BIODIVERSITY
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HOW HEALTHY IS A STREAM? ASK THE STREAM BUGS!

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YOUNG REVIEWERS:

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AGE: 15

The weird and wonderful variety of bugs that live in streams is more than cool—it is a great scientific tool. The mixture of bugs helps scientists understand water quality, which means whether the water is clean or dirty. Two kinds of tools translate bug variety into measures of stream health. One is called a multimetric index; the other is called an observed-to-expected index. The multimetric index "speaks bug" to us. It uses bug preferences for food and habitat, tolerance for pollution, and other bug attributes to decipher whether a stream is to a bug's liking. The observed-to-expected index uses scientists' knowledge of which bugs usually occur in clean water, to predict which should be present in a good-quality stream. Both indices give us the big picture of water quality and help scientists track the health of streams in US national parks.

SCORING THE HEALTH OF STREAMS AND RIVERS

How do scientists score a stream's health? Every student and teacher knows the importance of evaluation. Teachers evaluate how well their students are learning, to make sure students are on a healthy track. One way teachers do this is through test scores and final grades. But scoring a river, stream, or creek is not as easy as handing out pencils, test books, and checking students' answers.

Why would a scientist want to "score" a stream? To begin with, streams and rivers have many important uses. People around the world rely on rivers for drinking water. Rivers also provide habitat for fish—a food source—as well as habitat for endangered organisms. And streams can simply be a nice place to watch a sunset. Assessing the water quality in a stream, or scoring it, can help identify damage from water pollution and other human activities upstream, in the **watershed**. Identifying damage is the first step in fixing it. This is doubly important in our national parks, refuges, and other protected places where we expect to have the cleanest water, most beautiful sunsets, and homes for endangered species. Early detection of problems in rivers is the key to quick repair, before larger damage might occur.

WATERSHED

The area of land above a stream, usually bounded by mountain ridges, where rain will run off into the stream.

The clearest way to score a river is to "ask" the organisms that live there [1]. Some rivers have many fish species, and, in the past, scientists have "asked" the fish about the river's health. But many rivers do not have fish or have only a few types of fish, so we cannot always use fish for this purpose. But every river and stream has **aquatic invertebrates**—animals without backbones that live part or all of their life in water, which we commonly call "bugs" because most of them are insects [2]. In fact, streams can potentially have hundreds of species of aquatic invertebrates, and each species can respond differently to pollution. For example, aquatic invertebrates that are sensitive to pollution may disappear from unhealthy streams, while those that can stand pollution might increase. Scientists can use these differences to score the health of rivers (Figure 1). They do this using two complementary methods: a **multimetric index** and an **observed-to-expected index**. Both are calculated from samples of bugs collected from a stream using nets or other methods. Collection usually takes less than an hour and is usually done along with testing other qualities, like water chemistry. Multimetric and observed-to-expected index values provide different perspectives on stream health, which gives a better overall picture of the stream's condition.

AQUATIC INVERTEBRATES

Organisms without backbones that live a large part of their lives in water. Examples include insects, worms, leeches, and mites. Because most are insects, we commonly call them "bugs."

MULTIMETRIC INDEX

A tool used by scientists that uses biodiversity, life traits, feeding styles, and other characters of aquatic invertebrates to determine stream health.

OBSERVED-TO-EXPECTED INDEX

Score calculated by dividing the number of organism types collected (observed) by the number of organism types that should be there (expected), to help determine stream health.

MULTIMETRIC INDEX

Much like teachers and parents use grade point average (GPA) to understand a student's performance, a multimetric index can tell scientists about the health of a stream. A "metric" is something a scientist measures, like the number of bug species in a stream. If a

