Virginia Water Central

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Excerpt from the April-June 2002 issue:
"Bottom Dwellers Tell Stories about the Water Above": a Science Behind the News introduction to biomonitoring with benthic macroinvertebrates.

The excerpt begins on the following page.

Virginia Tech

VIRGINIA POLYTECHNIC INSTITUTE
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Bottom-dwellers Tell Stories about the Water Above

"Storm Water, Sewage Spill in Sugar Creek"

"A manhole overflowed Monday [Oct. 11, 1999] at a Charlotte [N.C.] sewage plant, spilling an estimated 100,000 gallons of storm water and sewage…At least some of the overflow…reached a storm drain that feeds into [Sugar Creek]. No fish kills were reported, utilities officials said."

—*Charlotte Observer*, Oct. 12, 1999

No doubt about it—dead fish are a bad sign. A fish kill in a stream, lake, or other water body obviously indicates that something's wrong. Assessing the impact of a water-pollution event, such as the one in Charlotte noted above, by the visible impacts on fish is a straight-forward example of an aquatic **biological assessment**. Aquatic biological assessment, or simply aquatic bioassessment, is defined by the U. S. EPA as "an evaluation of the condition of a waterbody using biological surveys and other direct measurements of the resident biota [living organisms] in surface waters."[1] The term **biomonitoring** is often used interchangeably with bioassessment.[2]

Bioassessment uses the responses of living organisms to indicate environmental conditions, such as water quality or the availability of suitable aquatic habitat. Fish clearly provide important signs about aquatic conditions. But, because fish can swim away from an unsuitable area and then return when conditions change, fish don't tell the whole story of the long-term health of a water body. So biomonitors often look below the water to the bottoms of lakes and streams for the presence, absence, and relative numbers of the many kinds of aquatic creatures that can't readily swim away from unfavorable conditions. This article, after a look at bioassessment in general, examines several groups of such creatures and the characteristics that make them valuable biological signs.

Aquatic Bioassessment In General

Bioassessment studies were first reported in the mid-1800's, when diminishing fish populations in the River Soar in Great Britain were found to be caused by pollution.[3] In the early 1900's, German scientists used bacteria and plankton (floating, microscopic animals and algae) to analyze pollution zones downstream of a known pollution source. Scientists in Illinois expanded bioassessment efforts to include fish and other organisms, and the U. S. Public Service Health Act of 1912 addressed federal bioassessment efforts in interstate waters.

Today, many state agencies have some sort of bioassessment effort in place, and volunteer programs across the country monitor various biological resources. Bioassessment is one of three major ways to evaluate aquatic resources, the others being assessment of the chemical conditions of water and assessment of the physical features of the aquatic habitat. Each of the three types of assessment has certain advantages and disadvantages in cost, time required, training required, and information provided. But one fundamental reason for using *biological* assessment is that living

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[1] M. T. Barbour *et al.*, *Rapid Bioassessment Protocols For Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*, 2nd Edition, U. S. EPA, Washington, D.C., July 1999.

[2] "Monitoring," which involves keeping track of and documenting conditions, is not strictly the same as "assessment," which refers to an *evaluation* of conditions. Ideally, ongoing monitoring allows for assessments to be made when needed.

[3] Information on the history of bioassessment comes from W. S. Davis, "Biological assessment and criteria: Building on the past," pp. 15-29 in Davis, W. S. and T. P. Simon, eds., *Biological Assessment and Criteria*. Lewis Publishers, Boca Raton, Fla., 1995.

organisms, in effect, record the *impacts* of varying environmental conditions. Because the living things in an aquatic system are continually exposed to pollutants and other stresses, bioassessment provides a historical perspective on the condition of the water body, unlike the instantaneous view given by chemical sampling. Bioassessment also helps reveal the effects of multiple stresses, which is not readily apparent from chemical or physical studies alone.

