquatic adaptations</u>

Ripple effect: Most aquatic insects are sensitive to water ripples to detect predators or prey. Some even create their own ripples on the water surface and process the returning "echoes" to detect prey.

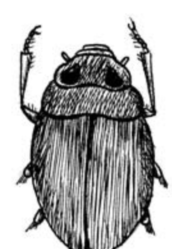

Figure 5. Whirligig beetle.

Many, such as the whirligig beetle, also create ripples to find mates and communicate with each other.

Double vision: The Whirligig Beetle has eyes divided horizontally to see both under and above water.

Oars: Many aquatic insects paddle underwater with oar-like legs. These legs are long, flattened and fringed. The hairy fringes spread out on the power stroke increasing the surface area, and bend in on the return stroke to reduce water resistance. An example would include the water beetle and the water boatman. These insects usually have flattened streamlined bodies or are torpedo-shaped.

Insect anatomy

Insects have 3 major parts to their anatomy: head, thorax, and abdomen. The head contains the eyes, antennae and mouthparts. Insects use the antennae to smell and touch things. The thorax has three segments, with one pair of legs on each and usually two pairs of wings (or wing pads). Adult insects and many larvae or nymphs have six segmented legs. Often, the last segment has a small claw that helps them cling to rocks, leaves, and other debris. Sometimes, gills can be found on the thorax as noted on the stonefly nymph in Figure 6. The abdomen contains the tail of the insect. Gills may also be found on the abdomen as noted on the caddisfly nymph in Figure 6. The abdomen can have up to 11 segments.

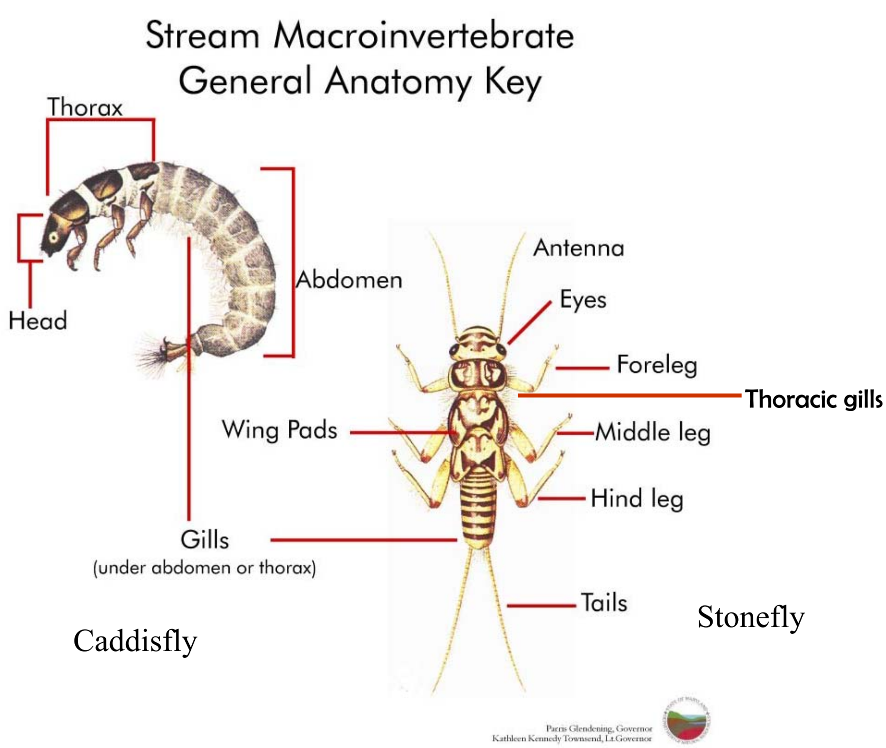

Figure 6. Insect Anatomy

The benthic community

The distribution and abundance of aquatic organisms in a benthic community involve many factors. Some of the major physical factors that determine what species are found in particular areas are:

1. Water temperature
2. Volume and velocity of water flow (discharge)
3. Substrates
4. Energy relationships

Think of the Potomac River and how much it changes from its headwaters to where it discharges into the Chesapeake Bay – It begins as a spring in the mountains and flows through wooded, farm, and urban areas; the substrate changes from cobbles at the headwaters to fine sand near the Bay.

Let's look at each of those physical factors that influence the benthic community in more detail:

Water temperature: Daily and seasonal patterns of temperature fluctuation affect an organism's metabolism, growth, and reproduction. Warmer temperatures usually increase metabolism, while colder temperatures have the opposite effect. The emergence of many aquatic insects is influenced by water temperature. Usually, warmer temperatures lead to earlier emergence. Life cycles are adapted to water temperatures. For example, eggs may hatch when temperatures reach a certain level in the spring. But, shredder insects will hatch in the fall, when there is a lot of leaf litter, so they can take advantage of the abundance of food.