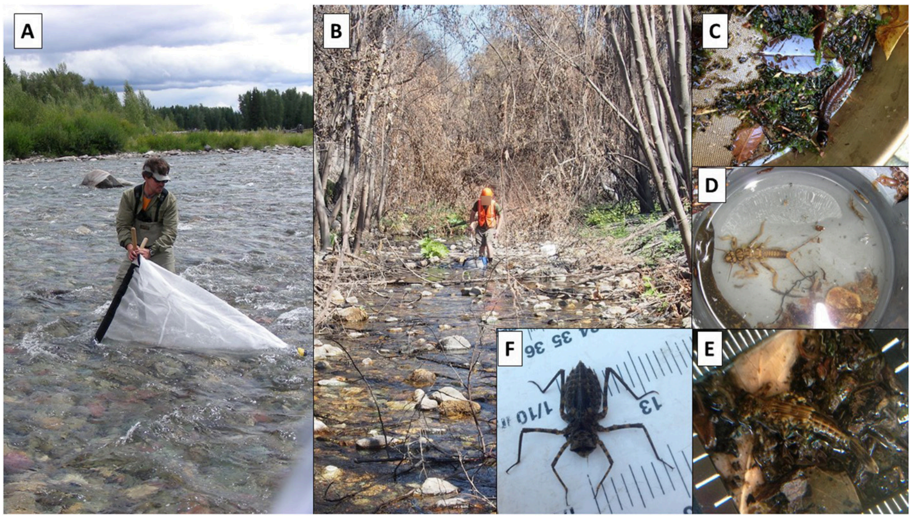

Figure 1

Figure 1

(A) A National Park Service scientist collects invertebrates from a pristine stream in Glacier National Park, and **(B)** from Whiskeytown National Recreation Area immediately after a large wildfire. This collection technique is rapid and easy to perform. The scientist kicks above the net and lets invertebrates drift into the net. Scientists analyze the mix of invertebrates found using either a multimetric index or an observed-to-expected index. Aquatic invertebrate predators that may show up in the sample include **(C)** hellgrammites, **(D)** stonefly larvae, **(E)** damselfly larvae, and **(F)** dragonfly larvae.

PREDATORS

Organisms that obtain food by eating other animals and not eating plants.

scientist finds 17 bug species in a stream, then the score for that metric is 17. A multimetric index is a mathematical tool that combines individual metric scores into a single overall score [3]. Each individual metric, like a bug's ability to withstand pollution, is based on decades of research identifying which stream bugs live only in unpolluted streams and which bugs can stand, or maybe even like, polluted streams. Another very useful metric is whether the bugs found in a stream are vegetarians (eating tiny stream plants called algae) or **predators** (eating other bugs). This is valuable information because streams with lots of predatory bugs are usually healthy. Similarly, in Yellowstone National Park (Wyoming, United States), healthy numbers of wolves and grizzly bears mean that the elk and deer they prey on, and the lush grasslands that feed elk and deer, are probably thriving.

Scientists combine the various individual metrics derived from a sample of stream bugs into one multimetric index score. This combination of scores (the "multi" part of "multimetric") for an overall assessment is similar to how a student's GPA is derived. A student's overall GPA is based on individual test scores from language, math, science, and history studies. And just as a high GPA indicates a good student, a high multimetric index score indicates clean water.

OBSERVED-TO-EXPECTED INDEX

The second way of measuring stream bugs to score a stream's health is a metric called the observed-to-expected index, abbreviated O/E [4]. It is a ratio comparing what scientists observe in nature with what they expected to observe. Let us pretend that a student's success in school was only about attendance. Your score would be as simple as counting the number of days that you attended and comparing that to the number of days you were supposed to attend. If you attended 99% or 100% of your classes, then you will have done well in school—certainly better than students who only attended 50% of their classes. This is easy to calculate—the teacher takes attendance. This is similar to how observed- to- expected index works.

The number of species of bugs in a stream sample, just like the number of days you attend class, is the "observed" value in our ratio. The scientist already knows which stream bugs she "expects" to find in a healthy stream in that area, just like your teacher expects you to come to class every day-—100% of the time. By comparing the observed to expected values, we get a percentage score. A stream that has 80% of its expected species might get a passing score, whereas a stream with only 50% of its expected species has problems. You might occasionally find a stream with even more species than expected, say 110%, which indicates super-clean conditions. This simple score is quick and easy to interpret. But let us dive a little deeper. If we have a stream with a score of 65%, for example, this means that the stream is missing 35% of the invertebrates that are supposed to be there (100–65% = 35%). Because we can interpret an O/E score this way, we can also refer to it as a measure of **biodiversity** loss.

