frontiers | Frontiers for Young Minds

# Taking the pulse of US national parks

Edited by
Erin Kathleen Shanahan, Rebecca Weissinger, Nina Chambers,
Sonya Daw, Matthew T. Lavin and Brian Smithers

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Frontiers for Young Minds believes that the best way to make cutting-edge science discoveries available to younger audiences is to enable young people and scientists to work together to create articles that are both accurate and exciting. That is why distinguished scientists are invited to write about their cutting-edge discoveries in a language that is accessible for young readers, and it is then up to the kids themselves – with the help of a science mentor – to provide feedback and explain to the authors how to best improve the articles before publication. As a result, Frontiers for Young Minds provides a collection of freely available scientific articles by distinguished scientists that are shaped for younger audiences by the input of their own young peers.

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# Taking the pulse of US national parks

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# About this collection

If you've ever had a medical check-up, did you wonder why they put a cuff around your forearm, gave it a squeeze, and made you sit still and quiet? Or why they asked you to open your mouth so they could stick a thermometer under your tongue? Or put that cold stethoscope against your chest while you took deep breaths followed by sticking a clothespin thingamabob on your finger? What's up with all the gizmos and gadgets and why all the bother?

What's up is that all of these instruments measure the conditions of some of the most important, life-supporting functions, or vital signs, which keep your carcass from becoming, well, a carcass. The squeezy cuff is reading your blood pressure, which indicates how strongly your blood is pumping through your pipes. The thermometer measures your core body temperature, which affects many chemical reactions in your body that supply energy for your cells. With a stethoscope, the swooshing sound of air moving in and out of your lungs can be listened to. And the clothespin doohickey tracks the amount of oxygen being carried by your blood. Vital signs are critical indicators of your body's overall health. By tracking them as you grow and mature, these measurements can be used as a guide or reference point for when your body isn't feeling all that great.

Now what does your blood pressure have to do with US National Parks? While human vital signs are important in evaluating your body's health, ecological vital signs are indicators for measuring ecosystem health. An ecosystem is a community of living organisms like frogs, trees, or bacteria, and nonliving materials such as water, dirt, and rocks that are located together and interact on some level. In a healthy ecosystem, all of the living and nonliving members exist in a state of natural balance in harmony with their environment. When something new enters the community, say a strange weed or insect, or something in the environment shifts, such as the air temperature becoming warmer, the health of the ecosystem can be threatened. Monitoring ecological vital signs gives scientists a reference point or baseline of the natural condition and alerts them when there is a change. While a healthy ecosystem can continue to support all its members and adapt to change, sometimes changes are too great and members of the ecosystem become stressed and have a hard time keeping up.

Although US National Parks are some of the most protected areas on the planet, the ecological health of many of these carefully safeguarded lands is increasingly uncertain due to our rapidly changing global environment. Here we present a collection of articles about how we study and understand the health of park ecosystems by measuring and tracking the condition of ecological vital signs. This scientific data helps park managers protect the valued resources of our parks and lessen harmful impacts when change is inevitable.

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# DO NOT CROAK! A STORY OF SURVIVING YELLOWSTONE'S FRIGID WINTERS

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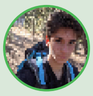
EVAN
AGE: 16


LUCY
AGE: 16


PACIFIC CREST MIDDLE SCHOOL
AGES: 11–13

Have you ever wondered how "cold-blooded" animals like amphibians (frogs, toads, and salamanders) survive the winter without fur or feathers to keep them warm? Yellowstone National Park's amphibians have found ways to stay alive during the cold winter months. These animals have evolved various coping strategies, from burrowing underground, to living in ponds, to tolerating the freezing of much of the water in their bodies. This article will explore the strategies used by several amphibians to survive the winter, including strategies used by the boreal chorus frog, Columbia spotted frog, western toad, and western tiger salamander. Understanding the diverse ways that amphibians survive in their winter habitats helps scientists to recommend ways to protect those habitats, to ensure that amphibians have healthy places to live and reproduce.

## SURVIVING YELLOWSTONE'S LONG WINTERS

Despite being known for its warm geysers like Old Faithful, Yellowstone National Park (United States of America) is a relatively cold, dry place (Figure 1). Winter in Yellowstone is the harshest season of the year, but it can be cold and snowy at any time. To survive, animals living there must deal with long, cold winters. Yellowstone's animals have a variety of strategies to deal with freezing winter temperatures. Some animals, like most songbirds and pronghorn antelope, migrate to warmer, less snowy places. Other animals, like weasels and wolves, stay put and must search for food year-round above the snowy surface. Pikas prepare for winter by stockpiling food and staying active beneath the snow. Finally, animals like the grizzly bear **overwinter** in their dens. All these animals are "warm-blooded" and have feathers or fur to trap the heat generated by their bodies' chemical reactions (called their **metabolism**).

**OVERWINTERING**

In animals, a state of inactivity and slowing of metabolism, used to save energy in difficult conditions.

**METABOLISM**

Chemical reactions in the cells of a living organisms that keep the body alive, such as digesting food, repairing damage, and growing.

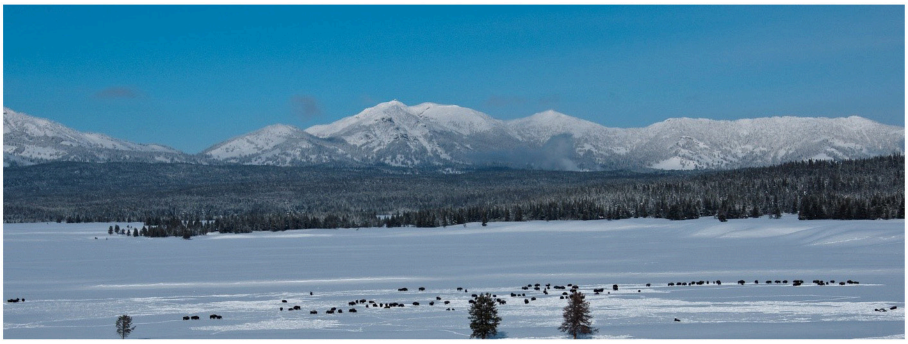

Figure 1

**Figure 1**

Bison in Hayden Valley, Yellowstone National Park (United States of America) in December 2010 (Photograph credit: Dr. Charles R. Peterson).

Other animals must deal with winter in a naked state. Fish and **amphibians** (frogs, toads, and amphibians) are "cold-blooded," or **ectothermic**, animals. Winter is a problem for ectotherms because their body temperatures are limited by the environment. Fish in Yellowstone's frigid waters live in ice-free areas of streams, rivers, or lakes. For Yellowstone's amphibians, no single solution has proven to be the best. Instead, Yellowstone's amphibians show diverse coping strategies. Some burrow into holes created by rodents. Some live in ponds under the ice. Others tolerate the freezing of much of the water in their bodies. These amphibians are so good at surviving that they have persisted in the park for thousands of years! Here we share the fascinating strategies that boreal chorus frogs, western toads, western tiger salamanders, and Columbia spotted frogs [1] use to survive the winter (Figure 2). We describe how various overwintering strategies allow species to coexist and survive in the harsh, winter-dominated landscape of Yellowstone National Park (Figure 3).

**AMPHIBIANS**

Animals with an aquatic phase of life, spent living in the water and breathing with gills; and a terrestrial phase of life, living on land and breathing with lungs.

**ECTOTHERM**

A "cold-blooded" animal whose body temperature depends primarily on external heat sources, such as sunlight. Ectotherms include most fishes, amphibians, reptiles, and invertebrates.

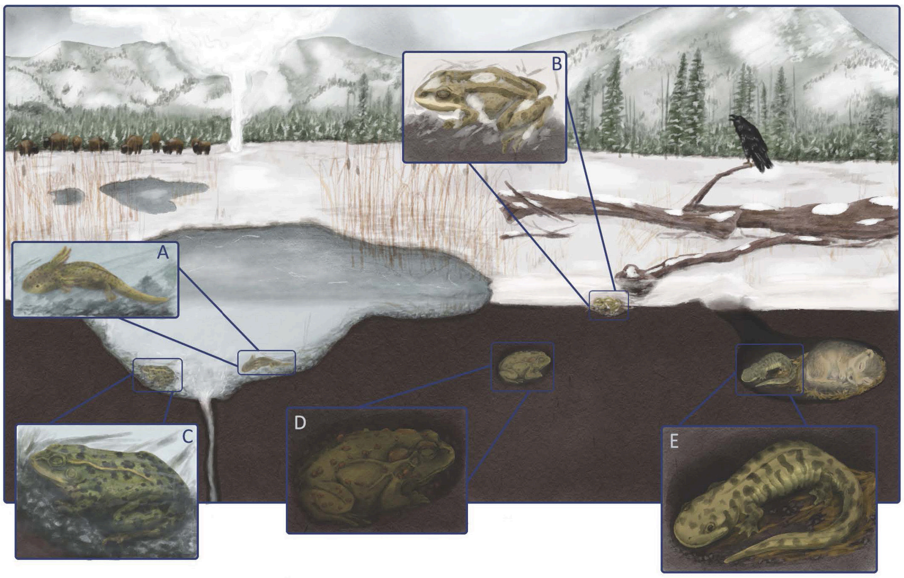


Figure 2

**Figure 2**

A Yellowstone National Park winter landscape, showing four amphibian species in their winter habitats. **(A)** A larval western tiger salamander in unfrozen water with enough oxygen; **(B)** a boreal chorus frog burrowed underneath a log; **(C)** a Columbia spotted frog on the bottom of an unfrozen pond; **(D)** a western toad in a burrow under the frostline; and **(E)** an adult western tiger salamander sharing a burrow under the frostline with other animals (Image credit: Ashelee Rasmussen).

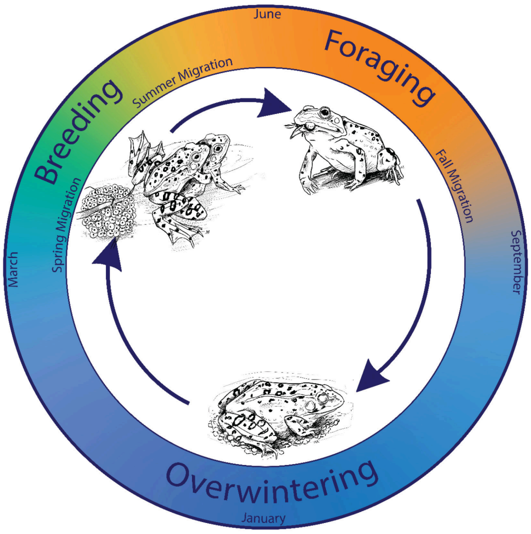


Figure 3

**Figure 3**

Seasonal variation in the activity periods of Yellowstone's amphibians. The colors in the outer circle show activity and reflect the approximate time of year spent in these activities. Note that over half of the time is spent relatively inactive, and under cold conditions (Image credit: Ashelee Rasmussen).

## COLUMBIA SPOTTED FROGS STAY WET

Columbia spotted frogs overwinter in water. They need unfrozen water with enough oxygen for them to survive all winter. For some spotted frogs, that can be just a few hops into a nearby pond. Others have longer journeys to find water bodies that would make good winter homes. These water bodies could be a spring from an underground water source, a deep lake, a pond fed by springs, or the right kind of flowing stream or river. Sometimes these suitable places can be far away and difficult to reach.

Some young spotted frogs in Yellowstone have been found to travel about 460 meters (500 yards) on their first trek to find a suitable winter spot, much of it over dry ground. Some adult spotted frogs go much farther on their journeys from their summer to winter habitats, over rough and rocky terrain. How frogs do this— especially the youngest ones—is still something of a mystery. We think they use vision, smell, an inner compass, and (for adult frogs) memory from previous years. Once in their winter homes, spotted frogs adapt to the cold by slowing their metabolism. They do not eat or grow, but they do not take a long winter nap, either. In winter streams, spotted frogs rest on the bottom of the stream, facing upstream, or they slowly move around under the surface ice of lakes. Frogs with radio transmitters attached to their backs revealed much about their winter activity, showing scientists that they move around in ponds and streams to find the best places to survive. These places could be spots where the water is warmer or has more oxygen that they can absorb through their skin. The frogs sometimes crawl up into cavities next to the water, where they can breathe air and keep their temperatures above freezing. Spotted frogs are early risers in spring. Adult frogs often arrive at breeding ponds with ice and snow still on them from the long Yellowstone winter.

## WESTERN TOADS BORROW WINTER HOMES

Like the spotted frog, western toads do not let their bodies freeze. However, they spend the winter on land instead of in the water. Toads find habitats below the **frostline**, which is the maximum depth at which the soil is frozen. They dig under the ground or use existing tree roots, peat hummocks, or decayed root tunnels. Toads also use underground habitats created by other animals, such as abandoned beaver dams or burrows and tunnels made by gophers, muskrats, and squirrels [2]. The toads slow down their breathing, heart rate, and metabolism to save energy. In this inactive state, they are vulnerable to predators who might eat them!

**FROSTLINE**

The maximum depth at which soil is frozen.

Adult toads can travel almost 2 kilometers (1.25 miles) and burrow over 100 centimeters (40 inches) underground to find good places to overwinter [3]. When the ground around them begins to warm, the toads make their way toward the surface. They emerge from the ground in the spring when the soil thaws and the frostline disappears. Then they find their way to ponds to breed.

## WESTERN TIGER SALAMANDERS HAVE SEVERAL OPTIONS

Western tiger salamanders spend winters in areas also used by other Yellowstone amphibians and mammals. Tiger salamanders are part of a group of amphibians known as mole salamanders. This name comes from the fact that they spend much of the day underground in burrows. **Metamorphosed** (animals who undergo changes in their form and habits when they transform from an immature stage, such

**METAMORPHOSIS**

A change in the form and habits of some animals during transformation from an immature stage (such as a tadpole or larva) to an adult stage (such as a frog or toad).

as a tadpole or larva, into their adult form, such as a frog or toad) tiger salamanders probably overwinter in burrows beneath the frostline. Tiger salamanders are strong diggers [4]. In sandy soil, they can dig burrows large enough to hide themselves in just 10–20 min. Some dig with such strength that they throw dirt into the air during the excavation process. In studies done in the Rocky Mountains, tiger salamanders were the second most common animals found in the burrows of pocket gophers, ground squirrels, and even badgers. That is right, salamanders appear to share the burrows of other animals!

Salamanders have another interesting twist to their overwintering strategy. Some will metamorphose and leave the ponds where they were born. Others will stay in their ponds long enough to develop into adults [5]. These pond dwellers keep their external gills and other larval characteristics. In this form, salamanders can become sexually mature without ever leaving the pond, and they spend their winters underwater. Their greatest danger is the pond freezing solid. This interesting ability to maintain an aquatic form as a reproductive adult happens more in males than in females. Maybe this ability has allowed these salamanders to adjust to the wetter and drier periods over the course of Yellowstone's history.

## BOREAL CHORUS FROGS TOLERATE FREEZING

Like the western toad, boreal chorus frogs do not overwinter underwater. Instead, they rely on leaves, logs, tree roots, rocks, and even layers of snow to help protect them from cold weather near the surface of the ground [6]. Sometimes these frogs will use burrows made by other animals, like rodents. Then, when temperatures drop below freezing, chorus frogs freeze, too!

When boreal chorus frogs freeze, their hearts stop beating, their blood stops flowing, and they even stop breathing. If you were to see a chorus frog in the winter, you might think that it was dead! But the bodies of chorus frogs make a chemical called **glucose** [7]. Glucose is a form of sugar that acts like antifreeze, preventing ice from forming inside the frogs' cells. At the same time, the water in the spaces outside of their cells is allowed to freeze. As long as their cells do not freeze, the rest of their bodies can freeze and they can stay alive for months. As Yellowstone begins to melt in the spring, the bodies of chorus frogs begin to thaw. Soon they are breathing, moving, and making their way back into the wetlands to begin a new year.

**GLUCOSE**

A sugar found in blood that is the main source of energy for animals.

## WHY IS THIS IMPORTANT?

Yellowstone National Park does not have many amphibian species. The four widespread species in the park use diverse strategies to stay alive during the long, cold winter months. Recent studies have shown that ectotherms who commonly live in places with extended cold environments will live longer than their counterparts in warmer areas [8]. Each amphibian species has developed its own successful strategy that has allowed it to live for centuries in these harsh conditions. By occupying different winter habitats, these species can coexist and endure Yellowstone's frigid climate. Studying these behaviors and identifying the essential overwintering habitats of Yellowstone's amphibians is also important for protecting the interconnected water and land habitats necessary for the survival of these incredible animals.

## REFERENCES

1. Koch, E. D., and Peterson C. R. 1995. *Amphibians and Reptiles of Yellowstone National Park*. Salt Lake City: Univ of Utah Press.
2. Breckenridge, W., and Tester J. 1961. Growth, local movements and hibernation of the Manitoba Toad, *Bufo hemiophrys*. *Ecology* 42:637–46. doi: 10.2307/1933495
3. Browne, C. L., and Paszkowski, C. A. 2018. Microhabitat selection by Western Toads (*Anaxyrus boreas*). *Herpetol. Conserv. Biol*. 13:317–30.
4. Semlitsch, R. D. 1983. Burrowing ability and behavior of salamanders of the genus Ambystoma. *Can. J. Zool*. 61:616–20. doi: 10.1139/z83-082
5. Hill, S. 1995. *Migratory chronology of adult tiger salamanders (Ambystoma tigrinum) and survey of larvae of the tiger salamander in the northern range of Yellowstone National Park* (master's thesis). Bozeman, MT: Montana State University. 65 p.
6. Froom, B. 1982. *Amphibians of Canada*. Toronto, ON: McClelland and Stewart.
7. Storey, K. B., and Storey, J. M. 1986. Freeze tolerance and intolerance as strategies of winter survival in terrestrially-hibernating amphibians. *Comp. Biochem. Phys. A* 83:613–7.
8. Cayuela, H., Dorant, Y., Forester, B. R., Jeffries, D. L., Mccaffery, R. M., Eby, L. A., et al. 2021. Genomic signatures of thermal adaptation are associated with clinal shifts of life history in a broadly distributed frog. *J. Anim. Ecol.* 91, 1222–38.

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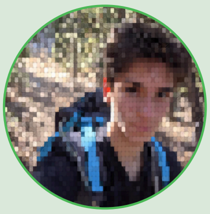

### EVAN, AGE: 16

My name is Evan and I am a science student at a stem charter school. Because of this, science is a very present part in my life and so I take a lot of interest in things like chemistry, biology, and genetics. Outside of school however, I enjoy skiing, handing out with my friends, and most importantly, rock climbing. I also love traveling and a good book.

### LUCY, AGE: 16

A junior in high school who is super interested in science and math, climbing, and learning!