Bioassessment can tell us about aquatic conditions because of the varying **tolerances** of organisms to environmental conditions. As a U. S. EPA manual on stream monitoring states, "The basic principle behind the [use of organisms for water-quality assessment] is that some are more sensitive to pollution than others."[4] By their physical structures, biochemical make-up, behaviors, and life cycles, all organisms are adapted to different ranges of environmental conditions, and they respond differently to contaminants, habitat changes, or other environmental disturbances. Through study of the presence (or absence) and abundance of organisms in relation to environmental factors, scientists are able to determine whether a certain kind of organism is **pollution-tolerant** or **pollution-intolerant** ("sensitive" is another term used synonymously with "intolerant). More specifically, scientists have assigned **tolerance values** to a large number of species, based on the conditions in which the species are typically found. These values vary from one region or state to another, and are always subject to being updated as scientists gather additional information.[5]

In aquatic bioassessment studies, the presence of a large number of intolerant or sensitive organisms indicates that the water body in question is largely free of pollution and stress. On the other hand, a relative lack of sensitive organisms and an abundance of tolerant organisms indicate more difficult environmental conditions, including *perhaps* some kind of past or present contamination. In the next section, we'll learn about the tolerances of several kinds of organisms used in aquatic bioassessment.

Evidence from Animals That Can't Swim Away

Though bioassessment investigations can focus on organisms from the smallest algae to the largest fish, many use **benthic macroinvertebrates**. These are organisms that live on the bottom of streams or other water bodies (*benthic*), are large enough to see without a microscope (*macro-*), and have no backbone (*invertebrate*). Benthic macroinvertebrates are popular in bioassessment for at least three reasons:

- Compared to much smaller or much larger organisms, it is relatively easy to collect, process, and identify a sample of benthic macroinvertebrates;
- Benthic macroinvertebrates have a fairly stationary lifestyle, meaning they do not easily move out of polluted areas;
- As a group, benthic macroinvertebrates exhibit a wide range of tolerances to pollution and stress.

I've selected six groups of benthic macroinvertebrates to illustrate how these creatures indicate environmental conditions. Each group includes dozens of North American species, living in a variety of waterbodies and habitats within those waterbodies. The first three groups—**stoneflies**, **mayflies**, and **caddisflies**—all include intolerant or sensitive species whose presence indicates good water quality. Three other groups— **midges**, **lung-breathing snails**, and **aquatic worms**—include much more tolerant species, including some that are found in water of the very worst quality.

As mentioned above, scientists have assigned tolerance values to many aquatic macroinvertebrates, typically using a scale of 0 (least tolerant) to 10 (most tolerant). The

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[4] U. S. EPA, *Volunteer Stream Monitoring: A Methods Manual* (EPA 841-B-97-003, 1997), p. 38.
[5] Typically tolerance values are based on professional judgment. Scientists judge organisms' tolerance on the basis of observations of the overall environmental conditions in which organisms are found. Few organisms have tolerance values based on *experimental* responses to specific types of environmental stress, such as low dissolved oxygen, high sediment, or contamination by toxins.

following table shows *median*[6] tolerance values for the organisms in each of the six groups we're considering here, based on values reported in a 1993 study of stream macroinvertebrates in North Carolina.[7] The group medians (middle column) show that stoneflies, mayflies, and caddisflies on the whole are noticeably *less* tolerant (*lower* tolerance value) than midges, lung-breathing snails, and aquatic worms, even though some species in each group are relatively tolerant (shown by the *high-end* values for each group in the right-hand column).

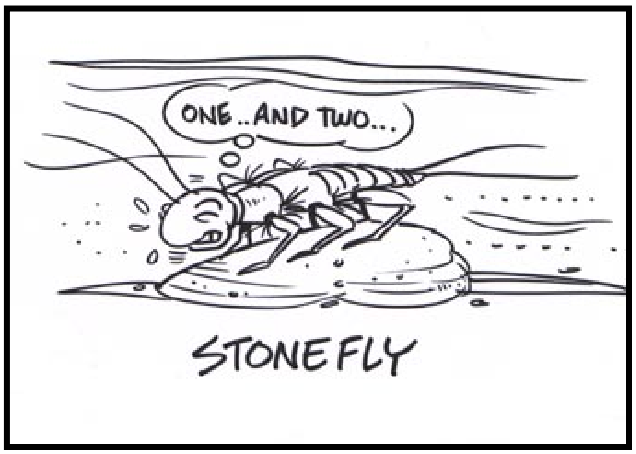
Group	Median tolerance values (0 = least tolerant; 10 = most tolerant)	Range of tolerance values
Stoneflies	1.4 (for 56 species)	0—6
Mayflies	2.2 (for 91 species)	0—9.3
Caddisflies	2.2 (for 102 species)	0—8.1
Midges	6.2 (for 130 species)	0—10
Lung-breathing snails	6.7 (for 17 species)	1.6—9.1
Aquatic worms	8.8 (23 species)	2.8—10

The following sections present some details on the six groups, with cartoons to highlight particularly distinctive features.