BIODIVERSITY

The various kinds of animals, plants, and other life that occur in a particular habitat.

Calculating the "observed" part is easy—all it takes is collecting stream bugs and identifying the species with the help of a microscope. Figuring out what is "expected" in a stream is more difficult. How many different invertebrate species would normally occur in a healthy stream like the one being sampled? This requires having what are called **reference streams**. A reference stream is known to have clean water, with no harmful conditions in it or in its watershed. Using reference streams, scientists identify which invertebrates typically occur in local, clean streams. This allows scientists to predict the number of expected invertebrates at a new site.

REFERENCE STREAM

A stream that drains a watershed that is unimpacted by human disturbances like farming, mining, or tree cutting.

USING THE SCORES IN US NATIONAL PARKS

In Glacier National Park (Montana, United States) managers must pay attention to streams that are nice and clean, to further protect them. But they also need to identify and pay even more attention to the few park streams that score low on the multimetric index. Managers have used multimetric scores to help understand and manage both the clean and the dirty. They have worked with park scientists on figuring out what is polluting the streams and how to improve them. Figure 2 shows multimetric index scores for streams in Glacier National Park. Scores range from pristine, with little human impact, to unhealthy, when human use might be hurting the stream. The photographs show one of the many remote, pristine streams and one of the unhealthy ones. The road construction near the unhealthy stream removed aquatic vegetation that many bugs depend on.

In Whiskeytown National Recreation Area (California, United States), a large wildfire burned most of park in 2018. Scientists used the