### PACIFIC CREST MIDDLE SCHOOL, AGES: 11–13

This awesome group of students took their science literacy classes seriously and provided great feedback for authors!

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Debra Patla has been engaged with the Yellowstone/Grand Teton cooperative amphibian monitoring program since its earliest days (2000). Her work on amphibians began in 1992 with her M.S. research of a Columbia spotted frog population near Lake Lodge in Yellowstone, with Charles Peterson (Idaho State University). Since then, she has continued annual amphibian survey and monitoring projects in the Greater Yellowstone Ecosystem, witnessing many local changes. Deb is a research associate of the Northern Rockies Conservation Cooperative.

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

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STINA
AGE: 14

UPWARD BOUND STUDENTS (716591)
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

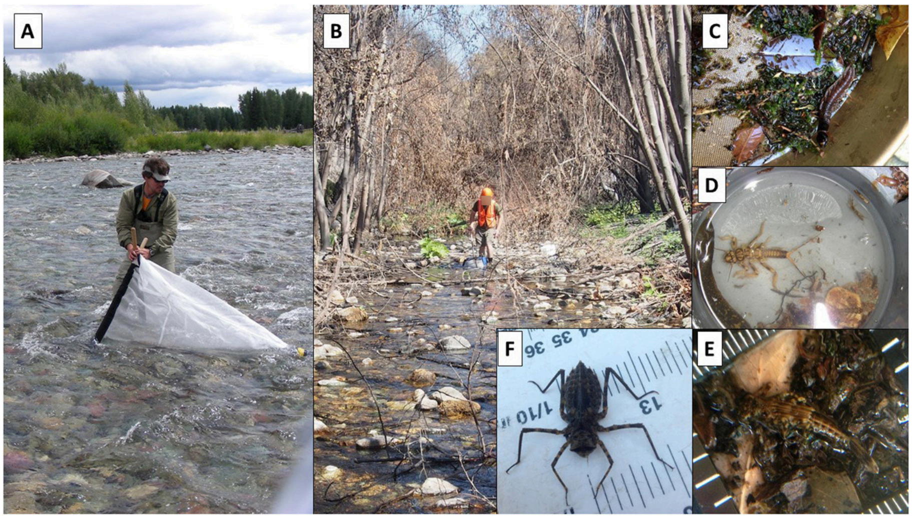


Figure 1

**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

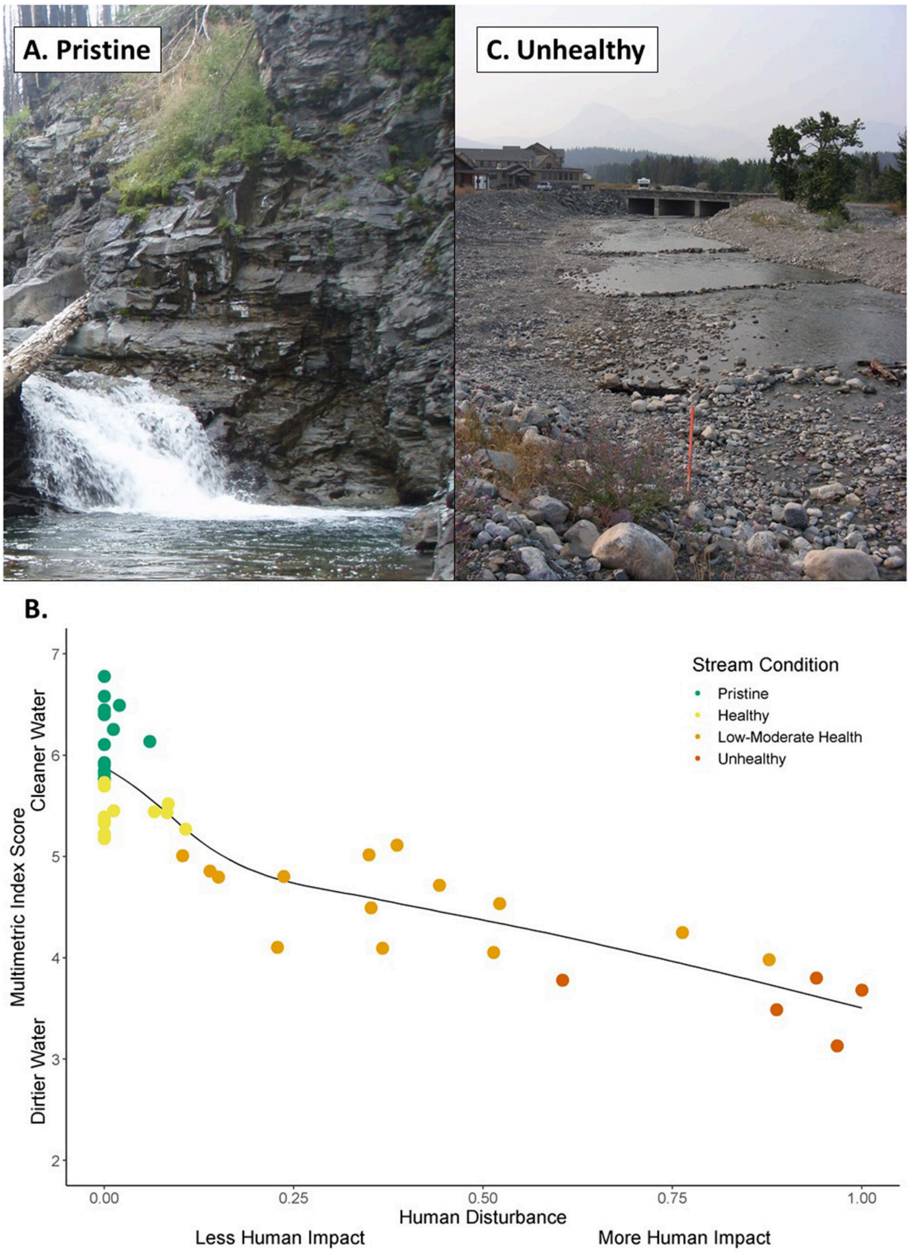


Figure 2

**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.

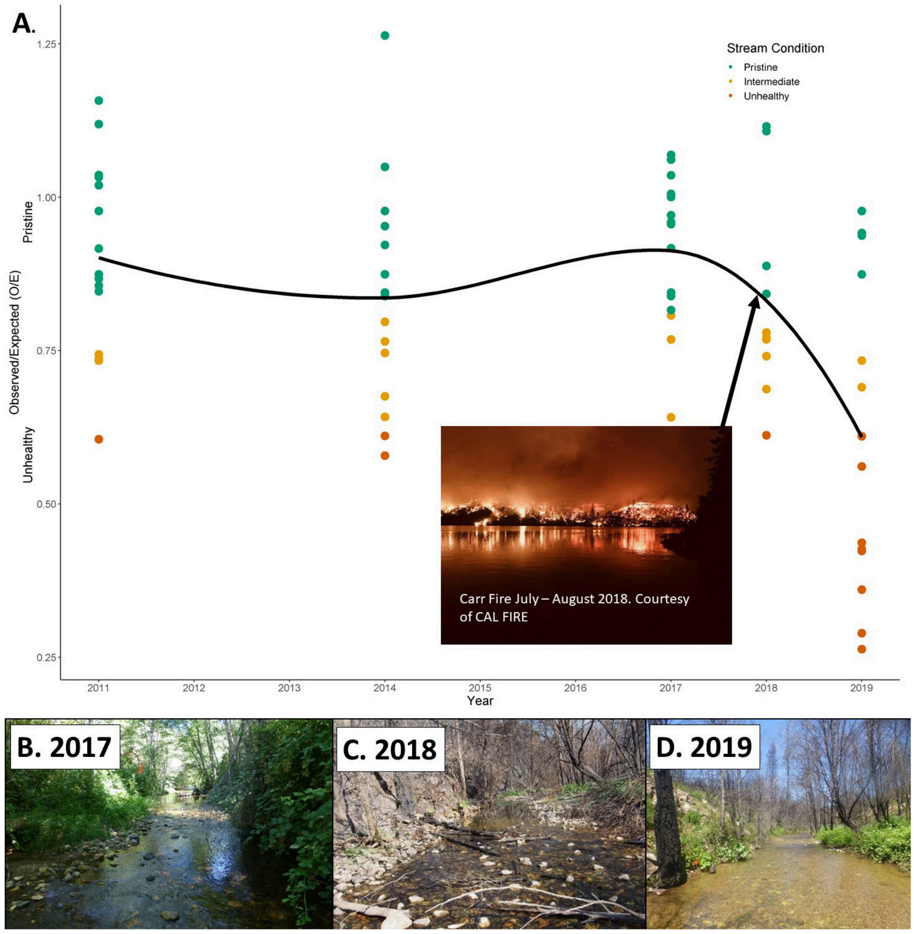


Figure 3

**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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## 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.

## AUTHORS


### ERIC C. DINGER

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

### E. WILLIAM SCHWEIGER

E. William Schweiger is the principal ecologist for the National Park Service Rocky Mountain Inventory and Monitoring Network. He is the lead for developing and implementing multiple long-term ecological monitoring protocols in six national parks in the northern and southern Rocky Mountains. He also conducts collaborative ecological research with several partners in and around these systems in support of the network and its associated parks' long-term goals. When not doing science, E. William Schweiger likes to race cars, play Ultimate Frisbee, and get lost in the wilderness.

### TREY SIMMONS

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.

BIODIVERSITY
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# INDICATOR SPECIES REVEAL ENVIRONMENTAL HEALTH

***Sophie Phillips*** [1*]***, Martha Merson*** [2]***, Nickolay I. Hristov*** [2]***, Louise Allen*** [3] ***and Robert Brodman*** [4]

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YOUNG REVIEWERS:

KAMARA
AGE: 15

SALENA
AGE: 15

When looking around outside, many people see reasons to worry about the environment. Often what they notice are the effects of pollution and climate change, which can be harmful to people, wildlife, and the ecosystems where they live. Understanding the condition of all living and non-living things in an ecosystem is important for maintaining a healthy environment. But collecting information on every element in an ecosystem takes time and effort and is not always possible. Luckily, the United States National Park Service scientists know that collecting data on the condition of one species, called an indicator species, can reveal a lot about the well-being of other species in an ecosystem. Based on what they learn from observing and studying indicator species, park managers can make decisions about restoring plants, using chemicals, and posting signs about fishing rules. In Indiana Dunes

National Park (Indiana, United States), researchers rely on frogs as indicator species.

## INDICATOR SPECIES

Have you ever felt sick and used a thermometer to check whether you have a fever? A fever is an indicator that you are sick and a thermometer is a tool to help determine how sick you are. In the outdoors, certain animals and plants, called **indicator species**, can be used as environmental "thermometers." Researchers measure and monitor the health of indicator species to determine whether the environment where these special animals and plants live is healthy. Without indicator species, scientists must collect many more samples and conduct more tests. Tests and samples can cause disturbances in the environment. Also, when there is more work to do, scientists must find both the time and money to conduct that work (Figure 1).

**INDICATOR SPECIES**

An organism that helps scientists figure out the health of the environment.

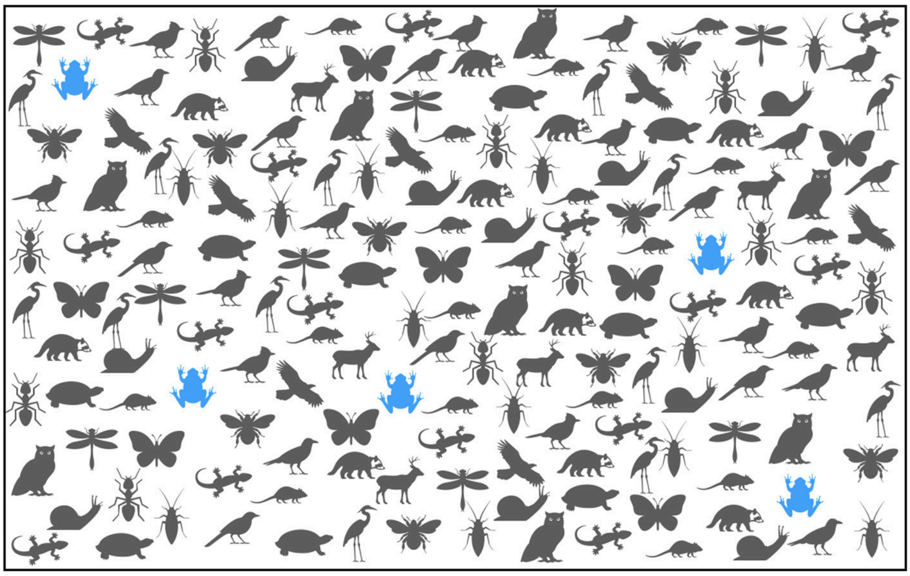

Figure 1

**Figure 1**

Would you rather count all the animals or just the frogs? If there are lots of frogs (the indicator species), then birds, fish, and insects will be present and likely be healthy, too. Fewer frogs indicate that other animals will also be absent or in poor health. (Image Credit: Nickolay Hristov).

## WHAT DO INDICATOR SPECIES TELL US ABOUT THE ENVIRONMENT?

Indicator species can help researchers understand environmental conditions in a variety of ways. Here are two examples. To check on forest habitat quality, researchers look for red cockaded woodpeckers. These birds are picky about their nests. If the right combination of trees is not present, the woodpecker numbers drop. Fewer woodpeckers suggests it is time to pay attention to the health of the forest.

**MERCURY**

A heavy metal contained in thermometers, electronics, and medicines. Mercury can be toxic in the environment.

Common dragonflies living in ponds or wetlands are useful indicator species because they reveal a lot about pollution. **Mercury** is a nasty

**toxin** that affects reproduction and brain function in wildlife and people. Heavy metals like mercury travel on the wind from polluting factories and settle in ponds and soil. To gather data on mercury, U.S. national park rangers and students collected dragonflies in their **larval stage**[1] [1]. Yes, indicator species can be tiny in size. If you have ever scooped up water from a pond, you might have seen organisms smaller than a baby's fingernail. Some of these organisms are young dragonflies. Dragonfly larvae eat other insects. Because those insects once ate plants contaminated with mercury, anything that eats them, like dragonfly larvae, takes in that toxic metal. The toxic mercury levels in dragonflies then continue to build up in fish and other wildlife that eat those insects. Laboratory analysis of hundreds of dragonfly larvae provided scientists with information about mercury levels in ponds and wetlands across the nation. As a result, rangers and public health professionals know which spots should be monitored closely. Using dragonflies as an indicator species, scientists can track where mercury is or is not a threat to wildlife, and they can post signs to warn people about the risks of eating fish from certain areas.

**TOXIN**

A poison that causes a disease when present even at a very low quantity in the body.

[1] For more information, see https://www.nps.gov/articles/dragonfly-mercury-project.htm.

**LARVAL STAGE**

The immature form of an insect or other animal that goes through a transformation before adulthood.

Each indicator species gives researchers valuable clues. An excellent example is the long-term research on frogs in lands around the Chicago area (Illinois, United States), which includes Indiana Dunes National Park (Indiana, United States). Fish, frogs, salamanders, and dozens of plants—with fun names like duckweed and Pitcher's thistle—live there. In and near the park, researchers focus on two indicator species: green frogs and gray tree frogs. Both make great indicator species because they are super easy to find. They are noisy, so researchers know where to look for them. If these species hid all the time or were rare, they would not make good indicators. They would be much too hard to find, even in a healthy environment.

Frogs are fascinating because they spend the beginning of their lives in the water and then they move onto land. When they are babies, they move in the water like fish, and eat tiny plants called phytoplankton. When the tadpoles grow legs and move to land, they eat animals like worms and insects. Frogs are never safe from being eaten. In the water, they are a snack for snapping turtles and fish. When frogs are grown up, raccoons hunt them. The fact that frogs live in and out of water makes them awesome indicators because they can tell researchers about the environmental health of both land and water (Figure 2). When these frogs are abundant, their predators are well-fed and can have more healthy offspring too! If frog populations decrease, it is noticeable. Their predators have a tough time finding food and some of the flies and moths that frogs usually eat can increase in numbers and become even more of a problem for humans.

Another reason frogs make great indicator species is the fact that they have thin, moist skin that breathes. Their skin's unique structure lets water enter their bodies. Frogs are super sensitive. When in contact with polluted water, they will absorb harmful substances that are

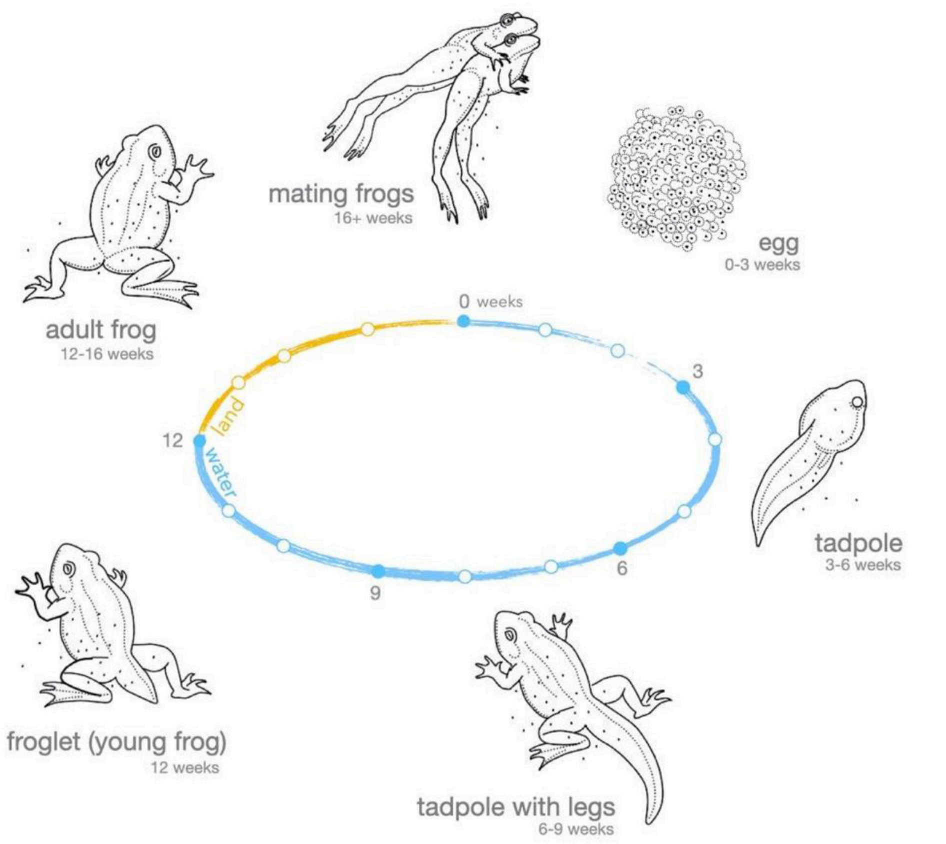

Figure 2

**Figure 2**

Frogs make great indicator species because they live both on land and in the water. From birth to 12 weeks old, they can only live in the water. After 12 weeks, they can hop out of the water and enjoy living life on land and in the water. (Image Credit: Nickolay Hristov).

present in the ecosystem, such as **pesticides**, fertilizers, medicines, and toxic chemicals used in manufacturing. Conducting studies to measure pollutants in water is expensive and time consuming. So instead, researchers monitor the presence and health of frogs to determine if pollutants are a problem.