Volume and velocity of water flow (discharge): Currents help shape river ecosystems. Aquatic invertebrates rely on the current to bring nutrients down from upstream, and flush wastes downstream. The current is fastest just below the surface, and slowest on the top and along the bottom (due to friction with the air and substrate). The land surrounding the area influences discharge. If an area can absorb heavy rainfalls, then discharge can be relatively stable. If, however, a river is surrounded by impervious surfaces, such as concrete parking lots or streets, discharge can be very erratic and high (and temperatures can be warm). As water flows over rocks, a protective boundary layer, about 1-4 mm thick, is formed where the velocity of the current falls dramatically. A flattened body shape allows the insect to live in this boundary layer and not be carried away by the current.

Substrates: Substrates provide sources of food and shelter for macroinvertebrates. Degradation of the substrate can be devastating to a macroinvertebrate community even when water quality remains good. Rocks, rubble, and sand offer different types of niches for aquatic insects in fast flowing streams. Leaf litter, algae, and aquatic plants provide suitable habitat for macro-invertebrates in slow moving streams. Macroinvertebrates have developed adaptations to live in these environments. For example, some caddisfly larva use pieces of the surrounding substrate to build cases of stones, leaves or twigs. Stonefly larvae have sharp claws that allow them to hold to and crawl on the bottom of fast flowing streams. Downstream, and in large pools, as the current decreases the substrate becomes siltier -- less mixing and more organic nutrients decrease dissolved oxygen levels. Organisms in this type of habitat generally create tube burrows to mine for food, search for prey, or seek protection. While the majority of the macroinvertebrates living in this environment would be considered pollution tolerant (worms, snails, midge larvae etc.) there are exceptions to the rule. Some mayflies, which are not tolerant of low oxygen levels, can survive in these areas by burrowing a u-shaped tunnel. The mayfly then creates a current by beating its large feathery gills, brining in fresh oxygen.

Energy relationships: The headwaters of a river are very important to the overall health of the entire river, because this is the source of food and nutrients carried downriver. In forested areas, leaves and wood from overhanging trees and shrubs provide food energy. Consequently, you will find many collectors and shredders in these types of areas. In areas not shaded by trees and shrubs, such as prairies, deserts, and mountains, algae and aquatic plants are the main source of energy. You will find that grazers dominate this type of environment. As the river widens and deepens, sunlight is a limiting factor. Rooted vascular plants may grow along the shoreline and algae may grow on rocks. Collector organisms will be found in this area, filtering out particles suspended in the water and gathering fine particles that have settled to the bottom.

Sampling methods

Scientists use several types of methods to sample macroinvertebrates. You should be familiar with these methods and the tools they use.

Using a D-Frame Net
Note: This method is suited for qualitative sampling, has the advantage of being potentially a one-person job, and is good for any type of substrate.

1. Standing facing downstream, hold the net upright with the bag resting on the bottom and open upstream.
2. Shuffle your feet vigorously along the bottom while moving sideways across the stream, keeping the net in front of you to catch dislodged organisms.
3. In soft substrates, repeatedly run the net along the bottom, washing excess mud and organic material from the net.
4. Transfer collected organisms to a wide-mouth jar containing 70% ethanol, or sort and release.

Using a Kick-seine
Note: This method is suited for qualitative sampling works best when three people team together, and is good for any type of substrate.

1. Select a fast-moving area of the stream at least 3 ½ inches deep.
2. Two people are to position the kick-seine downstream of the riffle, making sure the bottom edge fits tightly across the substrate. (Use rocks to hold it down if necessary.)
3. The third person is to disturb a 3-foot × 3-foot area of the stream bottom directly upstream of the kick-seine. This involves brushing all rock surfaces to dislodge insects and stirring up the bed with your hands and feet.
4. For 60 seconds, kick the streambed with a sideways motion toward the net to bring up ground-dwellers.
5. Remove the seine with a forwards scooping motion, trying not to allow any insects from being washed off the surface of the net.
6. Place the net on a flat, light-colored area and use tweezers to remove all specimens to the collecting jar.

Figure 7. Kick Seine

Using a Surber Stream-bottom Sampler
Note: This method is for quantitative and qualitative sampling, and can be a one or two person operation in the stream.