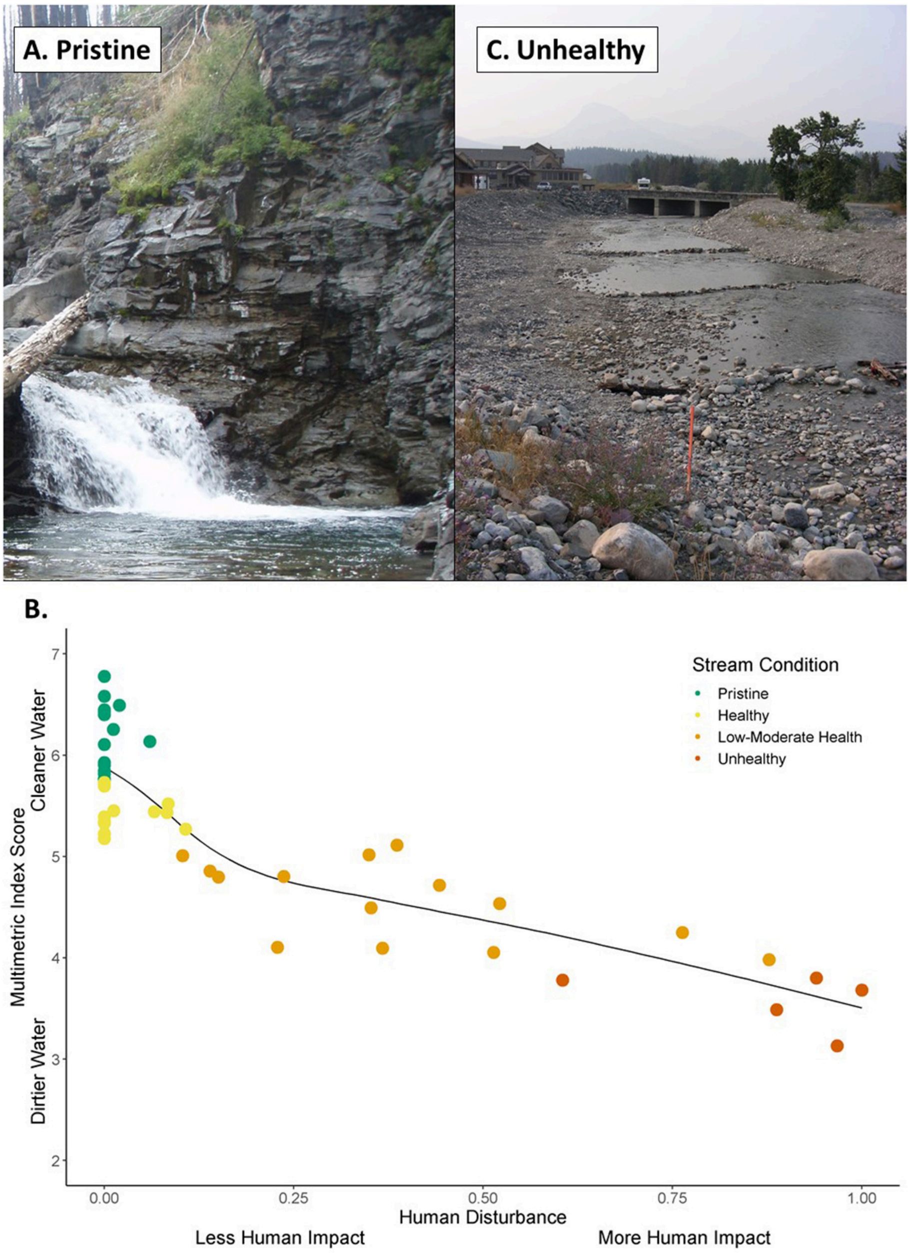

Figure 2

Figure 2

Multimetric index scores are lower with more human impact and higher with less human impact. **(A)** A pristine stream in Glacier National Park (Montana, United States). **(B)** Graph showing the relation of the multimetric index to human use. Points closer to the top of the graph mean better invertebrate and water-quality conditions. The points are the measured values, and the line is a "smoothed" average of the points. Points closer to the right side of the graph mean more human impact. **(C)** Unhealthy stream in Glacier National Park, just below a recently constructed road crossing.

Observed to Expected Index to understand how the fire affected the health of these streams over time. Figure 3 shows that, a couple of weeks after the fire, O/E dropped just a little bit compared to the previous year, meaning slightly fewer species were detected. But a year later, the scores dropped even more. What happened? O/E scores revealed that the immediate heat of the fires did not cause much change to the streams. Instead, later winter floods and the sand they washed down into the streambed caused more impact. This information is important because it helps park managers understand when and how streams are impacted, so they can try to prevent severe impacts.