**PESTICIDES**

Substances used on plants to kill insects or other organisms harmful to the plant. Pesticides can have undesirable or unanticipated side effects on other plants and animals.

Researchers who are curious about the health of Indiana Dunes National Park study gray and green frogs to understand if the wetlands are healthy places for wildlife to eat and breed (Figure 3). Scientists do an annual count of the frogs. If the number of frogs is roughly the same from year to year, then the environment is stable. If the frog population numbers get smaller from one year to the next, then researchers discuss possible actions to make conditions more favorable for frogs. A decline in the population of these two frog species indicates that the health of other species living in the same habitat might be at risk.

## HOW DO RESEARCHERS LOOK FOR INDICATOR SPECIES?

Scientists use three of the five senses to study indicator species: hearing, sight, and touch. The first thing scientists do to check the health of the wetlands of Indiana Dunes National Park is to listen for


Figure 3

**Figure 3**

Scientists look to frogs to indicate whether the environment is sick. If frogs are not doing well, then scientists can tell the environment is not doing well either. (Image Credit: Chris Tullar).

the sounds of gray tree frogs and green frogs. Once they hear their songs, they begin to locate the frogs by sight. They are looking for the bright, light green of the green frog and the striped gray of the gray tree frog. They look under dried leaves and next to tree roots to find them. The scientists catch the frogs using nets and quickly pick them up before they hop away.

We know frogs are very sensitive to chemicals. When researchers pick up frogs, they look for signs of chemical injury on each frog's skin. But researchers also look for clues that the frogs have absorbed chemicals through their skin. Often, pesticides run off from farms and surrounding land, ending up in the water. One pesticide, Atrazine, is used to kill weeds in corn fields. Increased Atrazine use causes more water contamination, which results in greater harm to frogs. Once pesticides are present in the water, frogs' biological traits can get messed up. Pesticides like Atrazine and chemicals like DDT disrupt the sexual development of frogs [2]. For example, male frogs will develop *both* male and female sex organs. Researchers have also noticed that male frogs exposed to chemicals have smaller vocal cords. Frogs with smaller vocal cords have a hard time making sounds to attract mates. If they cannot attract mates, they cannot reproduce. If researchers see a frog with strange organs, they suspect frogs in the area have been exposed to chemicals through their skin. Therefore, other species in the environment are likely suffering from unhealthy water, too. These are big problems for frogs and for the animals that eat them. If frogs cannot mate, the number of frogs declines. Frogs must reproduce to keep their species alive. Without indicator species like frogs, researchers would have a much harder time finding out what is happening in the environment, and many more animals would suffer.

## CONCLUSION

Indicator species are storytellers that researchers often rely on to determine the health of the environment. These important species save researchers time and money, draw attention to environmental problems, and provide managers with important information so they can start nursing the environment back to health. By being in the environment, calling out, and making themselves visible, indicator species help make a difference for not just their species, but for all the animals and plants that live with them. So, here is a big thank you to all the indicator species that are helping researchers as they try to protect the environment!

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## AUTHOR DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. More information about iSWOOP is available at www.iSWOOPparks.com or contact Martha_Merson@terc.edu.

## REFERENCES

1. Eagles-Smith, C. A., Willacker, J. J., Nelson, S. J., Flanagan Pritz, C. M., Krabbenhoft, D. P., Chen, C. Y., et al. 2020. A national-scale assessment of mercury bioaccumulation in United States National Parks using dragonfly larvae

as biosentinels through a citizen-science framework. *Environ. Sci. Technol.* 54:8779. doi: 10.1021/acs.est.0c01255
2. Sanders, R. 2010, March 1. Pesticide atrazine can turn male frogs into females. *Berkeley News*. Available online at: `https://news.berkeley.edu/2010/03/01/frogs/`.

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## YOUNG REVIEWERS

### KAMARA, AGE: 15

My name is Kamara. I enjoy making long-rise bread on the weekends. This was my first time reviewing a scientific paper. It was really fun to be part of the problem solving process before publication.

### SALENA, AGE: 15

My name is Salena and I love acting, playing music, and reading. I like science because it allows me to better understand the world around me.

## AUTHORS

### SOPHIE PHILLIPS

Sophie Phillips studies energy and environmental policy at the University of Delaware, U.S. She is also a Research Assistant for the Water Resource Center within the Biden School of Public Policy and Administration. As an undergraduate, she worked in the Robotics Discovery Lab, which is part of the University of

Delaware. Her research interests include wildlife conservation, environmental justice, and the connection between environmental history and race within the United States. Sophie inspired many people as Miss Delaware in 2021–2022 and plans to continue her public service either as a state representative or as a park ranger. *sophiekp@gmail.com

**MARTHA MERSON**

Martha Merson has co-led the project Interpreters and Scientists Working on Our Parks along with Hristov and Allen. Merson was never an outstanding science student, but she was curious about scientists' work. She has worked closely with scientists and park rangers to bring science stories to public audiences.

**NICKOLAY I. HRISTOV**

Nickolay I. Hristov is a scientist with interests in information and learning design and population dynamics. His research, done in tandem with Louise Allen, using LiDAR technology, has provided more accurate counts of clustering species like monarchs in Mexico and cave-dwelling bats in the south-central United States. Nick is a native Bulgarian and a huge fan of U.S. national parks.

**LOUISE ALLEN**

Louise Allen is a biologist and higher-ed administrator, formerly a zookeeper, with expertise in undergraduate mentoring. Her research has focused on anthropogenic impacts on behavior and stress in wildlife, including bats. She enjoys conducting research with park rangers and undergraduates on protected land.

**ROBERT BRODMAN**

Dr. Robert Brodman's research focuses on conservation of amphibians and reptiles, with questions ranging from ecology to animal behavior. He has developed undergraduate research programs centered on ecotoxicology studies investigating the impacts of herbicides, habitat restoration, and farming practices. His long-term studies in northwest Indiana have helped the National Park Service make decisions about wetland restoration projects and more. This video shows Dr. Robert Brodman walking through the wetlands of Indiana Dunes National Park. The video shows some of the animals that live there (`https://www.terc.edu/iswoop/collaborating-scientists/`).

frontiers FOR YOUNG MINDS
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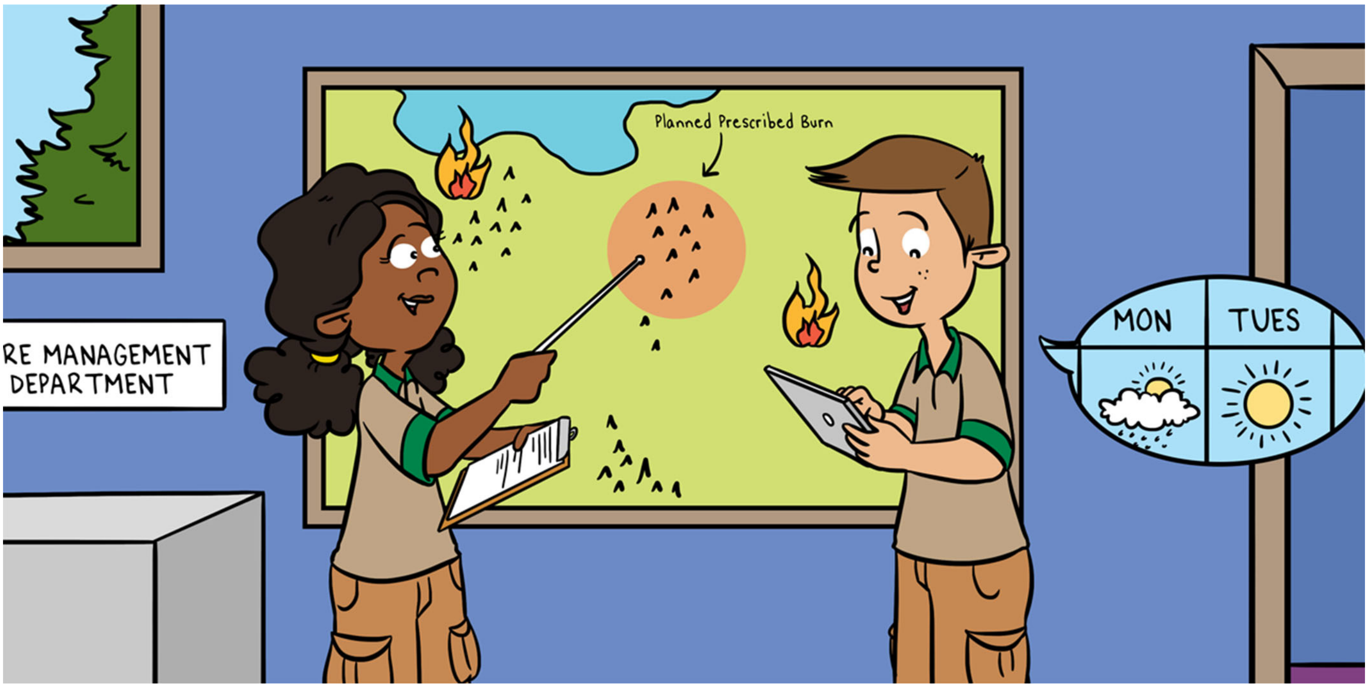


# RISING FROM THE ASHES: THE ROLE OF FIRES IN NATIONAL PARKS

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YOUNG REVIEWERS:


JASON
AGE: 13


TESSA
AGE: 13


VIOLET
AGE: 12

Fire is a natural and healthy part of many ecosystems, and many plant species rely on it to reproduce. Some species require the actual heat and flames for their seeds to be released and sprout. Other species rely on fire to burn off dried needles and leaves on the ground as well as many of the shrubs and small trees. This opens up the forest and allows more space and light for small plants and trees. While fire is a good thing for many plants and ecosystems, this is not the case everywhere. In areas that get high amounts of rain, ecosystems are not adapted to fire. Human-caused fires in these places can be devastating to the plants there. It is the job of fire managers and ecologists to manage wildfires, make decisions about fire suppression, and decide if additional fires are needed in key ecosystems.

## ARE FOREST FIRES A GOOD THING OR A BAD THING?

We have all seen images of raging forest fires that leave scorched bare ground and trees blackened like charcoal. As our climate changes, some wildfires are becoming more severe, killing trees that typically survived past fires. Many people do not realize, however, that fire is an important natural process in a variety of forests. Some ecosystems require fire to remain healthy, and the plants and animals that inhabit these places are adapted to periodic burns [1]. Some trees have thick bark that acts as insulation to protect them from fire, or cones that open and disperse seeds only after experiencing high heat from a burn [2]. After a fire, new trees and plants grow in the area that burned. For ecosystems that are adapted to fire, you can think of it as nature's way of hitting the reset button. Unfortunately, people did not always recognize the importance of fire.

For many years, people actively suppressed fires. This means people put out *all* forest fires as quickly as possible. Many of the problems that we see with large, intense wildfires today are the result of years of fire suppression. For example, in the absence of fire, fuel can build up. Fuel can include both living vegetation, such as shrubs and mosses, as well as dead trees that are still standing or have already fallen. Fire suppression over many decades results in conditions that are unhealthy for the forest and dangerous to humans [3]. Fortunately, scientists now see the important role that fire plays.

**SURFACE FIRE**

A fire that burns just above the ground. This typically burns old leaves and needles as well as living grasses and plants and allows more sunlight to reach the ground.

**CROWN FIRE**

A fire that burns the top part of the tree, where the leaves or needles are.

**CANOPY**

The highest part of a forest, including the leaves or needles and upper branches.

**SEROTINOUS CONE**

A cone of a conifer tree that is closed shut by a substance called resin. When a crown fire happens, the resin burns off, and the cone releases its seeds.

**FIRE REGIME**

The pattern of naturally occurring fires. The fire regime of an area includes such information as the length of time between fires and whether they are surface or crown fires.

## TYPES OF FIRES

Fire ecologists (scientists who study forest fires) classify fires into two main types, although combinations of the two can also happen. **Surface fires** burn the grasses and broad-leaved plants that grow just above the ground level (Figure 1). Grasses are especially well-adapted to survive surface fires. **Crown fires** burn the **canopy**, or the top parts of trees where the leaves grow (Figure 1). Where crown fires occur, trees with **serotinous cones** release their seeds. Serotinous cones only release seeds after they are exposed to the high heat of a fire. Other traits used to classify fires include severity, frequency of occurrence in a given region, and size. All of these characterize the **fire regime** for a place, which is closely tied to the local plants and climate or, in other words, the local ecosystem.

## FIRE IS IMPORTANT IN MANY ECOSYSTEMS…BUT NOT ALL!

In the Appalachian Mountains, oaks are the most common trees in the oak-hickory forests that stretch for hundreds of miles along the ridgetops from Alabama to New York. Animals of all sizes depend on the oaks, from the insects that hide in the trees' craggy bark, to the

Figure 1

**Figure 1**

The two main types of forest fires are surface fires (left) and crown fires (right). Surface fires burn off the leaves and kill small saplings of species not adapted to fire. The ground becomes a blank canvas with high light creating perfect conditions for seedlings of fire-adapted species to take hold. In crown fires, the cones of the mature, large trees open up in the heat and flames and their seeds scatter on the forest floor. The seedlings that grow from these seeds thrive in the high light of this new environment. Photos: Left: NPS, Right: Chris Havener.

chipmunks and black bears that rely on acorns (the oaks' seeds) to survive long, cold winters. Adult oak trees have thick bark that protects them from surface fires, while young oaks have long, thick roots full of nutrients, to fuel the trees' regrowth after fire. But Appalachian oak forests have a problem. After decades of fire suppression, the oak seedlings sprouting from acorns do not have enough sunlight or space on the forest floor to grow into mature trees [4]. Surface fires create the right environment for oak seedlings to thrive, by creating openings in the forest canopy and removing tree species such as maples that create dense shade. Surface fires allow oak forests to regenerate, and these fires protect habitat for thousands of plants and animals in the Appalachian Mountains.

**UNDERSTORY**

The lowest layer of the forests. This includes grasses, herbs, shrubs, and very small trees.

In savannas of the upper Midwest, black oaks and bur oaks dominate the landscape, while the **understory** species include not only grasses, but also broad-leaved species that are important to pollinators, and blueberries, which feed wildlife. Here, fire ecologists strive to maintain open conditions so that these important understory species can persist. The goal is to burn often enough so that there is generally not more than 40% canopy closure (you can think of this as 60% open sky). This helps ensure that important understory species receive enough light to survive and reproduce.

Of course, fire is important not only for oaks, but for conifers, or "evergreen" tree species, as well. In the Sierra Nevada mountains of California, giant sequoias are known for their size, long lifespan, and need for fire. Scientists who examine tree-ring samples have shown that fires burned often in the past, occurring every 6 to 35 years [5]. When managers suppressed fires for many decades, the number of young sequoias sharply declined. Why did that happen? Fire plays a key role in the sequoia life cycle. Serotinous cones high up in the trees release many seeds when exposed to heat from a fire. Fire also uncovers bare soil by burning dead branches and leaves. The sequoia seeds, and eventual seedlings, need bare soil to take root, and sunny gaps in which to grow. Adult sequoias have survived most fires because their thick bark resists burning and protects them from a

Figure 2

**Figure 2**

Firefighters conducting a prescribed burn in a giant sequoia forest in central California. They use drip torches to ignite material on the ground. Prescribed fires are carefully planned, and firefighters use natural barriers (like large rocks and trails) as well as additional "fireline" that they dig to remove burnable materials and contain the fire within a specific area. Prescribed burns can range in size from tens to hundreds to thousands of hectares depending on location, objectives, and safety considerations. Photo: Tony Caprio.

fire's heat. Since the 1970s, fire managers have used **prescribed burns** and lightning-ignited fires to restore fire to sequoia forests (Figure 2). Scientists monitoring the forest after fires find young sequoias are more abundant again.

Fires are also common in other western conifer forests. Many people are aware of fires in the western United States; fewer people realize how important fire is in Alaska. The summers in interior Alaska can be warm and lightning is common. The black spruce forest, or **boreal forest**, is adapted to both surface and crown fires and is designed to burn. Low-hanging branches drape into the flammable moss layer and ground vegetation. When a fire starts, it spreads across the ground and up to the crown of the tree—a crown fire! Although the trees are not well-protected from fire, the seed cones at the top of the trees are serotinous, so seeds are released, rejuvenating the forest. Young black spruce seedlings often begin to grow in the first 5 to 10 years after a fire (Figure 3). Shrubs and leafy trees such as birch and aspen come back quickly after fire, either from seeds or by re-sprouting from below-ground roots. These young forests are important for wildlife. Moose browse the leafy shrubs and trees and voles eat the new green plants. Voles are prey for other animals, including owls, fox, and

**PRESCRIBED BURN**

An intentional fire that fire managers conduct for the benefit of plants, animals, and soil. Managers ensure that the burn is carried out in a safe and controlled manner.

**BOREAL FOREST**

The northernmost, and most extensive, forest type in the world. In North America, boreal forest extends from Alaska across Canada and into the Great Lakes region of the United States.


Figure 3

**Figure 3**

A black spruce site in Alaska. The photo on the left was taken 2 years after a fire that burned both the crown and the surface. Note the grasses that are already abundant. The figure on the right is the same site 15 years after the fire. Note that there are multiple black spruce saplings visible in the photo, and that many of the dead trees have fallen. The scientists in these photos are monitoring the numbers and types of plants that have grown back after the fire at different time periods. Photo: NPS.

marten. Fire is a necessary part of the landscape in Alaska. Rather than being suppressed, many fires are managed, not only to protect people and communities, but also to help the forests and wildlife.

In contrast to Alaska, Hawai'i is quite different. Fire is usually very harmful to Hawai'i's native vegetation. Before people settled on these islands, fire was uncommon, mainly because lightning is not common [6]. Hawai'i has fewer native plant species than does the United States mainland. The plants that do grow there have adaptations that helped them to disperse across the ocean (such as seeds that could float, or had "wings"), but not to survive fires. Fires are now common in Hawai'i—most are accidentally started by people. These fires destroy the native vegetation, and the native plants are not good at recovering after this happens. One of the biggest problems is non-native species. These are brought over from elsewhere—usually accidentally—and they are sometimes much better at dealing with fire. After a fire, these non-native species often grow so quickly that the native plants cannot keep up with them, and do not ever grow back. Because of this, we try to put out fires in Hawai'i as quickly as we can!