Stoneflies

The most sensitive of all benthic macroinvertebrates are the stoneflies, an **order**[8] of insects known as Plecoptera (meaning "plaited winged," referring to the adults' hind wings being folded beneath the forewings[9]). Approximately 150 species of stoneflies are found in Virginia.[10] Immature stoneflies (called **nymphs**[11]) are aquatic, while the adult form is not; the nymphs, therefore, are the most useful form for aquatic bioassessment. Stoneflies need clean, silt-free rocks and water with a high level of dissolved oxygen. Consequently, streams with an increased sediment load that covers the streambed and clogs the spaces between rocks have less habitat suitable for stoneflies. Stoneflies are also susceptible to chemical pollutants. Studies have shown a decrease in stoneflies downstream of oil spills, mine drainage, and aerial pesticide applications.

In a stressful situation, stoneflies will use behaviors to try to improve the situation. When flow or oxygen levels decrease in the water (whether due to physical or chemical changes), some stonefly species will do "push-ups" to force water—and therefore more dissolved oxygen—past their gills. If conditions get too bad, stoneflies also may release their hold on the streambed and float downstream in an attempt to find better conditions—a behavior called **drift**.



[6] In a sample of values, the **median** is the value for which an equal number of observed values occur both above and below.

[7] D. R. Lenat, "A biotic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality ratings," *Journal of the North American Benthological Society* 12(3): 279-290, 1993.

[8] Scientists classify the insects into 27 orders. Below the level of order, the classification levels are **family**, **genus**, and **species**.

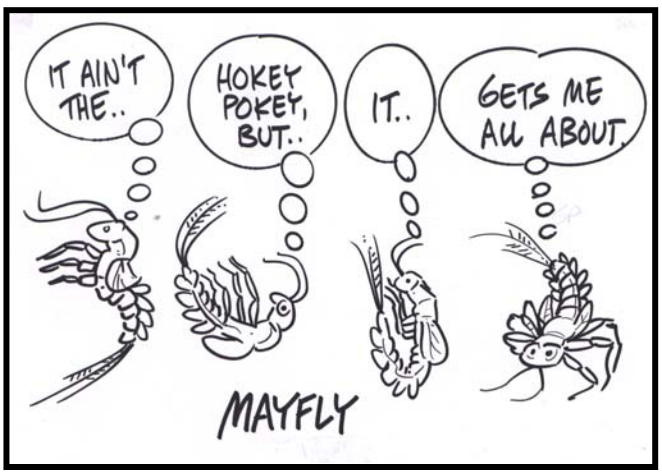
[9] The meanings of insect-order names are quoted from J. R. de la Torre-Bueno, *A Glossary of Entomology*. New York Entomological Society, New York, 1978.

[10] Estimates of the number of stonefly, mayfly, caddisfly, midge, and aquatic worm species in Virginia were provided by Reese Voshell, Virginia Tech Dept. of Entomology, May 1, 2002.

[11] Immature stoneflies and mayflies are also sometimes called "naiads."