1. Select a riffle no deeper than the frame of the Surber sampler.
2. Wade to the site from downstream and position the sampler firmly on the bottom with the mouth facing upstream.
3. Pick up all rocks from within the frame and while holding them in front of the net bag dislodge and remove insects using a stiff bristled nail or vegetable brush,and/or your fingers. Place scrubbed stones outside of sampler frame.
4. Use a trowel or your hand to stir up the remaining substrate to a depth of several inches and float organisms into the net.
5. Remove the Surber sampler from the stream and transfer the organisms to the collecting jar, turning the net inside out to remove any clinging animals.
6. Replace the rocks into the sampled area of the streambed.

Figure 8. Surber sampler.

When and where to sample

Ideally, macro-invertebrate sampling should occur at least once in each season to allow for seasonal changes in the fauna. At a minimum, sampling should occur twice a year, with recommended times being spring and autumn. Autumn sampling will collect larger specimens of insects that emerge during summer, making them easier to identify and will show the macro-invertebrate fauna during a period of lower flows and higher temperatures, when pollution inputs may have a greater impact.

Macro-invertebrate sampling is most useful for comparisons between local sites, or a series of different times at a single site. This is because macro-invertebrate numbers and variety will probably differ not only between streams but also between different sections of the same stream. For example, the variety in a stony upland forest stream will probably be greater than that in lowland silty streams, partly because the stony stream has a greater diversity of habitat.

Comparisons between sampling sites need to take into account differences between moving and still water habitats, the position in the catchment (whether upper, middle or lower catchment), the time of year samples were taken and the fact that various groups of macro-invertebrates within an Order may have differing sensitivity or tolerance levels to salt, pesticides, heavy metals etc. Approach your sampling site from downstream to avoid disruption at the sampling location before you are ready to collect. Samples should be collected from the best available habitat at a sampling site. For mountain, piedmont, and some coastal plain streams, this would be a riffle area. In streams without riffles, the best habitat would include areas of fast(er) current that flow over large woody debris (logs, branches, etc), along root mats at a bank, and in areas with submerged or emergent vegetation. Avoid sampling in pools or other deep slow water.

Sort your samples at the site by picking live organisms. But if you have to leave before you can sort them - because of time, bad weather or other constraints - take your samples back to your work base in buckets of water to make sure they stay alive.

Applying what you have learned

Now that you have a basic understanding of macroinvertebrate ecology, you should take the time to get out in the field and practice what you have learned. Here are some suggested activities (be sure you follow appropriate safety procedures when working in or near the water – always have an adult with you, never go alone, and always let someone know where you are going!):

Measuring velocity:

1. Measure 20 meters along the stream.
2. Position someone upstream and someone downstream.
3. Release an orange (or any small object of neutral buoyancy – mostly full plastic bottle, wet sponge) into the main current.
4. Have someone time (in seconds) the passage of the orange from the beginning to the end of the marked length.
5. Record your results. Repeat this 3 times and take an average. Your velocity should be in meters/second.

- What types of macroinvertebrates did you find?

- How would you expect the population to differ in a faster moving current? A slower moving current?
- How do your macroinvertebrate samples differ upstream from downstream? Along the bank versus the center of the stream?

Calculating discharge: Discharge is the volume of water passing a certain point over a certain period of time. The following formula is called the Embody Float Method, where the "float" can be an object that floats just beneath the surface and is not influenced by the wind (such as an orange):

$$D = \frac{WZAL}{T}$$

D=discharge
W=average width of stream
Z=average depth
L=length of stream measured
T=time for float to travel length L
A=a constant:
(0.9 for sandy/muddy bottoms)
(0.8 for gravel/rock bottoms)

Shredder experiment: Collect leaves from one or more types of trees, shrubs, or grasses growing along a stream. Air-dry the leaves for one week. Place 5-10 grams of leaves in a mesh bag. Secure the bag to the shore with a string and place the bag in the water. Let it sit for 3-4 weeks. Count the number of shredders on the leaves and release them back into the water. Take the leaves back to your work area, dry and weigh them. Vary the experiment by using different types of leaves or placing the bags in different areas of the stream.

- How does the type of substrate influence the type of insect found on it?
- Do you find different insects in different parts of the stream?
- How might the results change if you tried this experiment in the spring? Summer? Fall?

Resources

Edelstein, Karen. *Pond and Stream Safari: A Guide to the Ecology of Aquatic Invertebrates.* 4-H Leader's Guide 147L24. A Cornell Cooperative Extension Publication.

Mitchell, Mark K. and William B. Stapp. *Field Manual for Water Quality Monitoring: An Environmental Education Program for Schools.* Eleventh Edition. Kendall/Hunt Publishing Company. 1996.

Voshell, J. Reese, Jr. *A Guide to Common Freshwater Invertebrates of North America.* The McDonald and Woodward Publishing Company. Blacksburg, VA. 2002.