## MANAGING FIRE IS A BALANCE BETWEEN RISKS AND BENEFITS

Most national parks have developed fire-management plans that identify priorities and approaches for managing wildfires. Unplanned, human-caused fires are nearly always suppressed as soon as possible, since they usually occur in places or under conditions where they may threaten human life or property, as well as natural or cultural resources like wildlife, plants, or historic buildings. At higher elevations or in remote wilderness, lightning-caused fires may be managed and monitored if they do not cause threats to human life or property. These fires may benefit forests, meadows, shrublands, or other park ecosystems.

Some national parks also conduct prescribed burns. Each year, park managers identify the type, number, and timing of prescribed burns they hope to conduct. For a prescribed fire to be approved, certain conditions must be met. The weather must be favorable (without extreme winds or very dry conditions) and enough fire staff must be available to manage the fire.

## WE NEED FIRE

Fire is a natural, important process in many ecosystems. Without it, fire-dependent forest types will be lost from national parks, eliminating important habitats for animals and plants that depend on these forests. Decades of fire suppression and a changing climate can contribute to extremely severe fires that convert forests into other vegetation types, such as shrublands or grasslands. Therefore, for forests adapted to periodic fire, it is important that the National Park Service and other land management agencies allow fires that start from natural sources to burn when possible, in addition to conducting prescribed burns. This will result in healthier forests, improved wildlife habitats, and safer conditions for people who live near or spend time in forests.

## REFERENCES

1. Pausas, J. G., and Keeley, J. E. 2019. Wildfires as an ecosystem service. *Front. Ecol. Environ.* 17:289–95. doi: 10.1002/fee.2044
2. Schwilk, D. W., and Ackerly, D. D. 2002. Flammability and serotiny as strategies: correlated evolution in pines. *Oikos* 94:326–36. doi: 10.1034/j.1600-0706.2001.940213.x
3. Turner, M. G., Romme, W. H., and Tinker, D. B. 2003. Surprises and lessons from the 1988 Yellowstone fires. *Front. Ecol. Environ.* 1:351–8. doi: 10.1890/1540-9295(2003)001[0351:SALFTY]2.0.CO;2
4. Brose, P. H., Dey, D. C., and Waldrop, T. A. 2014. *The Fire—Oak Literature of Eastern North America; Synthesis and Guidelines*. General Technical Report NRS-135. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.
5. Swetnam, T. W., Baisan, C. H., Caprio, A. C., Brown, P. M., Touchan, R., Anderson, R. C., et al. 2009. Multi-millennial fire history of the Giant Forest, Sequoia National Park. *Fire Ecol.* 5:120–50. doi: 10.4996/fireecology.0503120
6. Smith, C. W., and Tunison, J. T. 1992. "Fire and alien plants in Hawai'i: research and management implications for native ecosystems," in *Alien Plant Invasions in Native Ecosystems in Hawaii: Management and Research*, Stone, C. P., Smith, C. W. and Tunison J. T. (eds). Honolulu: University of Hawai'i Press. p. 394–408.

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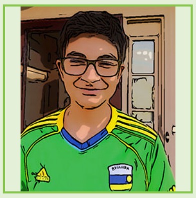
## YOUNG REVIEWERS

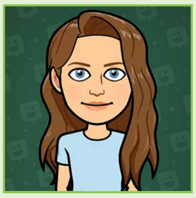


### JASON, AGE: 13

Hi! My name is Jason. I like science and I want to study paleontology in college.

### TESSA, AGE: 13

My name is Tessa and I live in Oregon. I can remember many summers with long days of bad wildfire smoke. I like to read fantasy books. I am also interested in the evolutionary biology of unicorns.



### VIOLET, AGE: 12

My name is Violet. I live in Oregon. I am 12 years old and my hobbies are skiing and kayaking. I love reading. My favorite book is *Number The Stars* by Louis Lowry. I like walking downtown with my friends and looking in the store windows.

## AUTHORS

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Suzanne Sanders is a forest ecologist with the National Park Service, working at nine national parks in the Great Lakes region. She studies how forests respond to natural and human-caused changes in the environment. In her free time, she enjoys getting out and biking or skiing on the trails of northern Minnesota. *suzanne_sanders@nps.gov

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Linda Mutch is a science communication specialist with the Inventory and Monitoring Division of the National Park Service. She uses a variety of methods to communicate science findings to different audiences, from national park managers to the public. She previously worked as a forest ecologist and as a firefighter. She loves to hike, bike, ski, and go birding.

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Mark Wasser is an interdisciplinary biologist with the Inventory and Monitoring Division of the National Park Service in Hawai'i. He mostly makes maps, but he also works to bring scientists and fire managers together during fire responses, and to help firefighters do their jobs while protecting resources and plant communities. Mark loves to hike, fish, and grow plants, but is very bad at surfing.

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Jennifer Barnes is a fire ecologist with the National Park Service in Alaska. She studies what happens before, during, and after a fire. Her work helps fire managers understand how fires burn and the effects of fire on vegetation, soils, and wildlife habitat. Jennifer loves to garden, fish, and ski in Alaska.

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Stephanie Perles is a plant ecologist with the Inventory and Monitoring Division of the National Park Service. She studies how forests in national parks are changing, so that parks managers can use forest health data to protect healthy, resilient forests in parks. When not hiking in the forest looking at plants, Stephanie enjoys gardening and biking.

BIODIVERSITY
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# WHAT'S THE BUZZ ABOUT NATIVE BEES?

***Jessica Rykken*** *

*Denali National Park and Preserve, AK, United States*

YOUNG REVIEWERS:

DISCOVERY CHARTER SCHOOL
AGES: 13–14


EVA
AGE: 13


MAPLE
AGE: 13

Most plants depend on insects for pollination. Honey bees pollinate many of the foods people eat, but did you know that wild plants, and animals like birds and bears, also depend on pollinators? Native bees are the most diverse and efficient pollinators. Thousands of bee species transport pollen between plants in deserts, forests, mountains, meadows, and many other habitats. This service helps plants reproduce successfully, and the plants provide food and shelter for other animals. Bees are important for keeping our wild landscapes healthy. Scientists are discovering that climate change and other human-caused threats are changing bee populations. Therefore, it is important that we learn more about pollinators in wild places like national parks and that we support bees in our own backyards.

## THERE IS MORE TO BEES THAN HONEY

When you think of a bee, what kind of bee do you imagine? Most people are familiar with honey bees. These bees are important **pollinators** for many of the plants that farmers grow and that people

**POLLINATOR**

An animal that moves pollen from the male anther of a flower to the female stigma of a flower which begins the process of producing a new seed.

like to eat, like almonds, apples, and pears. But honey bees have not always lived in North America. People brought them from Europe hundreds of years ago, to help pollinate their crops and to make honey. Before honey bees arrived in North America, there were many native bees pollinating wild plants. Native bees continue to be essential pollinators in parks and other wild landscapes today.

You might wonder why we need pollinators in wild places where people do not grow food. If you have ever hiked in a mountain meadow full of wildflowers, walked along a stream early in the spring when the pussy willows have just emerged, or been lucky enough to see a super bloom of flowers in the desert, you have seen the work of pollinators. Without bees and other pollinators, most of these plants would quickly disappear [1].

Not only plants benefit from pollinators. Animals like bears and birds eat seeds and fruits from pollinated plants. In Denali National Park and Preserve in Alaska, grizzly bears eat huge numbers of blueberries at the end of the summer. This helps prepare bears for their winter hibernation, when they will not eat for many months. Bumble bees pollinate blueberry plants, so without them, the bears would not have enough to eat. American robins, blue jays, and other birds eat berries too, like cherries, raspberries, and elderberries. Bees also pollinate all these plants. Without native bees and other pollinators, our wild places would lack the beautiful colors and shapes of flowers and there would be less food for many animals.

## HOW DOES POLLINATION WORK?

Pollinators are animals that carry pollen between plants. Most pollinators are insects, such as bees, butterflies, beetles, flies, and wasps. These insects feed on **nectar** and **pollen** from flowers. As the insects move between plants to feed, tiny grains of pollen stick to their bodies and then later get brushed off onto other plants (Figure 1). Many plants must be pollinated by insects to produce seeds that will grow into new plants. This kind of win-win relationship, in which the plants need help from the pollinators to reproduce successfully and the pollinators need the plants for food, is known as a **mutualism**.

Of all the insect pollinators, bees are the best at carrying pollen on their bodies. That is because they feed on nectar and pollen just like other pollinators, but they also carry pollen back to their nests to feed their young. So, bees have areas on their bodies designed to carry big loads of pollen (Figure 2). Bumble bees have little baskets on their hind legs to carry pollen balls mixed with nectar. Other bees have hairy legs or hairy bellies where pollen grains can stick. The more pollen bees carry on their bodies, the more likely it is that some will accidentally brush off on the plants they visit, and this makes them really good pollinators.

**NECTAR**

A sugary liquid made by plants to attract pollinators. The sugar-filled nectar provides energy to pollinators.

**POLLEN**

Tiny dust-sized grains produced by the male part of a flower that contain the plant's sperm. Many pollinators eat pollen because it contains a lot of protein.

**MUTUALISM**

An interaction between two or more species in which each species benefits.

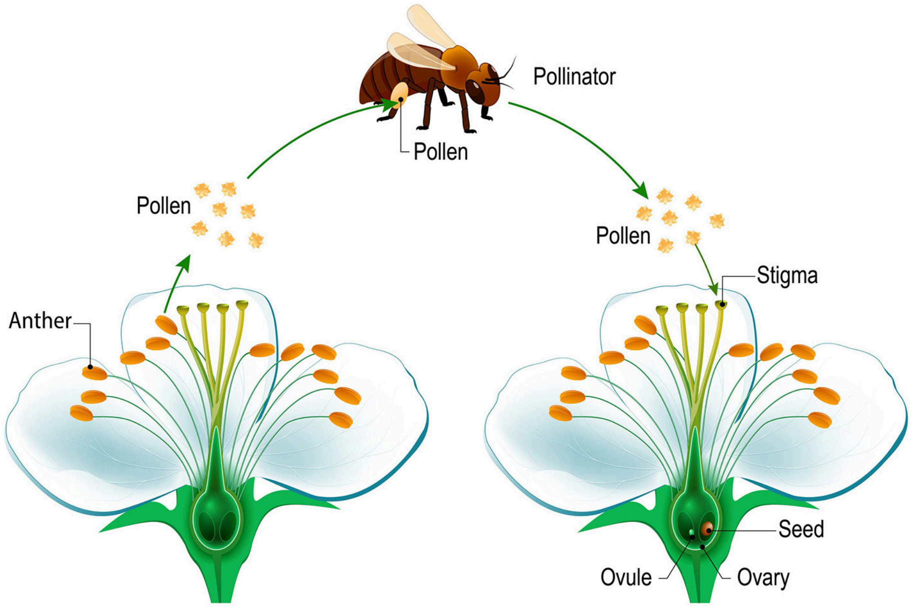


Figure 1

**Figure 1**

A bee lands on a flower to feed and collect pollen. Pollen grains from the anthers (male part of the flower) stick to the bee's body. The bee flies to another plant and, while it is foraging, some of the pollen grains from its body accidentally brush off onto the stigma (female part of the flower). Pollen on the stigma will grow a long tube that reaches down into the ovary which contains the ovule (egg). Sperm from the pollen passes down the pollen tube and fertilizes the ovule to create a seed. Eventually the seed will grow into a new plant.

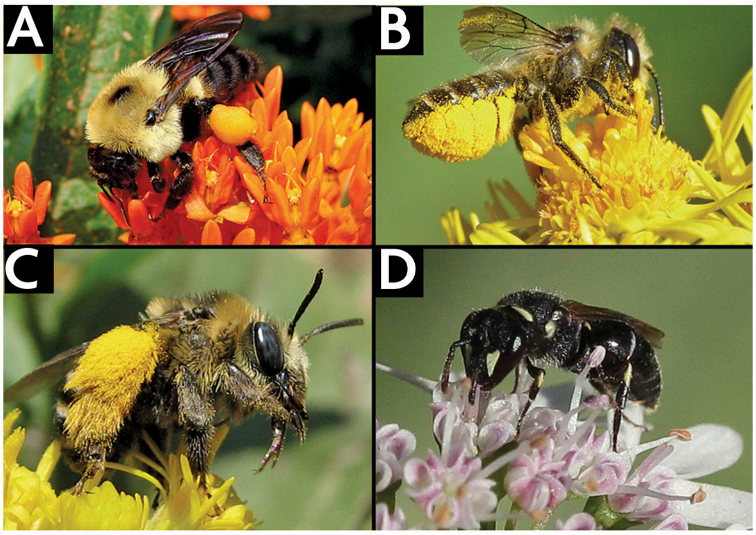


Figure 2

**Figure 2**

Most bees carry pollen back to the nest on various parts of their bodies. **(A)** Many bees carry pollen on brushes of hair. **(B)** Leafcutter bees have hairy bellies for carrying pollen. **(C)** Long-horned bees carry pollen on their hairy legs. **(D)** This tiny masked bee swallows most of the pollen it collects and then throws it back up when it returns to the nest! [Image credits: `https://education.eol.org/observer_cards` (BY-NC-SA)].

## NATIVE BEE DIVERSITY

Native bees live all over the world, in almost every habitat where plants grow. In North America, there are close to 4,000 species. That is about four times the number of bird species found on the continent! Bees come in many colors, sizes, and shapes. They also have many different nesting, feeding, and social behaviors. The kind of plant a bee prefers to visit depends on the length of the bee's tongue. Bees with long tongues are best at getting nectar from flowers with deep necks, like blue bells. Bees with short tongues typically visit more open flowers, like sunflowers.

Native bees also vary in their social structure and nesting habits. Bumble bees are social bees. They live in colonies with one queen who lays all the eggs, and lots of workers who gather food from flowers and feed the young (Figure 3A). Bumble bees have thick, long fur and can shiver their bodies to warm up. They can live in cold places like mountain tops and way up north in the Arctic. If you wanted to go to one place in the world to see a lot of bumble bees, the Himalayan mountains in Nepal and Tibet have more species than anywhere else.

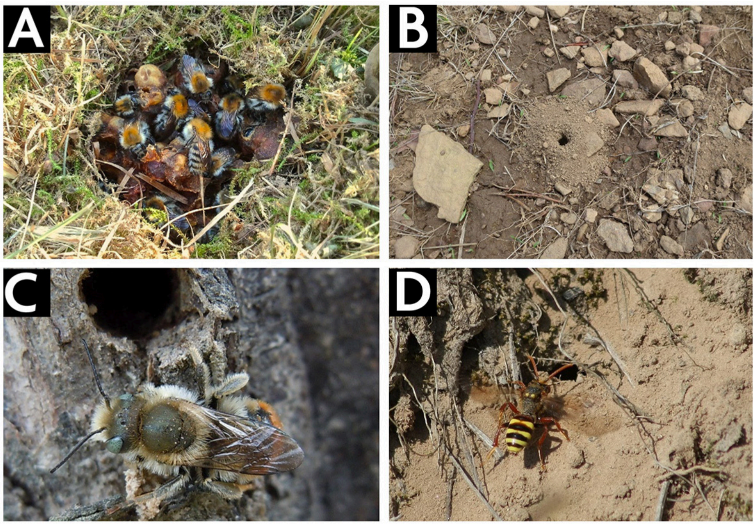

Figure 3

**Figure 3**

There are many kinds of bee nests. **(A)** Bumble bees often nest in abandoned mouse burrows under the ground. **(B)** About 70% of all bees nest in the soil, often in open patches of ground with few plants. **(C)** This mason bee is using an abandoned beetle hole in the trunk of a tree for her nest. **(D)** Cuckoo bees search out the nests of other bees (in this case, a mining bee nest in a sandy bank) in which to lay their eggs. [Photo credits: **(A)** GMarques CC BY-NC 4.0; **(B)** J. Rykken; **(C)** Panoramedia CC BY-SA 3.0; **(D)** Chipiok CC BY-NC 4.0].

## SOLITARY BEES BUILD MANY KINDS OF NESTS

Most other native bees in North America live a solitary lifestyle [2]. Each female bee makes her own nest, lays eggs, and provides each egg with all the nectar and pollen it needs to grow into an adult. Many solitary bees dig their nests in the soil or in sandy banks along rivers (Figure 3B). These include mining bees, digger bees, sweat bees, and polyester bees. Polyester bees get their name because they protect the insides of their nests with a waterproof lining that also keeps out mold. Some soil-nesting bees live in large groups, so you might see lots of little entrance holes in the ground near each other making up a bee neighborhood.

Other bees nest in dead trees in tunnels made by beetles (Figure 3C), cracks and cavities in wood and rock, hollow plant stems, and a few species even nest in empty snail shells! Some of these nests are lined with mud, chewed-up leaves, or plant resin. Leafcutter bees line their nests with almost perfectly round pieces of leaves that they cut out carefully with their huge jaws. Wool carder bees make very cozy nests, lined with soft hairs that they gather from leaves. Carpenter bees chew into dead wood to make their nests, though they do not eat the wood.

About one fifth of all bees have a very different lifestyle—they are known as cuckoo bees. Like cuckoo birds, the females invade the nests of other bee species and lay their eggs next to the eggs already in the nest (Figure 3D). Once the cuckoo larvae emerge, they kill the resident eggs or larvae and eat their nectar and pollen. These greedy bees are also known as **cleptoparasites**. Although their lifestyle may seem underhanded, cuckoo bees are good indicators of a healthy bee community [3]. If there are lots of cuckoo bees at a site, it means there are also lots of other bees to steal food from!

**CLEPTOPARASITE**

An animal that takes food from another animal that caught or collected the food.

## DO NOT TAKE BEES FOR GRANTED!

If you were to tour all the national parks in North America, you would find an amazing diversity of bees in every one, including the dry deserts of Mojave National Park, oak woodlands of Shenandoah National Park, alpine meadows of Rocky Mountain National Park, and sandy beaches of Cape Cod National Seashore. Fortunately, bees living in parks and other protected areas are usually safe from many threats that bees living elsewhere face. Human activities like farming, the use of pesticides, paving and building, and the introduction of **non-native** plants and diseases can all impact bee health. Climate change is one human-caused threat that impacts bees everywhere, even in very remote places. As temperatures rise around the planet, some bee species have been forced to move farther north or up mountainsides to seek cooler climates [4]. In places where climate change is causing spring to warm up earlier than normal, plants and their pollinators may be affected. For example, if plants flower earlier than bees emerge from their hibernation, the mismatch in timing may result in fewer plants being pollinated and reproducing successfully [5].

**NON-NATIVE**

A non-native species is one that occurs in a place where it did not naturally evolve. Often non-native species are unintentionally carried to new places by humans.