Mayflies

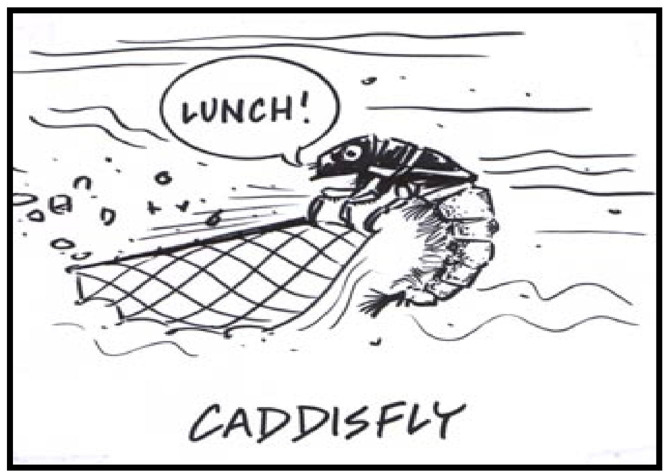
Another intolerant group is the **mayflies**, the insect order **Ephemeroptera** (meaning "briefly winged," referring to the very short life span of the winged adult forms—as short as 90 minutes for some species). Approximately 150 mayfly species are found in Virginia. Like stoneflies, the nymph stage is aquatic and is most valuable for bioassessment. Many mayfly species have been found to be as sensitive as stoneflies to pollutants and stresses, but other species are more tolerant of certain kinds of pollution, such as increased organic matter (which leads to reduced dissolved oxygen levels). In response to insufficient dissolved oxygen, mayflies also try behaviorally to improve their situation by increasing drift and by using body movements (fish-like swimming motions in some species) to increase the flow of water past their gills.



Caddisflies

A third group of relatively intolerant organisms is the **caddisflies**, the insect order **Trichoptera** (meaning "hairy winged," referring to hairy forewings of the adults). Approximately 250 caddisfly species are found in Virginia. Caddisflies undergo **complete metamorphosis**, so they have a larval stage, and the **larva** is the key aquatic stage. Caddisfly species have been found to be intolerant of high levels of sedimentation, pesticides, industrial pollutants, mine wastes, road salt, and other such pollutants. While the order *as a whole* is considered intolerant, it includes one fairly *tolerant* family, the Hydropsychidae, or common netspinners. As their name implies, these organisms build nets of silk-like material that the insect produces. They use the nets to collect food by filtering organic material from the water. Some types of pollution add moderate levels of nutrients to a waterway, in turn leading to an increase in the kinds of material netspinners can capture. Such pollution can therefore result in increased numbers of this kind of caddisfly, compared to other species that feed in a different manner.

Caddisflies are also distinctive for the many kinds of cases that different species construct from their "silk" and a variety of other materials (such as stones, leaves, and sticks). Besides providing shelter, cases increase the ability of certain kinds of caddisflies to get oxygen from water, allowing the insects to live in relatively low-oxygen waters (such as ponds, rather than streams).

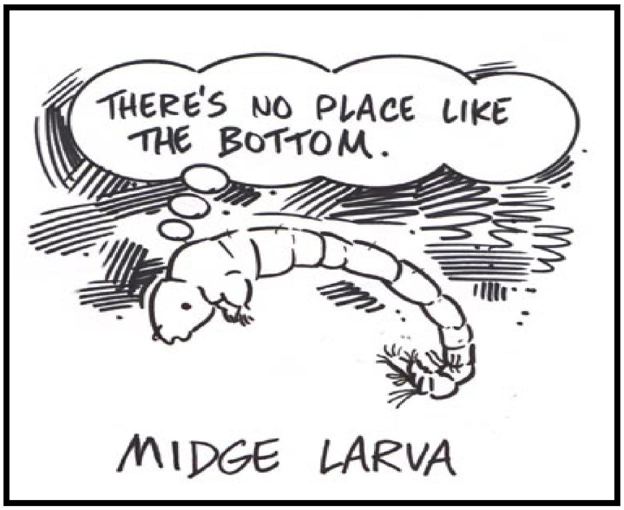


Midges

One of the largest (approximately 250 species in Virginia) and most tolerant groups of aquatic macroinvertebrates is the midges, the family Chironomidae in the insect order Diptera (meaning "two-winged," referring to the adults having only two wings as opposed to the four wings of most winged insects). This order contains the "true flies," including mosquitoes, blackflies, houseflies, and many others. As with caddisflies, the larva is the key aquatic stage in midges. Midge larvae can survive high levels of many chemical pollutants and can even survive oil spills.