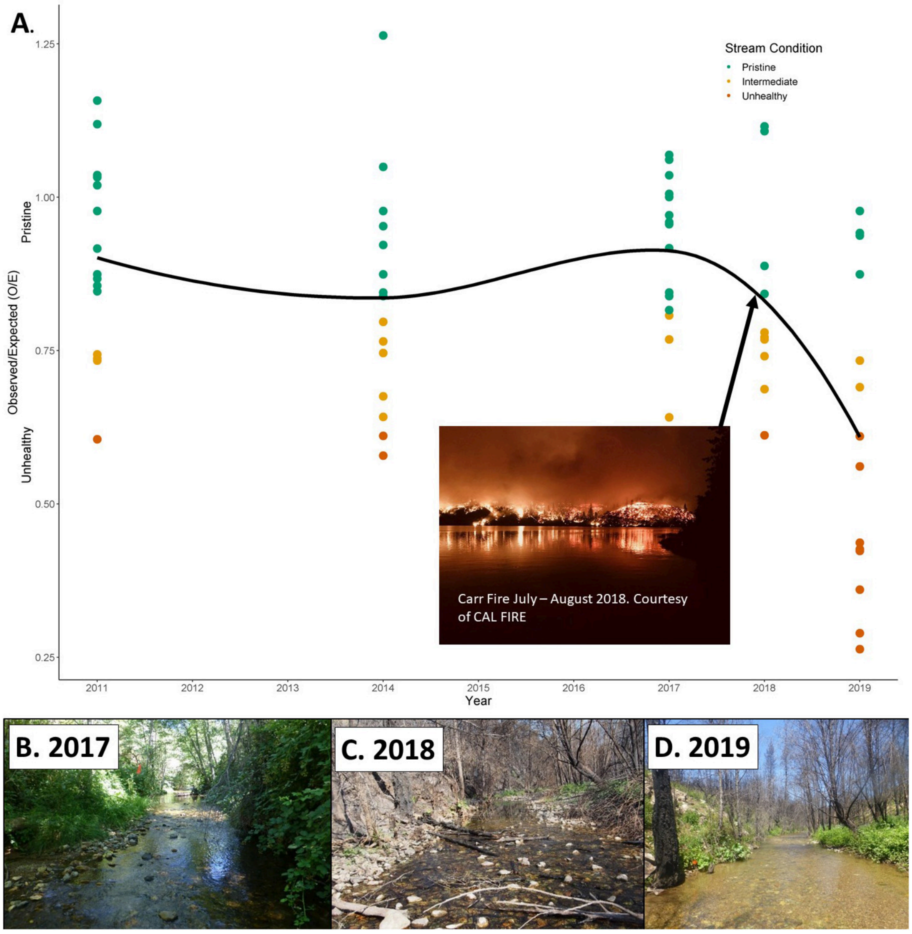

Figure 3

Figure 3

Observed-to-expected index scores show a major drop in water quality in the streams of Whiskeytown National Recreation Area (California, United States) after the 2018 wildfire, but not until 2019. **(A)** Graph showing O/E scores from samples collected between 2011 and 2019. Scores near the top indicate pristine conditions. Scores near the bottom indicate unhealthy conditions. Inset photograph shows the Carr Fire, which burned most of the park. **(B)** Whiskey Creek in 2017 before the fire. **(C)** Same location in 2018, weeks after the fire. **(D)** Same location in 2019, 1 year after the fire, showing large amounts of sand in the stream.

These are just two examples of how stream bugs have helped us understand the conditions of streams and rivers. These tools are not just limited to US national parks or other protected areas. Scientists near you might be checking on your own nearby streams! Do you think your local streams will be clean or dirty?

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REFERENCES

1. Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecol. Appl.* 1:66–84.
2. Simmons, T., Dinger, E. C., and E. W. Schweiger. The wild and wonderful world of stream bugs. *Front. Young Minds*. doi: 10.3389/frym.2022.716573

3. Barbour, M. T., Swietlik, W. F., Jackson, S. K., Courtemanch, D. L., Davies, S. P., and Yoder, C. O. 2000. Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity. *Hydrobiologia* 422:453–64. doi: 10.1023/A:1017095003609
4. Hawkins, C. P., Norris, R. H., Hogue, J. N., and Feminella, J. W. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. *Ecol. Appl*. 10:1456–77. doi: 10.2307/2641298

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

STINA, AGE: 14
Hi! My name is Stina, and I am 14 years old. I love biking, skiing, reading, learning, and of course my dogs! Have a nice day!

UPWARD BOUND STUDENTS (716591), AGE: 15
Math and Science Upward Bound provides opportunities for participants to succeed in their pre-college performance and higher education pursuits. The program serves high school students from low-income families and families in which neither parent holds a bachelor's degree. The goal is to increase the rate at which participants complete secondary education, help students develop their potential to excel in math and science, enroll in and graduate from institutions of post-secondary education and ultimately obtain careers in math and science professions.

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Eric C. Dinger is an ecologist for the National Park Service, conducting monitoring and assessment of streams, lakes, and intertidal zones in national parks in southern Oregon and northern California. He grew up backpacking in the mountains and enjoying his time visiting wilderness streams and lakes. During university studies, he fell in love with aquatic invertebrates and what they can teach us about our ecosystems. Since then, he has been active in monitoring and assessing ecosystems for the past 25 years. When not working, Eric keeps visiting the mountains and coasts with his family, and sometimes rock climbing or running. *eric_dinger@nps.gov

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Trey Simmons is an ecologist for the National Park Service. His job is to characterize river and stream ecosystems in three large wilderness parks in Alaska and to determine how these ecosystems are changing over the long term. Altogether, the parks where he works cover 22 million acres, which is bigger than the state of South Carolina. Because there are very few roads in these giant parks, Trey uses helicopters and airplanes to get to most of the streams where he works. When he is not working, Trey loves skiing, hiking, and playing with his dog Regan.