## WHAT YOU CAN DO TO HELP NATIVE BEES

Bees are important pollinators in the wild. They are very diverse and live in many habitats. Bee health may be impacted by human-caused threats like climate change. It is up to all of us to make sure that pollinators and the plants they visit are still around for future generations. Parks and other protected areas support bees by preserving native habitats. We can support bees in our own backyards by providing food and nesting areas. Plant native wildflowers and shrubs of various colors, shapes, and blooming times, so that bees have access to nectar and pollen through the growing season. Bees love a messy yard for nesting! Leave patches of bare soil for ground-nesting bees (they can not nest in thick green grass), dead wood and last year's hollow berry canes for cavity-nesting bees (you can also drill holes in blocks of wood to attract cavity nesters), and thick brush piles for bumble bees.

Most importantly, keep learning about your local pollinators! Even though there is still a lot we do not know about native bees, we do know that without them, even our wildest places will lack the busy buzz that keeps nature thriving.

## REFERENCES


1. Ollerton, J., Winfree, R., and Tarrant, S. 2011. How many flowering plants are pollinatedby animals? *Oikos* 120:321–6. doi: 10.1111/j.1600-0706.2010.18644.x
2. Batra, S. W. T. 1984. Solitary bees. *Scientific Am.* 250:120–7. doi: 10.1038/scientificamerican0284-120
3. Sheffield, C. S., Pindar, A., Packer, L., and Kevan, P. G. 2013. The potential of cleptoparasitic bees as indicator taxa for assessing bee communities. *Apidologie.* 44:501–10. doi: 10.1007/s13592-013-0200-2
4. Kerr, J. T., Pindar, A., Galpern, P., Packer, L., Potts, S. G., Richardson, L. L., et al. 2015. Climate change impacts on bumblebees converge across continents. *Science.* 349:177–80. doi: 10.1126/science.aaa7031
5. Kudo, G. and Cooper, E.J. 2019. When spring ephemerals fail to meet pollinators: mechanism of phenological mismatch and its impact on plant reproduction. *Proc. R. Soc. B.* 286:20190573. doi: 10.1098/rspb.2019.0573



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## YOUNG REVIEWERS

### DISCOVERY CHARTER SCHOOL, AGES: 13–14

Discovery Charter School is located south of Lake Michigan in Indiana. Our 8th grade class is very eccentric. We love to joke around, but we also enjoy exploring the trails outside our school and learning more about the wildlife. We are a hard working class. Participating in this article review allowed us to learn more about the things that we always see during the summer. It was pretty cool to be a part of something that would be made public.

### EVA, AGE: 13

Hi, I am Eva. I love skateboarding, skiing, and running. I love to play music on my saxophone and guitar. I love hanging out with my friends and having fun.

### MAPLE, AGE: 13

Maple is 13 year old who loves spending time outdoors. She likes camping, swimming & hiking but LOVES skiing/snowboarding and big, snowy winters. Maple enjoys science at school, especially learning about weather patterns and snow science; she gets daily reports and avalanche forecasts so she can get amazing turns all winter long. Maple also loves animals—her dog Winter & bunny Birdie, playing soccer and creating art.

## AUTHOR

### JESSICA RYKKEN

Jessica Rykken is an entomologist who has studied bees and other pollinators in national parks across the U.S. for more than 15 years. Currently she works in Alaska, where she spends a lot of her time in the mountains and in Arctic regions researching bumble bees. Her favorite landscape is tree-less tundra because of all the colorful wildflowers and pollinators and because you can see the bears coming! *jessica_rykken@nps.gov

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EARTH AND ITS RESOURCES
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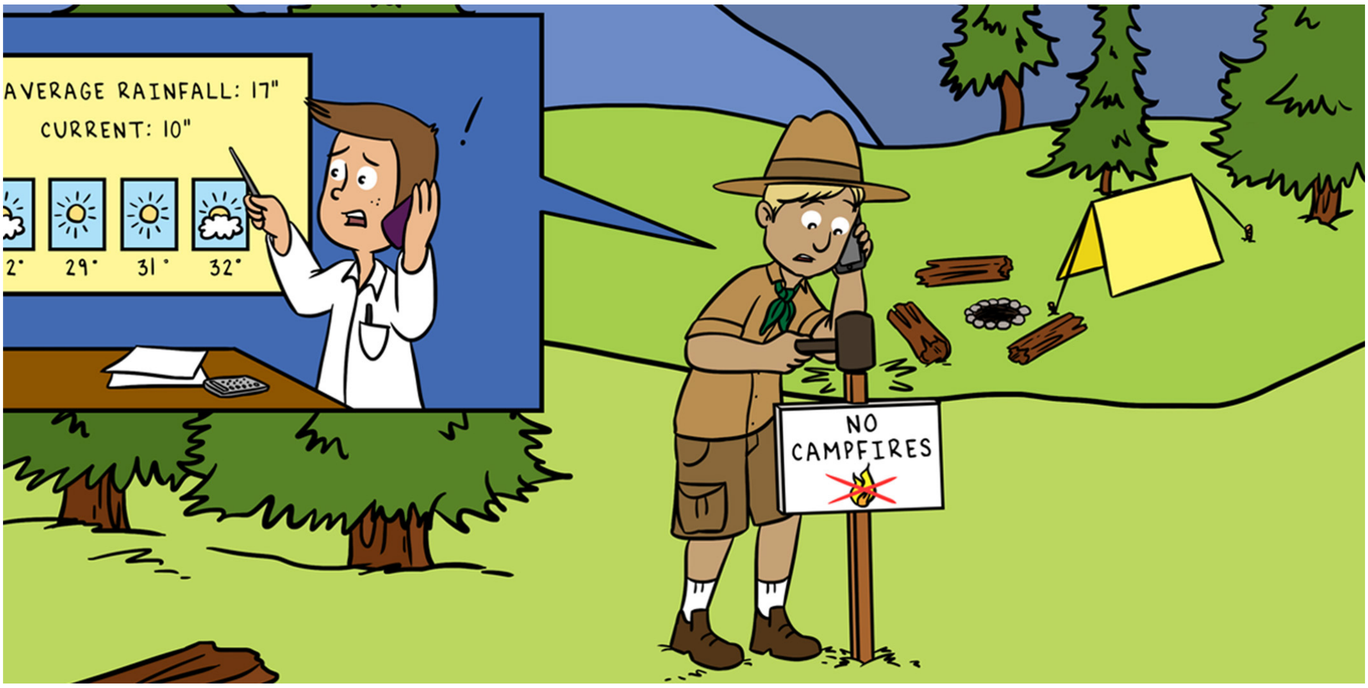


# WHEN NATURE GETS THIRSTY

***Rebecca H. Weissinger*** [1*]***, David Thoma*** [2] ***and Alice Wondrak Biel*** [1]

[1] *Northern Colorado Plateau Network, National Park Service, Moab, UT, United States*

[2] *Northern Colorado Plateau Network and Greater Yellowstone Network, National Park Service, Bozeman, MT, United States*

YOUNG REVIEWERS:

ETHAN
AGE: 8

KING'S SCHOOL, CANTERBURY
AGES: 14–15

Water is the fountain of life. Without water, nothing grows, including us! But not everything in nature can have all the water it needs, all the time. If plants and animals get too thirsty, they get stressed. When nature dries out, dangerous conditions like droughts and wildfires can happen. It is important for national park managers to understand where and when nature is thirsty. As scientists, we track how much water falls as rain and snow. Then we subtract how much water leaves through rivers, groundwater, and evaporation. The leftover water can be used by plants and animals. We compare how much water plants want to how much water is available, so we can know how thirsty plants are. The hotter it is, the faster water disappears. By knowing when and where nature is thirsty, park managers can take actions to help protect parks.

## HOW DO WE KNOW WHEN NATURE IS THIRSTY?

How do you feel when you do not drink enough water? Your mouth gets sticky, you feel hot, and then there is that unique feeling of drying out. Thirst, like hunger, is a need that must be satisfied. Every plant and animal can get thirsty, no matter where they are, how big, how small, or how old. You can tell if a plant in your house is thirsty by its drooping or wilted leaves. In national parks, how can park managers tell if a forest or grassland or desert is thirsty? When does a stream or wetland become thirsty?

## MANY FORMS OF WATER, IN BALANCE

Before we can understand thirst in nature, we must think about water and where it exists. Picture yourself on a hike through your favorite national park. You follow the trail around a corner and spot a beautiful watery scene. What do you see? A mountain lake? Waves on the ocean? Nice! Now put on your detective's cap and look again. Can you find more water? We will give you a hint: water is everywhere, hiding in plain sight! Water can be frozen in snow or ice. There is water running up the trunk of the tree beside you, as sap, and pulsing in the blood of a squirrel in the tree's branches. There is invisible water in the air around you. There is even water in the soil under your feet. With water in so many forms and places, how can a scientist possibly keep track of it all? We use a concept called **water balance** to help us out. Water balance means that the water that goes *into* a system is equal to the water coming *out of* that system. It is balanced, like a math equation!

**WATER BALANCE**

The idea that water flowing into a system, like rain and snow, equals the water stored in a system plus the water flowing out of a system.

Let us start with a system you know well: your own body. The water that goes into your body is the water you drink. Some water is stored in your cells for your body to use. You can probably think of one way that water leaves your body—as pee! Other water leaves your body when you breathe and when you sweat. If you could measure it all, you would know how much water your body uses to keep you alive and healthy. But some of that water is hard to measure, right? How do you measure the invisible water in your breath, or the sweat that keeps you cool via **evaporation**?

**EVAPORATION**

The process of water turning from liquid to gas.

That is where a little bit of math comes in handy. If you take the inputs that are easy to measure (the amount of water you drink) and subtract the outputs that are easy to measure (the volume of your pee), there is still some water left. The leftover part is everything else: storage, sweat, and breath. So, the water you drink equals the water leaving your body, but there is some water that stays inside you to keep you alive. All of the water moving into, through, and out of your body is your personal water balance.

## WHAT ABOUT WATER IN NATURE?

Water in nature works just like it does in your body. Water comes into a park as rain or snow. See if you can follow the paths water might take in a park like Yellowstone, in Figure 1. Some water fills rivers, streams,

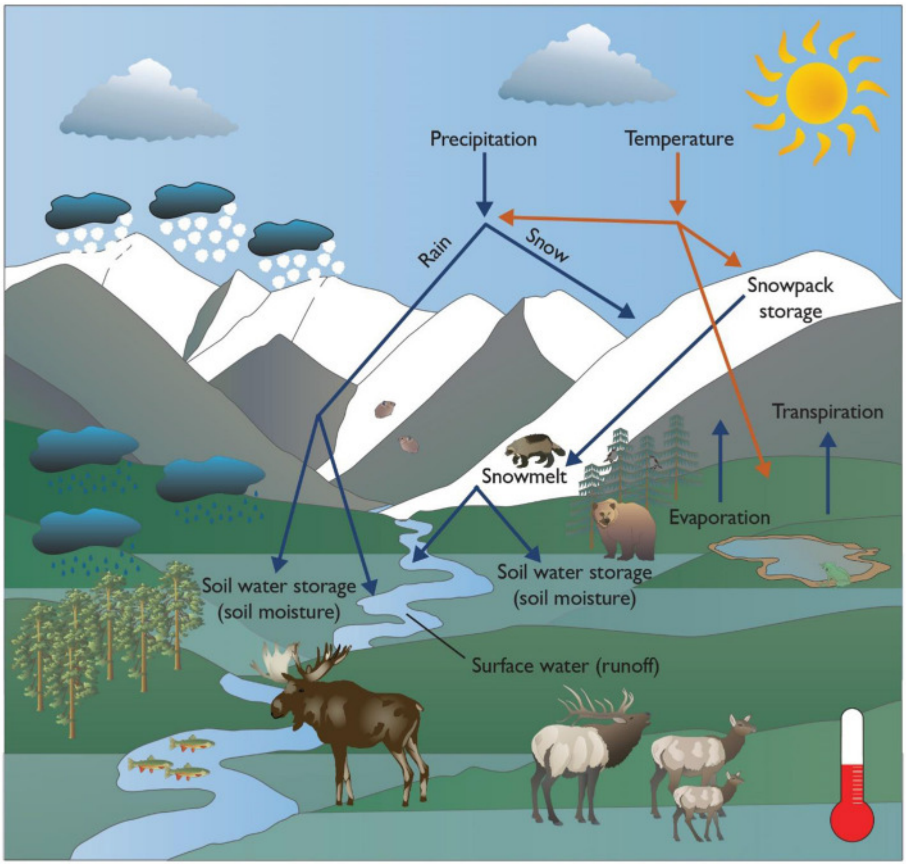

Figure 1

**Figure 1**

Nature's water balance has water in different "pools," like rivers, snow, soil, and air, in this example from Yellowstone National Park. Plants and animals use the different pools to survive and thrive [Conceptual diagrams by the Northern Colorado Plateau Network. Graphic elements courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/)].

**TRANSPIRATION**

The process of water moving through a plant and out its leaves.

**EVAPO-TRANSPIRATION**

The sum of water moving into the air through evaporation and transpiration.

**ADAPTED**

Having qualities that make it easier to live and survive in a particular place.

and wetlands where wildlife can take a cool drink. Other water is stored in the soil where it can be used by plants. This hidden water is like the water in your cells that keeps you alive. Like your sweat, some water evaporates from the soil and through plant leaves as they make food. Water evaporating through plant leaves is called **transpiration**, and it is actually the dry air pulling water through the plants, like you do when drinking from a straw. Scientists smash two words into one, to describe the process by which nature's water goes back into the air via evaporation and transpiration: **evapotranspiration**. Once water is in the air, it is no longer available for plants and animals to use.

To understand thirst in nature, scientists need to know how much water is in different pools (streams, wetlands, soil, and plants) and where it goes as it leaves a park. Scientists study plants and animals over time, checking their conditions in dry years and wet years. What they find again and again is that plants and animals survive in places that have the *right kind* of water (frozen, liquid, or gas) in the *right amounts* and at the *right times* to meet their needs. A frog and a cactus can both live in the desert if they have the right pools of water at the right times (Figure 2). We say those plants and animals are **adapted** to their environments. But that does not mean conditions are perfect all the time. Some years have more rain and snow than other years. It

Figure 2

Figure 2

A cactus and a treefrog can both live in the desert because they use different pools of water to survive. The cactus uses water stored in the soil and in its stem, while the frog is never far from a stream or wetland (Photos by R. Weissinger and M. Weissinger near Moab, Utah, USA).

makes sense that nature gets thirsty when there is less rain and snow than usual, because then there is less water to go around. But another important factor helps determine thirst: heat!

## WHAT HAPPENS WHEN THE TEMPERATURE GOES UP?

How much water do you drink in a day? Is the amount different if you are running around outside than if you are reading a book indoors? When you exercise, you breathe hard and sweat, losing water. This water loss can really add up! To meet your body's needs during a summer bike ride, you need to take a drink to fill up again. Just like you, plants and animals have water needs that can change. When it is hot, sunny, and dry, plants and animals run out of water faster because evapotranspiration is faster.

Remember water balance: water coming in equals water going out. If more water enters the air through evapotranspiration, then less water is available in streams, rivers, and wetlands. The soil starts to dry out, too. It becomes harder for plants and animals to get the water they need. But unlike you, a plant can not grab a glass of water, and even most animals can not move far to find water. Unless it rains or snows, nature's pools (streams, wetlands, rivers, lakes, soil moisture, water in plants and animals) get emptier and emptier. Heat is an important part of the water-balance math because it determines how quickly water moves from pools that plants and animals can use into the air, where it is inaccessible.

## WHAT HAPPENS WHEN PLANTS AND ANIMALS GET THIRSTY?

**DROUGHT**

The duration and amount of water shortage.

When plants and animals can not have all the water they need, they get thirsty. In nature, this thirst is called **drought**. Every plant and animal can experience drought. Using water balance, we have found that on hot days, desert springs in Arches National Park have less water for wildlife to drink [1]. Warm winters bring less snow, changing where salamanders at Yellowstone National Park can live [2]. Dry conditions also make it harder for plants to grow and easier for forests to catch

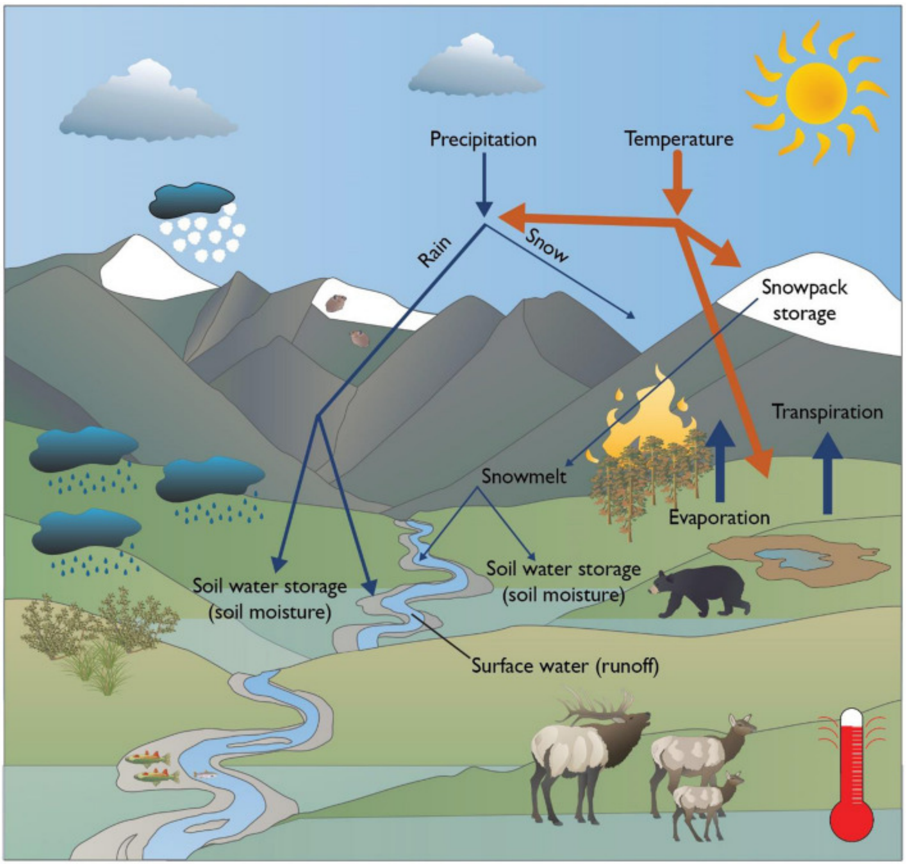


Figure 3

**Figure 3**

Scientists predict many changes will occur at Yellowstone National Park as temperatures go up. How many can you find, compared to Figure 1? Some of these changes are likely to happen in the future, such as changes in where wolverines and moose can live. Some have already started, like large wildfires and drying wetlands [Conceptual diagrams by the Northern Colorado Plateau Network. Graphic elements courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/)].

on fire and keep burning [3, 4]. How many differences can you spot when we add heat to Yellowstone in Figure 3? Plant types change and some animals, like pikas and wolverines, move to new places [5]. A changing water balance can change individual habitats or even entire landscapes.