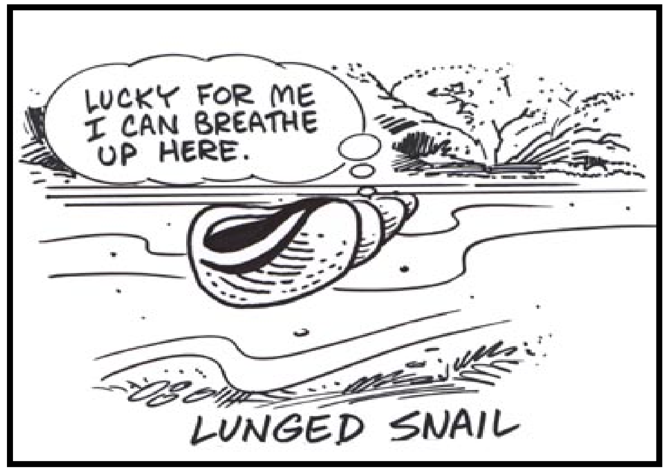
Midge larvae's burrowing lifestyle allows them to survive high levels of sedimentation and to colonize lake bottoms in vast numbers. Some midge species also have a physiological adaptation to living in sediments: hemoglobin, giving them a bright red appearance and allowing them to extract more of the low levels of oxygen available in sediments and store it for a few minutes.

While midges can be found in virtually any type of water body, there are limits to what even they can survive. Road salt, which alters water-regulation abilities, can be a fatal pollutant to freshwater midges, and some species in this diverse group are considered intolerant of poor water-quality generally.



Lunged Snails

A second group of organisms that are tolerant of pollution and stress are the lunged snails, in the mollusk order Pulmonata. Approximately 150 lung-breathing freshwater snails are found in North America, according to the 1982 U. S. EPA report *Freshwater Snails of North America.* These snails, some of which are able to inhabit "grossly polluted sites,"[12] have a biological adaptation that allows them to survive in low-oxygen conditions: their mantle cavity functions as a lung. Lunged snails do not rely on gills to absorb dissolved oxygen from the water; rather, the Pulmonata fill their lung with air at the water's surface. Therefore, lunged snails can survive in waters with pollution—such as sewage or manure—that creates oxygen-depleting conditions. Under such conditions, organisms that rely on moderate or high levels of dissolved oxygen will decrease, leaving less competition (for food and space) for the Pulmonata.

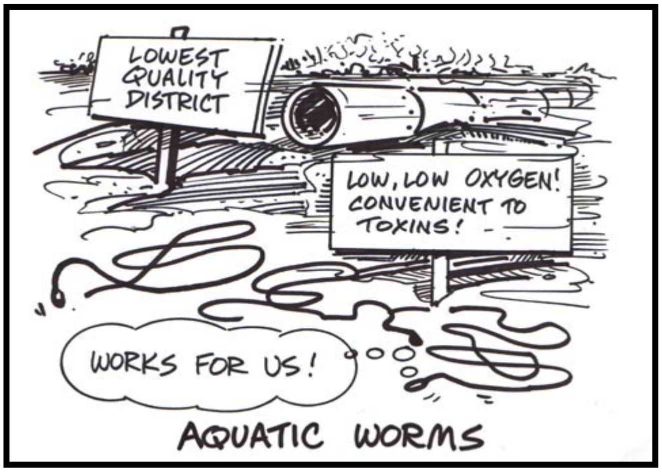


Aquatic Worms

The final group of pollution- and stress-tolerant macroinvertebrates we'll consider is the aquatic worms, in the segmented-worm class Oligochaeta. (This class also includes the familiar terrestrial earthworm and many other species.) There are about 50 species of aquatic worms, in Virginia. Some of the species live among plants, but most live among sediments, and some species are particularly common in sediments contaminated by organic pollution (such as untreated sewage). The latter are members of the family Tubificidae and are commonly referred to as **tubificid** worms. Like midge larvae, some tubificid worms are able to withstand high levels of sedimentation, low levels of oxygen, and even avoid some heavy metals associated with various industrial pollutants (by burrowing below them).

[The aquatic worm cartoon follows on the next page.]

[12] B. L. Peckarsky *et al.*, *Freshwater Macroinvertebrates of Northeastern North America*, Cornell Univ. Press, Ithaca, N.Y., p. 335.