## HOW CAN WE HELP NATURE HANDLE THE HEAT?

We know that temperatures around the world are going up. As the world gets hotter, many places we care about will experience more drought, even if the same amount of rain and snow falls. Understanding water balance can help park managers prepare for this future by helping them to know which plants and animals might have trouble, which ones might be just fine, and which places will allow plants and animals to thrive.

Park managers can not just add water to prevent drought. Parks are way too big for that. Instead, they can help plants and animals in various ways. By calculating nature's water balance, park managers know when campfires could become forest fires. They can tell when streams need more water and when fish must work harder to survive. In those cases, they might post signs that say, "No Campfires

Allowed," or "No Fishing." When conditions improve, they take down those signs.

Being prepared for changes can help minimize the effects of drought and heat. Park managers can prepare for a warmer future by planting pine trees on cooler slopes at Yellowstone. They can choose grasses wildlife like to eat that are adapted to drought in the desert. They can use controlled fires to clear undergrowth and protect giant sequoia groves from severe wildfires. They can predict which ponds will persist for frogs and make sure to remove non-native fish that eat frogs from those ponds, to help keep the frogs safe. Park managers can even plan for drinking water sources that may go dry, so future visitors have enough to drink! By understanding how heat and water interact in nature's water balance, park managers are preparing for hotter and drier days in the future. But there is much we still need to learn. Can you help scientists find solutions for nature?

## REFERENCES

1. Weissinger, R., Philippi, T., and Thoma, D. 2016. Linking climate to changing discharge at springs in Arches National Park, Utah, USA. *Ecosphere* 7:e01491. doi: 10.1002/ecs2.1491
2. Ray, A. M., Sepulveda, A. J., Irvine, K. M., Wilmoth, S. K. C., Thoma, D. P., Patla, D. A., 2019. Wetland drying linked to variations in snowmelt runoff across Grand Teton and Yellowstone national parks. *Sci. Total Environ*. 666:1188–97. doi: 10.1016/j.scitotenv.2019.02.296
3. Thoma, D. P., Tercek, M. T., Schweiger, E. W., Munson, S. M., Gross, J. E., and Olliff, S. T., 2020. Water balance as an indicator of natural resource condition: case studies from Great Sand Dunes National Park and Preserve. *Glob. Ecol. Conserv*. 24:e01300. doi: 10.1016/j.gecco.2020.e01300
4. Allen, C. D., Breshears, D. D., and McDowell, N. G. 2015. ESA Centennial Paper on underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere* 6:1–55. doi: 10.1890/ES15-00203.1
5. Ashton, I. 2010. *Observed and Projected Ecological Response to Climate Change in the Rocky Mountains and Upper Columbia Basin, Natural Resource Report NPS/ROMN/NRR–2010/220*. Fort Collins, CO.

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## YOUNG REVIEWERS

### ETHAN, AGE: 8

Ethan is an 8-years old boy that is currently in the third grade. He enjoys reading, writing, and studying math and history. During his free time, he plays basketball, tennis, and various other sports with his younger brother. He also loves exploring and learning about the nature. He lives in Virginia with his younger brother and parents. One day, he hopes to get a pet.


### KING'S SCHOOL, CANTERBURY, AGES: 14–15

We are an energetic year 10 class who are curious about the latest science. We are glad that scientists are doing their best to continue their research in these difficult times! It makes us happy that we can support them through this review.

## AUTHORS

### REBECCA H. WEISSINGER

Rebecca H. Weissinger studies water in national parks in Utah and Colorado. She has two kids and likes to go hiking, boating, and camping with her family. The most fun part of her job is hiking to springs in the desert. The most challenging part of her job is trying to understand how water moves underground where you can not see it. The best days of her job are when she uses science to help a park protect its water for the future. *rebecca_weissinger@nps.gov

### DAVID THOMA

David Thoma studies water in all its forms and how it affects nature in national parks. Here he is testing the soil to see how much water it can hold. He uses measurements made on the ground along with measurements made from satellites to understand nature's response to water abundance and shortage. He loves studying water balance in nature! This can help managers understand how nature may respond to climate change and what they can do to help.

### ALICE WONDRAK BIEL

Alice Wondrak Biel helps scientists express their thoughts through writing and images. Most of her job is done in front of a computer, working with words and pictures to make sure everyone can benefit from the stories scientists have to tell. But one of the best parts of her job is when she gets to go out and see things through her own lens!

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BIODIVERSITY
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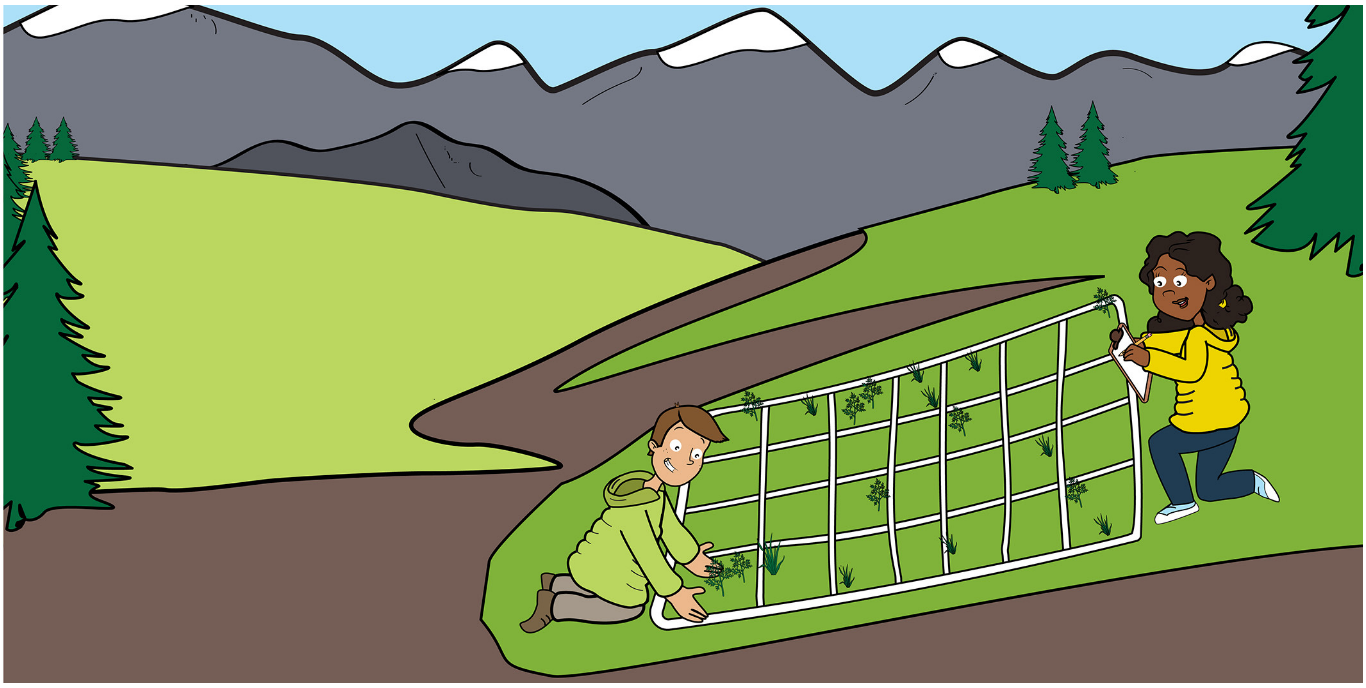

# A RECIPE FOR PLANT DIVERSITY IN SUBARCTIC ALASKA

*Sarah E. Stehn*[1,2]* *and Carl A. Roland*[1,2]

[1] *Denali National Park and Preserve, Denali National Park, AK, United States*

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YOUNG REVIEWERS

SLEEPING GIANT MIDDLE SCHOOL

AGES: 12–14

Hungry for a little plant diversity? Let us mix some up! First, we gather available ingredients—a bit of soil, a few nutrients, and a selection of nearby plants. Then, we add them together, pour them onto a landscape and let our concoction sit. Sound easy enough? But wait... was that soil we used too acidic? Did we add enough liquid? Was our landscape flat or tilted? How can we adjust our recipe to grow the most plant species in one place? As plant ecologists, we travel to remote places in subarctic Alaska to look at which species grow there. At each place, we record the condition of the environment and tally the number of plant species we find. Over 1,000's of visits, we now have a pretty good recipe for cooking up plant diversity! By learning about where plant diversity is high now, we can help protect it into the future.

## WELCOME TO THE SUBARCTIC KITCHEN

**SUBARCTIC**

An area of the world with warm but short summers, and very cold winters. The subarctic contains many habitats including forest, shrublands, and tundra.

The **subarctic** is the area of the world that is not quite "arctic" and not quite "temperate." It has long, cold, dark winters, and brief, warm summers. The subarctic can be a difficult place to be a plant. The sun hits the ground at a low angle and is less powerful than at the equator. Even worse, the summer season lasts only 3 months! Most plants do not have a long time to grow each year and must produce all their energy in only a few months. As a result, many plants have adapted a life strategy in which they take more than one season to grow a flower, set fruit, and develop seeds. Even the small plants you see could be many (even 100's!) years old.

**PLANT ECOLOGISTS**

A scientist who studies how plants relate to and interact with their environment, including other plant or animal species.

**Plant ecologists** are scientists interested in how plants interact with their environments. They observe where plants grow, how species got there, and the tricks plants use to survive. One way plant ecologists learn is by going to a place of interest, looking around, and recording all the plant species they see. They also record information about the site itself, such as whether it is on a steep slope, and the temperature of the soil. But how do they study plant ecology in a place that is enormous?

## TAKING A "BITE" OF PLANT DIVERSITY

Denali National Park and Preserve, in Alaska USA, contains about 2.4 million hectares (9,500 square miles) (Figure 1). It is a bit bigger than the state of New Hampshire in the United States or the country of Belize. To gather information about plants there, plant ecologists have visited over 1,000 different sites and measured plots. A plot is like a bite of land—an area that they can survey in a few hours. Surveying these bite-sized plots makes the job of learning about where plant species grow in a large wilderness area possible.

Plant ecologists aim to measure each plot in the same way. That way, they can compare the data collected among plots and can repeat measurements in the future (Figure 1). By seeing species many times in many places, scientists can get to know plant "preferences," for example, where certain plants like to grow and which other plants grow near them.

## WHAT ARE PLANT COMMUNITIES? WHY LOOK FOR DIVERSITY?

Plant communities form as particular plant species associate with each other. Sometimes they align with environmental conditions. For example, at a dry site, there may be a gathering of plant species that have evolved structures that make them suited to dry conditions, like long roots or hairy leaves. Other times there are gatherings of species

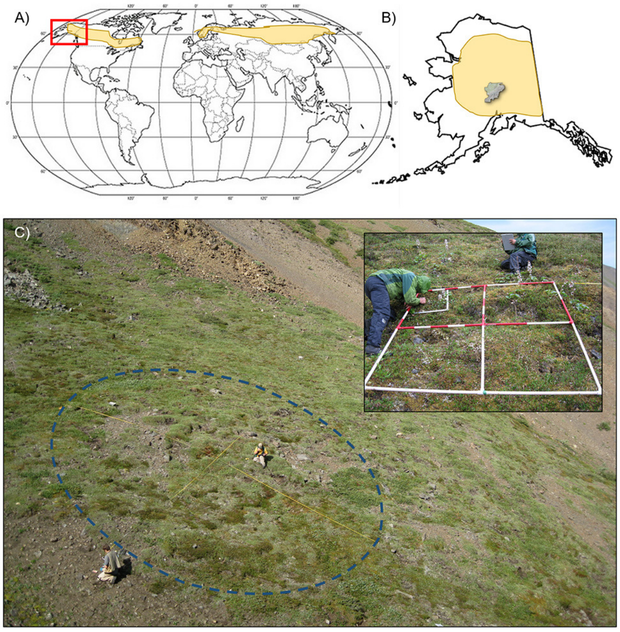


Figure 1

**Figure 1**

**(A)** This map shows the approximate location of the subarctic climate zone in yellow. The red box shows where Alaska is. **(B)** Denali National Park and Preserve is located in central Alaska and considered part of the subarctic. **(C)** Plant ecologists use tools to take a "bite" of the landscape. This system of measuring a site can be repeated at many places on the landscape. The yellow lines are tapes laid out to measure 16 m across the ground. The blue circle is added to show the area in which we record plot characteristics and count plant species.

**DIVERSITY**

Referring to the variety found within a given community. For plant diversity, this would be a measure of the number of different plant species or species types.

that complement each other. For example, where tall trees grow, their dense canopies limit the amount of sunlight that reaches the ground. Smaller plants, tolerant of shade, may thrive under the canopy. The dense canopy excludes other species that need lots of sunlight.

Some plant communities have high **diversity**, meaning they contain many different species. Other plant communities are less diverse, hosting only a few. In human neighborhoods and schools, diverse perspectives enhance creativity and improve problem solving. Diversity in plant communities provides similar benefits. Diverse plant communities provide a variety of habitats for other creatures. Diverse plant communities also tend to include unique species that are not found in other places on the landscape. By understanding where and when diverse plant communities develop, we can better protect them.

## TIME TO GET COOKING!

How can we find diverse plant communities on the landscape? To start, let us follow the cooking steps below for hints on where and when diverse subarctic plant communities may develop (Table 1). Then we will look at some data to see where the greatest plant diversity has developed.

### Step 1: Gather the Ingredients

In our recipe for plant diversity, the primary ingredients are plant species. Do you think there are tropical flowers that can grow in

**Table 1**

A recipe for plant diversity. The "Information needed" column includes some of the most important items to consider when investigating diversity at a particular place. Note that this table is most relevant to places in the subarctic [1]. For determining diversity in other regions, additional information may be needed.

| Procedures | Information needed | Why? |
|---|---|---|
| Step 1: Gather the ingredients | Available plant species | The possible plant species come from the species pool, which is dependent on the biogeographic history of the region. |
|  | Soil type and age | Soils are developed over time and depend on the rock type and climatic conditions, as well as how often the soils are disturbed (like by flooding or wildfire). |
| Step 2: Choose a baking pan and adjust the oven | Site characteristics | Landscape characteristics of a site generally include elevation, slope, and aspect, which together provide a lot of information about how much sunlight and warmth a site receives. |
|  | Climate and micro-climate | Additional information about warmth and moisture specific to plant communities can be found by investigating the patterns of temperature and precipitation experienced by the plants, both at larger (hillslope, for example) and smaller (under a forest canopy, for example) scales. |
| Step 3: Mix, pour, and let sit | Order of species arrival and level of competition | Some species have traits that allow them to compete with other species for resources, while others do better on their own, when they do not have to compete. |
|  | Patterns of disturbance | Some portions of the landscape are likely to be disturbed, and their plant communities restarted many times. An example is near a river prone to flooding. Other portions of the landscape are more stable, like gentle slopes. |

Table 1

Alaska? Or piles of seaweed sitting atop the tall mountains? No, that is unlikely. In cooking up plant diversity in the subarctic, we are somewhat limited by the plants currently found in and around the subarctic region. This is called the **species pool** and it contains the greatest number of species that could survive in an area *and* are in that area currently or have been there in the recent past. For a plant species to be part of a plant community, that species must be there already or be able to arrive there.

**SPECIES POOL**

All the species that could colonize and survive in a particular area. The species pool is based on the history of an entire region over 1,000's of years.

Another important ingredient is soil. Soil is the foundation for how most plants interact with their environments. Soil conditions vary due to the rock type the soil came from, climate-related heat and moisture inputs, and how long the soil has been developing. In the subarctic, young soils (younger than 100 years) tend to be rocky and warm. Older soils (older than 5,000 years) tend to be full of organic muck and are frozen [2]. Individual plant species have different tolerances of these soil conditions. Thus, soils play a critical part in influencing how diverse a plant community in a specific area may be.

### Step 2: Choose a Baking Pan and Adjust the Oven

When baking, the type of cookware you use makes a difference in how the batter receives heat from the oven. Applied to our quest for plant diversity, this means we must consider the shape of the landscape. Even when beginning with the same set of plant species and other ingredients, the land where the plants grow affects their survival.

Elevation, slope, and **aspect** are important landscape characteristics in determining plant diversity. Slope is the steepness of the land and aspect is the direction the land faces. Together, they determine how much sunlight a site receives and how much moisture it can hold. At the high latitudes of the subarctic, the sun hits the earth at a low angle, so it is not, by itself, very powerful. But, if the land slopes to meet the sun, its warming effects can be greater.

**ASPECT**

The direction in which a surface faces. For a plot, the aspect is measured with a compass and influences the amount of sun exposure received.

Speaking of sun and warmth, when baking, the temperature of the oven matters! Have you ever followed a recipe that says to place your pan on the top rack only? Or to rotate the pan partway through baking? **Microclimate** is a term used to describe small parts of a landscape (or oven) that experience a different climate. A diversity of microclimates allows for a wider variety of plants to thrive there.

**MICROCLIMATE**

The usual weather conditions specific to a small area. For example, the temperature, moisture, and wind under a forest canopy may differ from those of the hill the forest grows on.

### Step 3: Mix, Pour, and Let Sit

As any good cook knows, there is more to a recipe than a list of ingredients! The order that you add ingredients often matters. In plant communities, the plant species that arrive first often have a competitive advantage over the ones arriving later. In other cases, certain species cannot survive unless those early arrivers have done some work to the site to make it more inhabitable.

Occasionally a site is disturbed by a wildfire, a landslide, a flood, or even a bear digging a den. When that happens, it is a bit like spilling the bowl of ingredients. Sometimes the recipe is salvageable and can be prepared as expected. Other times, a critical piece is lost, and the resultant concoction comes out different. When a disturbance "restarts" a plant community, a different set of species may take over. This restart may change the plant diversity of an area for many years to come [3].

**Figure 2**

These sites in Denali National Park and Preserve display **(A)** low (11 species, 743 m in elevation), **(B)** medium (24 species, 767 m), and **(C)** high (45 species, 1,008 m) plant diversity. Can you match any of the site characteristics you see to our recipe for plant diversity?