Evidence from Invertebrates Assembled

We have talked about a few groups of benthic macroinvertebrates, but biomonitors look at all the macroinvertebrates at a site, or the macroinvertebrate **assemblage**. A macroinvertebrate bioassessment considers what kinds of organisms are present, the relative numbers of the organisms present, and what kinds are missing. Typically one assumes that a "healthy" stream will be highly diverse—that is, have many different kinds of organisms, both tolerant intolerant kinds—and no one species will greatly outnumber the others. In contrast, in polluted or otherwise impacted streams the diversity is expected to be greatly decreased, usually with many individuals of a very few (tolerant) species outnumbering the others.[13]

Real life, however, is not always typical. There is great natural variation in what organisms would be present at a clean or healthy site based on stream size, geography, and geology. A clean site in the headwaters of the Jackson River in Bath County, Virginia, would be very different from a clean site in the Nottoway watershed in Sussex County, Virginia. Both would be expected to be different from a clean site in my home watershed, the Little Miami in Greene County, Ohio. Many studies therefore collect date not only from the stream in question but also from a comparable **reference site**. Reference sites are sites have similar size, geology, and geography as the study site but are considered to be mostly free from human impacts or impairments. Ideally the reference site and study site should be in the same watershed. In practice it can be very difficult to find reference sites in the necessary location and with the desired conditions.

Conclusion

Despite the sometimes-tricky issue of reference sites, bioassessment is a strong tool for assessing aquatic conditions, especially when used in conjunction with chemical monitoring and physical habitat assessments. The roll call of organisms in an aquatic system gives an overall idea about the system's general health. If bioassessment indicates a problem in the biological community, increased or more-targeted chemical and physical monitoring can often identify the cause of the problem. With bioassessment in the monitoring toolbox, we are better able to understand, assess, and protect water resources.

Because bioassessment is relatively easy, volunteers with little scientific background can—with a little training—conduct various bioassessment methods. This makes it an excellent educational tool, exposing children and adults alike to living aquatic worlds that many people may have never seen or even know exist.

Benthic macroinvertebrates are a key component of bioassessment. Although most of these organisms are unfamiliar to most people, these bottom-dwellers with no backbones contain a world of information about the conditions of our waterways. That's why even when a news report ends

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[13] Bioassessments of benthic macroinvertebrate communities can involve a large variety of measurements and calculations to summarize sample data; these data summaries are known as **metrics.** A metric is a calculation that tells us something about the biotic community from which a sample has been taken. Much research has been done to identify useful metrics and the appropriate combination of them for accurately assessing aquatic conditions in different geographic areas. For more on metrics used with benthic macroinvertebrates, see Barbour *et al.*, listed in the References section.

with "no fish kill," someone's usually thinking, "Better go check on the bugs!"

—By Sarah Engel

Sarah Engel, a native of Ohio, is currently a subcontractor for Environmental Services & Consulting in Blacksburg, Va. She obtained a master's degree in aquatic entomology from Virginia Tech in December 2000.

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References and Further Reading

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More Information On-line

"**Freshwater Benthic Ecology and Aquatic Entomology Homepage**." Soil and Water Conservation Society of Metro Halifax, Nova Scotia, Canada, at www.chebucto.ns.ca/Science/SWCS/ZOOBENTH/BENTHOS/benthos.html. The site has information and good photos about many groups of aquatic invertebrates.

"**Biological Indicators of Watershed Health**." U. S. EPA, at www.epa.gov/bioindicators/. This site has sections on key concepts, indicator species, state programs, statistics, and other resources. Through the "state programs" link at this site, you can reach information about the Va. Department of Environmental Quality's biomonitoring efforts.

"**Bioassessment and Biocriteria**," maintained by the EPA's Office of Science and Technology, at www.epa.gov/ost/biocriteria/, has some of the same information as the site just mentioned, but it also has specific information about bioassessment in *five types of habitats*: streams and rivers; lakes and reservoirs; estuaries and coastal areas; wetlands; and coral reefs.

Virginia Save Our Streams: The Virginia Izaak Walton League's Save Our Streams (SOS) program is a leader in benthic macroinvertebrate monitoring by citizen volunteers in Virginia. The program's Web-site is www.sosva.com.

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