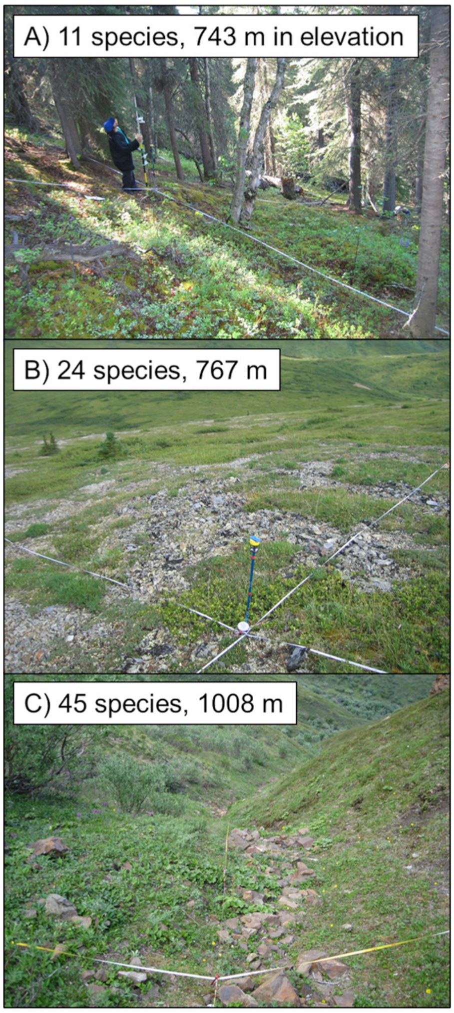


Figure 2

## A SUBARCTIC SURPRISE? DENALI'S DIVERSE ALPINE

The open alpine tundra contains the most diverse plant communities in subarctic Alaska [1]. This may seem strange because you may envision the top of a mountain being cold, snowy, and windy. But high elevations allow for the perfect combination of ingredients, baking pan, oven, and procedures (Figure 2).

**PERIOD OF GLACIATION**

An interval of time, generally 1,000's of years, when glaciers covered larger portions of the landscape than they do today.

In our species pool, there are many small and hardy plants well-adapted to alpine conditions. Over many **periods of glaciation**, these species survived in the alpine as the valleys below filled with ice [4]. Mountain tops are made of exposed bedrock or otherwise young soils. These are better for growth than the frozen, acidic soils common in the lower elevations [1]. Some mountain slopes tilt to the south and allow more warmth to accumulate earlier in the season. This lengthens the potential period of growth. Where the land slopes, there are small-scale soil differences due to mini-landslides. These small disturbances create microclimates that attract species in the species pool [5]. Many of these species are tolerant of alpine conditions. The wind and cold keep out larger shrubs and trees that would take up a lot of growing space and soil nutrients.

## REFINING THE RECIPE

The arrangement of plants on the landscape is a phenomenon that occurs over many years. It is the result of a complex series of predictable and unpredictable events. Plant diversity is likely to change as global-scale climate changes alter the landscape. For example, in the subarctic, we have found trees and shrubs growing into higher elevations. They take space away from the diverse, open alpine tundra communities [1]. If those communities are lost, how will the recipe for plant diversity change?

It is important to learn about where individual plant species, and the communities they form, exist on the landscape today. This information helps plant ecologists predict how those species may be able to adapt to changes in the future. By monitoring plant communities as they respond to changes over time, ecologists can refine the "recipe" for plant diversity. Have you noticed what influences the diversity of plants and animals where you live? What elements of the climate, history, and community development may contribute? Time to wash up, gather your ingredients, and get cooking!

## REFERENCES

1. Roland, C. A., Stehn, S. E., and Schmidt, J. H. 2017. Species richness of multiple functional groups peaks in alpine tundra in subarctic Alaska. *Ecosphere* 8:1–18. doi: 10.1002/ecs2.1848
2. Viereck, L. A. 1966. Plant succession and soil development on gravel outwash of the Muldrow Glacier, Alaska. *Ecol. Monogr.* 36:181–99.
3. Roland, C. A., Stehn, S. E., Schmidt, J. H., and Houseman, B. 2016. Proliferating poplars: the leading edge of landscape change in an Alaskan subalpine chronosequence. *Ecosphere* 7:1–30. doi: 10.1002/ecs2.1398
4. Roland, C. A., and Schmidt, J. H. 2015. A diverse alpine species poll drives a "reversed" plant species richness-elevation relationship in interior Alaska. *J. Biogeogr.* 42:738–50. doi: 10.1111/jbi.12446
5. Roland, C., Sadoti, G., Nicklen, E. F., McAfee, S., and Stehn, S. 2019. A structural equation model linking past and present plant diversity in Alaska: a framework for evaluating future change. *Ecosphere* 10:e02832. doi: 10.1002/ecs2.2832

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## YOUNG REVIEWERS

### SLEEPING GIANT MIDDLE SCHOOL, AGES: 12–14

Students at Sleeping Giant Middle School, Livingston, Montana, USA: Mathew, Alexis, Bella, Brooklin, Caen, Chase, Chloe, David, Ed, Freddy, Grace, Haggen, Hunter, Isabella, Jackson, Kinzey, Lexi, Lily, Mathew, Matine, Nevaeh, Neve, Rose, and Weston. We are two classes of students comprised of girls and boys who are interested in science and reading—in our free time some of us like video games, skiing, watching anime, drawing, shooting, running, technology, biking, soccer, board games, softball, hunting, reading, writing, and cooking.

## AUTHORS

### SARAH E. STEHN

Sarah E. Stehn works on a team of passionate place-based scientists in the US National Park Service. They aim to understand and conserve the ecological communities they live in. As a botanist, her focus is on the plants, particularly the often-overlooked mosses, liverworts, and lichens. She strives to contribute knowledge on how "the little guys" affect ecosystem function and adaptation to change. Examining data from an extensive network of long-term monitoring plots, she is often amazed at both the resilience and vulnerability of subarctic plant life. *sarah_stehn@nps.gov

### CARL A. ROLAND

Carl A. Roland is a botanist/ecologist who has studied the flora and vegetation of Alaska since 1990. Each year, he cultivates a large garden and a small orchard in the Fairbanks area during the short (but increasing) subarctic growing season. He serves as plant ecologist for Denali National Park and leads the botany program for the Central Alaska Inventory and Monitoring Network for the NPS. Sometimes, he only knows where he is based on the plants that are growing there!

BIODIVERSITY
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# DIVERSITY AND DISTURBANCE: HOW MUSSELS AND SEA STARS STRENGTHEN THE ROCKY INTERTIDAL COMMUNITY

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*[3] Klamath Inventory and Monitoring Network, National Park Service, Ashland, OR, United States*

YOUNG REVIEWERS:

FERN
AGE: 11

LENORE
AGE: 14

SEWARD MIDDLE SCHOOL
AGES: 11–13

In the rocky intertidal zone, tides and rocks set the stage. Together they create habitat for a diverse community of species adapted to a world both underwater (high tide) and exposed to air (low tide). In some protected areas, like national parks, we study rocky intertidal ecosystems as vital signs of nature's health. Studying them helps us understand the impact of disturbances, which play an important role in shaping these communities. Some disturbances, like the tides, happen daily. Others, like diseases, might happen once every decade. This article is about how tides and diseases affect two important members of rocky intertidal communities—mussels and sea stars. We explain the roles these organisms play and what happened when ochre sea stars, an important species in these habitats, suffered a major disease outbreak. Last, we emphasize the importance of

protecting these vital ecosystems so we can continue to learn about the health of the natural environment.

## THE ROCKY INTERTIDAL ZONE

All over the world where the ocean meets the land, we find intertidal ecosystems. "Intertidal" refers to land that gets covered and uncovered by the tides (Figures 1A,B). Where the land is rocky, we find rocky intertidal ecosystems, where tidepools often occur. Tidepools contain unique lifeforms that we do not often find in other intertidal systems like sandy beaches or mudflats. On the western coast of North America, the rocky **intertidal zone** is shaped by tides that have four phases every day: two low tides and two high tides. These tides create four zones within the rocky intertidal region (Figure 1C), (1) spray zone (dampened by ocean spray, high waves, and storm surges), (2) high intertidal zone (underwater only during very high tides), (3) middle intertidal zone (exposed to air between high and low tides), (4) low intertidal zone (almost always underwater). Without these four habitats, the rocky intertidal zone would not be as biologically diverse as it is.

**INTERTIDAL ZONES**

The different spaces of the shore area between the lowest water level and the highest water level, where the water level is determined by the tides.

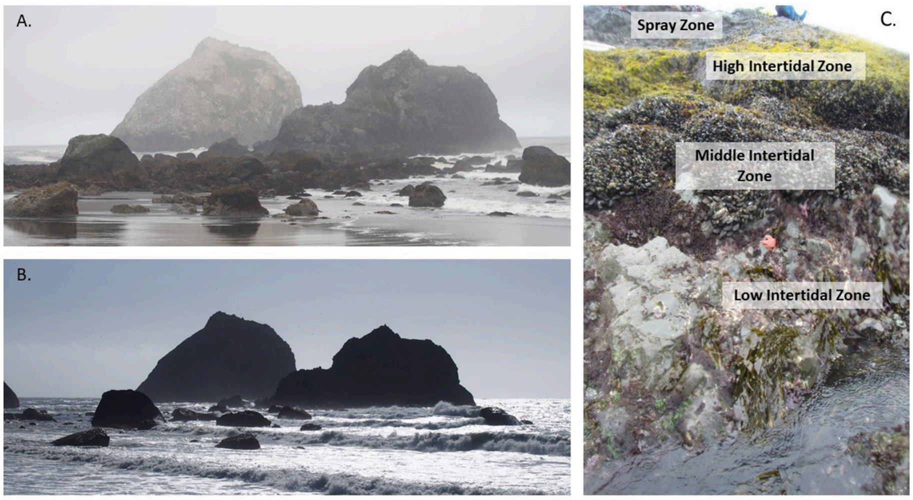


Figure 1

**Figure 1**

An intertidal site in Northern California (United States). **(A)** The site at low tide, when many rocks and surfaces are exposed. **(B)** The site at high tide, when the water covers most surfaces. **(C)** A closer look, showing the four types of habitats or "zones" that exist in the intertidal site.

**SEA STAR WASTING SYNDROME**

Disease of many sea star species, with symptoms including lesions, decaying tissue, and eventually death. The recent outbreak is the largest marine disease die-off ever recorded.

Like the tides, diseases also shape intertidal communities. Diseases often harm specific species, which in turn affects community relationships. A recent disease called **sea star wasting syndrome** affected many sea star species along the western coast of North America [1], and one of those species (the ochre star) plays an important role in shaping rocky intertidal communities. Both forms of disturbance—tides and disease—are natural engineers that change these communities. While tides enhance **biodiversity** by creating multiple zones, disease tends to reduce it.

**BIODIVERSITY**

All the different kinds of life found in one area.

## WHO STUDIES THESE THINGS?

United States National Park Service scientists study rocky intertidal zones in collaboration with other scientists, as part of the Multi-Agency Rocky Intertidal Network [2]. Together, we look at marine animals and seaweeds, plus sea-surface temperatures. Tracking sea-surface temperatures is important because it gives us information about how global warming is impacting marine organisms. Sea-surface temperatures might also be important for understanding sea star wasting syndrome.

By keeping a close eye on rocky intertidal communities, we can understand how they respond to disturbances like tides, disease, temperature changes, storm surges, oil spills, or fishing. We can use this information to make smart decisions about how to manage parks with rocky intertidal ecosystems.

## IMPORTANT INVERTEBRATES: MUSSELS AND SEA STARS

Every year, in national parks along the western coast of the United States, we survey rocky intertidal communities. We take pictures and measurements, often going out very early in the morning at low tide. Some species are common and easy to find, but some are **cryptic**, or difficult to find. Many of these are small species like algae or tiny **invertebrates** (like snails) that live within mussel beds that often cover much of the middle intertidal zone. In a mussel bed, we often find hundreds of these hidden species in areas no bigger than a small backyard! These cryptic critters are important food sources for many larger animals.

**CRYPTIC**

Characterized by coloration or markings that camouflage an animal in its natural environment, often helping to reduce predation.

**INVERTEBRATE**

A cold-blooded animal with no backbone.

Like the cryptic animals they support, mussels are also invertebrates. The most common mussel in this part of the United States is the California mussel (Figure 2A). California mussels are well-adapted to the rocky intertidal zone. They occupy mostly low and middle intertidal habitats where there is enough water to keep them from drying out. They form huge beds in which thousands of them live packed together. When waves come crashing in, mussel beds slow down the water that passes through them, which reduces wave impacts for other animals. California mussels make little threads that attach them to each other and to the rocks they live on, to keep them in place. These mussel beds create habitat for cryptic animals and trap the food that those animals eat. Not only do California mussels provide food for these secretive animals, they themselves are food for predators like sea stars and some snails. California mussels are right in the middle of the rocky intertidal food web, providing essential resources to other members of the community.

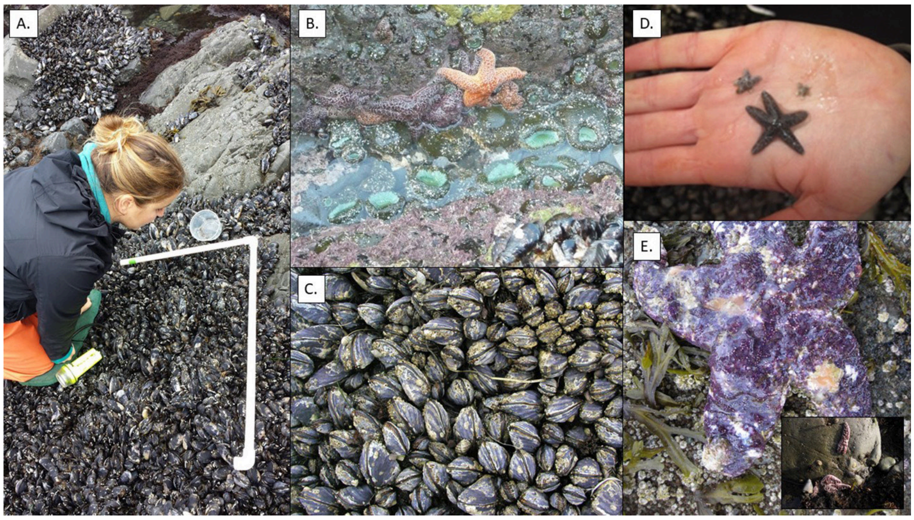


Figure 2

**Figure 2**

**(A)** A researcher measuring mussel beds. **(B)** Sea stars (orange and purple) in a tidepool. **(C)** Up close and personal with mussels. **(D)** Juvenile (baby) sea stars. **(E)** Sea star wasting syndrome, which causes sea stars to "melt" and lose their arms.

The most important intertidal sea star in this coastal area of the Pacific Ocean is the ochre star (Figures 2B–E). Like California mussels, ochre stars are invertebrates that occupy mostly low and middle intertidal habitats. We already know that when we remove ochre stars from the community, California mussel populations increase [2]. This happens because the size of the rocky intertidal habitat is restricted to the area that is covered and uncovered by the ocean each day, space for animals and algae is limited. California mussels are very good at competing for space on the rock. When ochre stars are present, they keep mussel populations in check, creating space for other species to live. But, when ochre stars are missing, mussels can quickly take over open habitat and exclude other species. Ochre stars can thus increase the biodiversity of species that must attach to rock to survive.

Compared to California mussels, which are abundant, ochre stars are sparse and have less **biomass**. Despite their low biomass, their impact in rocky intertidal communities is huge [3]! For this reason, ochre stars are considered a **keystone species**. In fact, ochre sea stars were the first species ecologists used to define the concept of keystone species, which are species that (like the ochre star) have huge impacts despite being low biomass. We now know that all ecosystems—terrestrial, freshwater, marine, and everything in between—have keystone species. The loss of a keystone species has a big impact. Without ochre stars, biodiversity would decrease.

**BIOMASS**

The total amount or mass of living organisms in a given area or ecosystem. Biomass can refer to species biomass, which is the total mass of one or more species in an area.

**KEYSTONE SPECIES**

A species with a larger effect on its environment than its biomass suggests, like beavers creating dams making new wetlands, or sea otters eating urchins allowing kelp forests to flourish.

## SEA STAR WASTING SYNDROME AND OCHRE STAR RECOVERY

In 2013, scientists at Olympic National Park in the state of Washington (United States) discovered an outbreak of sea star wasting syndrome. This disease had been killing sea stars in large numbers from San Diego in southern California, all the way to Alaska. No one is sure where this disease came from, but some think there is a connection to high sea-surface temperatures. While it killed many different species of sea stars, one of the hardest hit was the ochre star [1]. When this keystone species declined, what do you think happened to mussel populations? As expected, mussel populations increased in some places, but not all. We are not exactly sure why this is, but we are studying how factors other than the presence of ochre stars can influence how much mussel populations can grow.

Within 2 years after the die-off, ochre star populations started to come back in some places, but not everywhere. Where populations were recovering, there was a new problem: the new ochre stars were all babies, and baby ochre stars do not eat as much as adults (Figure 3). In other words, they do not exert as much **predation pressure** on mussels [4]. Why does this matter? Without the predation pressure from adult sea stars, mussel populations can grow large very quickly. They will out-compete other species that need the same habitat. So, even where the number of ochre stars came back, mussel populations did not decrease right away [4]. The community needed adult ochre stars to make that happen, and it can take 5 years for baby ochre stars to mature into adults. Once ochre stars mature, mussel populations should decrease, and biodiversity of animals and algae attached to the rock should increase again. It is our hope that the baby ochre stars stay free of sea star wasting syndrome and grow up to regain their role as a keystone species.

**PREDATION PRESSURE**

The effect of predators (organisms that eat other organisms) limiting the number of prey (organisms that get eaten) by eating them.

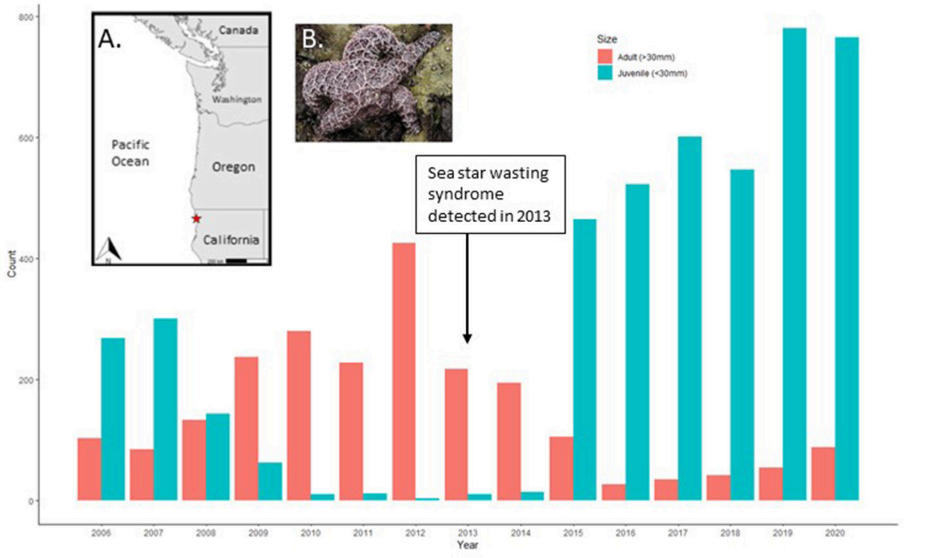


Figure 3

**Figure 3**

After detection of sea star wasting syndrome in 2013, adult sea stars declined (red), followed by a large rise in juvenile (baby) sea stars 2 years later (blue). **(A)** Location of monitoring in Redwoods National and State Parks on the northern coast of California, USA. **(B)**. The ochre sea star.

Since the disease outbreak, we have continued to survey every year. At Redwood National and State Parks in Northern California, ochre stars seem to be recovering—a good sign for the community! At Channel Islands National Park in Southern California, they do not seem to be recovering. Why the difference? We do not know yet, but we will keep studying these ecosystems long into the future. The more data we can gather about all the elements shaping rocky intertidal communities, the better our understanding will be. This includes studying the seaweeds, animals, water and air temperatures, and other biological or environmental disturbances.

## CONCLUSION

People have been studying rocky intertidal zones for decades, which has given us a clear understanding of what healthy rocky intertidal communities look like. The western coast of North America has keystone species (sea stars), mussel beds, and many cryptic organisms. The tides create four types of habitats, providing a place suitable for every intertidal species. The rocky intertidal zone is a vital ecosystem connecting the ocean to the land.

The United States National Park Service plays an important role in protecting the rocky intertidal zone. As we study the impact of sea star wasting syndrome, we will continue learning. In case sea surface temperature had something to do with this disease, we will watch for disease outbreaks when temperatures are high again. Our work allows us to manage our parks to protect rocky intertidal communities when they are especially vulnerable. As the Earth's climate continues to change and human activities impact rocky intertidal zones, monitoring for changes will be especially important. If you want to get involved, please consider joining **citizen science** groups, so you too can survey these beautiful intertidal communities [2].

**CITIZEN SCIENCE**

Science done using the general public. Scientists generally guide and assist in empowering local communities to engage in local research or even global studies.

## REFERENCES

1. Miner, C. M., Burnaford, J. L., Ambrose, R. F., Antrim, L., Bohlmann, H., Blanchette, C. A., et al. 2018. Large-scale impacts of sea star wasting disease (SSWD) on intertidal sea stars and implications for recovery. *PLoS ONE* 13:e0192870. doi: 10.1371/journal.pone.0192870
2. MARINe 2021. *Sea Star Wasting Syndrome*. MARINe. Available online at: seastarwasting.org (accessed May 2, 2021).
3. Paine, R. T. 1966. Food web complexity and species diversity. *Am. Naturalist*. 100:65–75. doi: 10.1086/282400
4. Moritsch, M. M., and Raimondi, P. T. 2018. Reduction and recovery of keystone predation pressure after disease-related mass mortality. *Ecol. Evol.* 8:3952–64. doi: 10.1002/ece3.3953

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## YOUNG REVIEWERS

**FERN, AGE: 11**

Hi, I am Fern! I am 11 years old and in 6th grade. I am currently homeschooled, and my favorite subjects are English and Science. I like poetry, reading, sketching, fishing, mountain biking, XC skiing, and sledding. I play the mandolin and flute, and I love bluegrass music. I have a goofy and cute golden retriever who loves popcorn. My favorite foods are spaghetti, cupcakes, and Brussel sprout leaves cooked in bacon grease. I am doing this project with my Girl Scout troop.

**LENORE, AGE: 14**

Hello, I am Lenore, a 14-year-old 8th grader. I am experimenting with pronouns, and currently go by they/them. My favorite animals are the Canadian Lynx, closely followed by Golden Retrievers. I play the clarinet and banjo, and am a huge fan of We Banjo 3. I enjoy walking with my family and dog, and biking (road + mountain). I also enjoy role-playing, drawing, and paint-by-stickers. My dog constantly steals my food. I am doing this project with my Girl Scout troop.

**SEWARD MIDDLE SCHOOL, AGES: 11–13**

Seward Middle School is nestled on the edge of the ocean and base of stunning mountains. We are an active and tight-knit community that values arts, sports, and taking care of each other. This crew of students is a strong, intelligent, and driven group of ladies! They are competitive dancers, backcountry skiers, amateur botanists, entrepreneurs, master seamstresses, athletes, and more. These ladies are academic and social leaders in their school, setting examples for behavior, study habits, and focus.

## AUTHORS

### ELLIOT HENDRY

Elliot Hendry is a student of ecology at the University of Wisconsin-Madison, where he is researching desert springs. Elliot grew up in Missouri where he spent lots of time outside. Upon finishing an undergraduate degree in environmental studies, he began working with the National Park Service. After 7 years of working in national parks and forests, Elliot entered graduate school. Elliot hopes to use his research on desert springs to improve the way we appreciate and conserve the diversity of aquatic ecosystems on Earth. In addition to ecology, Elliot loves cycling, running, backpacking, music, and reading.

### KARAH N. AMMANN

Karah N. Ammann conducts field research in the rocky intertidal, in partnership with the Multi-Agency Rocky Intertidal Network (MARINe). "Office time" involves exploring one of the most dynamic ecosystems on the planet; and "work" includes participating in biodiversity surveys and monitoring intertidal species along the west coast of North America.

### ERIC C. DINGER

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, sometimes rock climbing or running as well.

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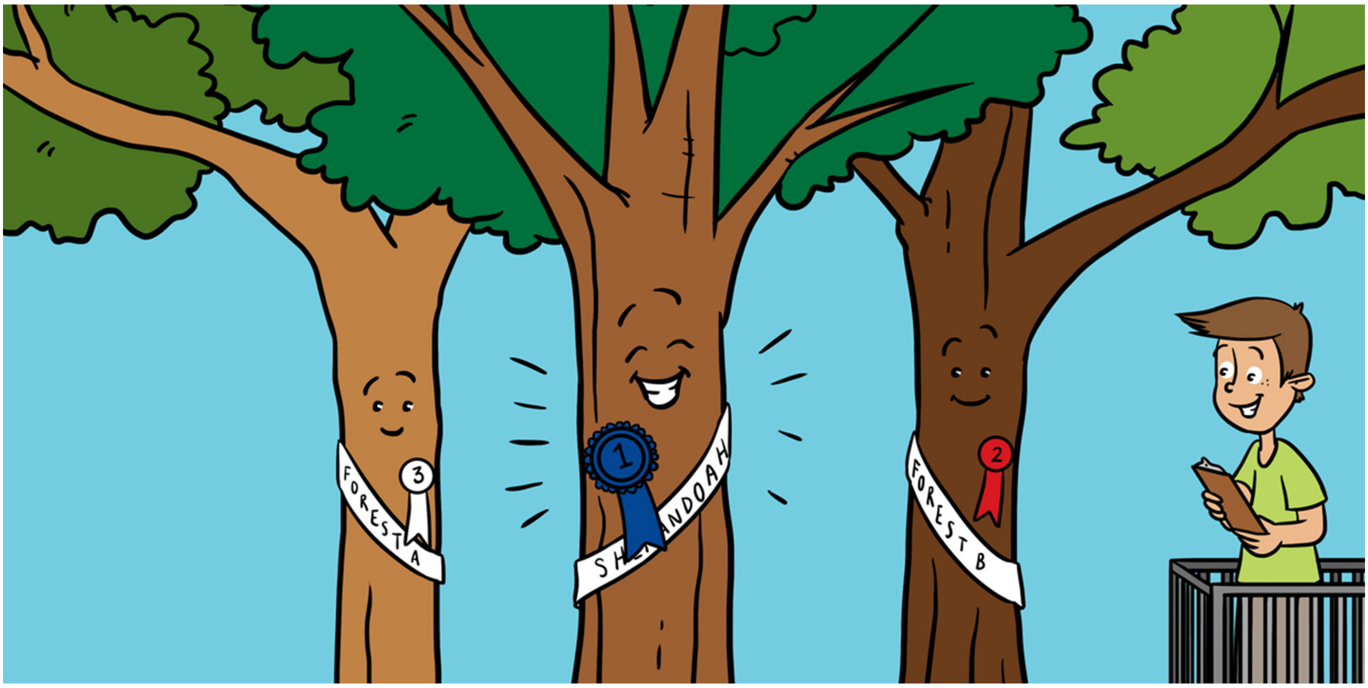


# DO PARKS HELP FORESTS?

*John Paul Schmit*[1*], *Kathryn Miller*[2], *Elizabeth R. Matthews*[1] and *Andrejs Brolis*[1]

[1] *National Capital Region Network, National Park Service, Washington, DC, United States*
[2] *Northeast Temperate Network, National Park Service, Bar Harbor, ME, United States*

YOUNG REVIEWERS:

EL
AGE: 14

MOAB CHARTER SCHOOL
AGES: 11–12

National Parks were created to help protect nature. But does that protection really matter? Are forests inside parks actually any better off than nearby forests outside of parks? How could you even tell? To find out, we studied thousands of trees inside of parks. We measured every tree's diameter to see how big it was and returned 4 years later to see how they had changed. Then we compared the trees in parks to thousands of other trees that had been measured in similar unprotected forests nearby. It turns out that there are more trees growing in parks, and large trees are much more common. Trees in parks are less likely to die, but due to their large size, they grow more slowly. Parks even have more dead trees and dead wood on the forest floor. All of these things are signs of a healthy forest.

## WHAT DO PARKS PROTECT?

National Parks in the United States protect important places. Some of these places are important because they include natural wonders, like the Grand Canyon, or contain large areas of forest, like Shenandoah

National Park. In these parks, plants and animals can live far from any humans that might bother them. Some parks, however, protect places that are not large wildernesses. These smaller parks often protect places that are important in history. Such parks could include the site of a Civil War battle, such as Gettysburg, or the houses where famous Americans like George Washington or Booker T. Washington grew up.

We expect the large, wild parks to protect the plants and animals that live there, but what about small parks? Little parks often include fields, farms, and old buildings that show us what life was like in the past. These parks have forests, but the forests are usually small and scattered around the park. You might think that small forests that are close to places where people live or work do not get much benefit from being in a park. But there is one big difference between parks and other areas. Even in small parks, people are not allowed to cut down trees to use for wood, but outside of parks, people can do that.

We wanted to find out if parks are doing a good job at protecting forests. To do this, we compared forests inside of parks with similar nearby forests outside of parks. Since the forests we compared are close to each other, any differences we see are probably caused by the protection provided by the park. If the forests in the parks are in better shape than the forests outside the parks, we could conclude that the parks are making a big difference. On the other hand, if forests inside and outside of parks are basically the same, then the parks are not helping the forests very much. We also wanted to know if park size makes a difference—in other words, are forests in small parks protected as much as forests in large parks?

## WHAT MAKES A GOOD FOREST?

Before we can see if parks are helping to protect forests, we need to know what we are looking for. When scientists study forests, they often use what are called **permanent plots**. Permanent plots are places in the forest that scientists visit for many years, so they can see how the trees grow and change. For this study, park scientists visited 2,000 permanent plots in 50 national parks in the northeastern United States. The parks are on the east coast between Maine and Virginia, and near the Great Lakes in the Midwest. We also used information other scientists collected from over 22,500 plots outside of parks. Scientists visit the permanent plots again and again, over many years. Hundreds of thousands of trees grow in these plots, and scientists measured every one!

**PERMANENT PLOT**

A place that scientists visit many times to see how forests are changing.

When we looked at the forests in each plot, we were especially interested in the sizes of the trees. While all forests have trees, not all forests have *large* trees. Scientists determine the size of a tree by measuring its **diameter at breast height** (**DBH**) (Figure 1). This is simply

**DIAMETER AT BREAST HEIGHT (DBH)**

A measure of how wide a tree is at 1.37 m off the ground. DBH provides a measure of a tree's overall size.

a measure of how wide the tree is at 1.37 meters off the ground, about chest high on an adult. Trees that have a 30 cm DBH are considered large and those that have a 60 cm DBH are classified as very large. Large and very large trees are important, as many animal species, including many birds, will only live in forests with lots of large trees [1]. Therefore, we hoped that parks would have a lot of large trees.

Figure 1

**Figure 1**

A park scientist measures the DBH of a tree at Saratoga National Historical Park (New York, USA).

By coming back to the same permanent plots, we could also measure how fast the trees grew and how often they died. It takes a long time to grow a large tree in a healthy forest, so if trees are dying often, they will never grow to be large. Trees in parks should die less often, because people cannot cut them down.

Dead trees are also important to forests. Dead trees can be divided into two types: **snags** and **coarse woody debris** (**CWD**). Snags (Figure 2) are trees that have died but are still standing. CWD (Figure 3) consists of large pieces of wood on the forest floor that come from falling trees or large branches. Many species, such as insects and mushrooms, only live in dead wood and would not be in a forest without those dead trees [2]. Some weasel-like mammals, such as American martens and fishers, use holes in large CWD and snags as dens to raise their young [3]. Even trees can benefit from CWD. Tree seedings are often found on CWD because the dead wood holds rainwater that helps the seedlings grow [4]. So, forests in parks should have more snags and CWD than unprotected forests outside of parks.

**SNAG**

A dead tree that is still standing.

**COARSE WOODY DEBRIS (CWD)**

Large pieces of dead wood on the forest floor.

## WHAT WE FOUND

We found that the forests in the parks are in better shape than the forests outside the parks. Of the 50 parks we studied, 46 had more large and very large trees than nearby forests! The trees inside the parks were growing more slowly, probably because they are bigger. In 31 parks, trees were less likely to die than those in forests outside the parks. In 8

**Figure 2**

A snag provides a good home for oyster mushrooms in Acadia National Park (Maine, USA).

Figure 2

**Figure 3**

This coarse woody debris in Acadia National Park (Maine, USA) supports many other species, including tree seedlings and a thick coating of moss.

Figure 3

parks, the trees were *more* likely to die. These were usually either new parks, or parks that were turning fields back into forests. Some of these new younger forests were similar to forests outside the parks, but as time passes, they should grow to have many large trees. Finally, there were 11 parks that we only visited once, so we could not tell what was happening to the trees over time. We also found that there was more dead wood in the parks than outside the parks. Of the 50 parks, 38 had more large snags and 48 had more CWD. In fact, park forests had over double the CWD of nearby forests.

## WHAT DOES IT MEAN?

We found that the protection provided by parks *did* make a big difference to forests. Compared to forests outside of parks, the forests inside parks had many more large trees. The trees in parks were also less likely to die, and forests in parks had more snags and more CWD than forests outside parks. This means that animals that need large living or dead trees can find homes in parks, even if they can not live in the forests outside of parks.

When we looked at the small parks, we found that they were usually protecting the forests just as well as the larger parks did. Although they are small, these parks are playing a big role in protecting nature. This is all good news—not just for large national parks, but for any small parks! Protecting trees is important not just for the trees themselves, but also for the many other species that rely on trees to survive. Our research shows that parks of any size can help safeguard all the species that live in forests.

## ORIGINAL SOURCE ARTICLE

Miller, K. M., Dieffenbach, F. W., Campbell, J. P., Cass, W. B., Comiskey, J. A., Matthews, E. R., et al. 2016. National Parks in the eastern United States harbor important older forest structure compared with matrix forests. *Ecosphere*. 7:e01404. doi: 10.1002/ecs2.1404

## REFERENCES

1. Guénette, J. -S., and Villard, M. -A. 2005. Thresholds in Forests Bird Response to Habitat Alteration as Quantitative Targets for Conservation. *Conserv Biol.* 19:1168–80. doi: 10.1111/j.1523-1739.2005.00085.x
2. Müller, J., and Bütler, R. 2010. A review of habitat thresholds for dead wood: a baseline for management recommendations in European forests. *Eur J Forest Res*. 129:981–92. doi: 10.1007/S10342-010-0400-5
3. Powell, R. A., Buskirk, S. W., and Zielinski, W. J. 2003. "29. Fisher and martin," in *Wild Mammals of North America Biology, Management and Conservation*, *2nd Edn*, eds G. A. Feldhamer, B. C. Thompson, J. A. Chapman (Baltimore, MD: The John Hopkins University Press).
4. Gärtner, M., Lieffers, V. J., and Macdonald, S. E. 2011. Ecology and Management of Natural Regeneration of White Spruce in the Boral Forest. *Environ Rev.* 19:461–78. doi: 10.1139/a11-01

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## YOUNG REVIEWERS

**EL, AGE: 14**

My name is Stella but I go by El (they/them). Some of my hobbies include acting, cosplay, reading and almost everything science-related. One topic I am currently looking into/studying is forensic science. My favorite subject in school is Science but Reading/English is a close second. I love to read and often find myself up late at night hyper-focused on a book. A food I really like is chicken-flavored ramen. When I am older I hope to have a career in forensic pathology.

**MOAB CHARTER SCHOOL, AGES: 11–12**

We are a unique human sixth grade class in Moab, Utah. We consist of seven students with interests such as rocks, Minecraft, longboarding, cosplay, animals, and dirt biking. Our favorite subjects are math and science and we also like doing community service projects. We enjoy living in and exploring the desert of southern Utah.

## AUTHORS

**JOHN PAUL SCHMIT**

John Paul started camping and exploring nature in middle school and has liked working outdoors ever since. He also enjoys learning about mathematics. As an ecologist for the National Park Service, he gets to combine both interests. John Paul helps to monitor natural resources in parks, like forests and streams, and then uses math and statistics to understand how they are changing. This information can help people make better decisions to protect the parks. *john_schmit@nps.gov

**KATHRYN MILLER**

Kate has always been fascinated by nature, but she did not realize people could make a living studying nature until college. After her first forest ecology class, she switched majors from English to natural resource management, and never looked back. She went on to get an M.S. and Ph.D. in ecology and biological sciences. Kate is an ecologist with the National Park Service, where she monitors forest health in 20 parks in the eastern U.S., to help parks better manage their forests. When not working, Kate enjoys gardening, hiking, and foraging for edible plants and fungi.

**ELIZABETH R. MATTHEWS**

Liz grew up in a city but spent her childhood summers in the mountains of North Carolina, where her interest in nature and love of eastern deciduous forests was born. After majoring in natural resources in college, she moved to North Carolina to work for a conservation organization, where she got her hands dirty doing ecological restoration. She went on to get a Ph.D. in plant ecology, and after a detour to California, returned to the eastern deciduous forest as a botanist, and later program manager, with the National Park Service.

**ANDREJS BROLIS**

Andrejs has always been a city boy who loved nature. Although he grew up in the suburbs of Washington DC, he spent most of his summer tromping around forests and playing in creeks. After graduating from Virginia Commonwealth University with a degree in biology, he spent the next few years exploring our public lands by hiking the Pacific Crest and Continental Divide National scenic trails. Wanting to return to greener forests, Andrejs moved back east and began working with the National Park Service. He is now a biologist overseeing forest and water monitoring for the NPS Inventory and Monitoring Program.

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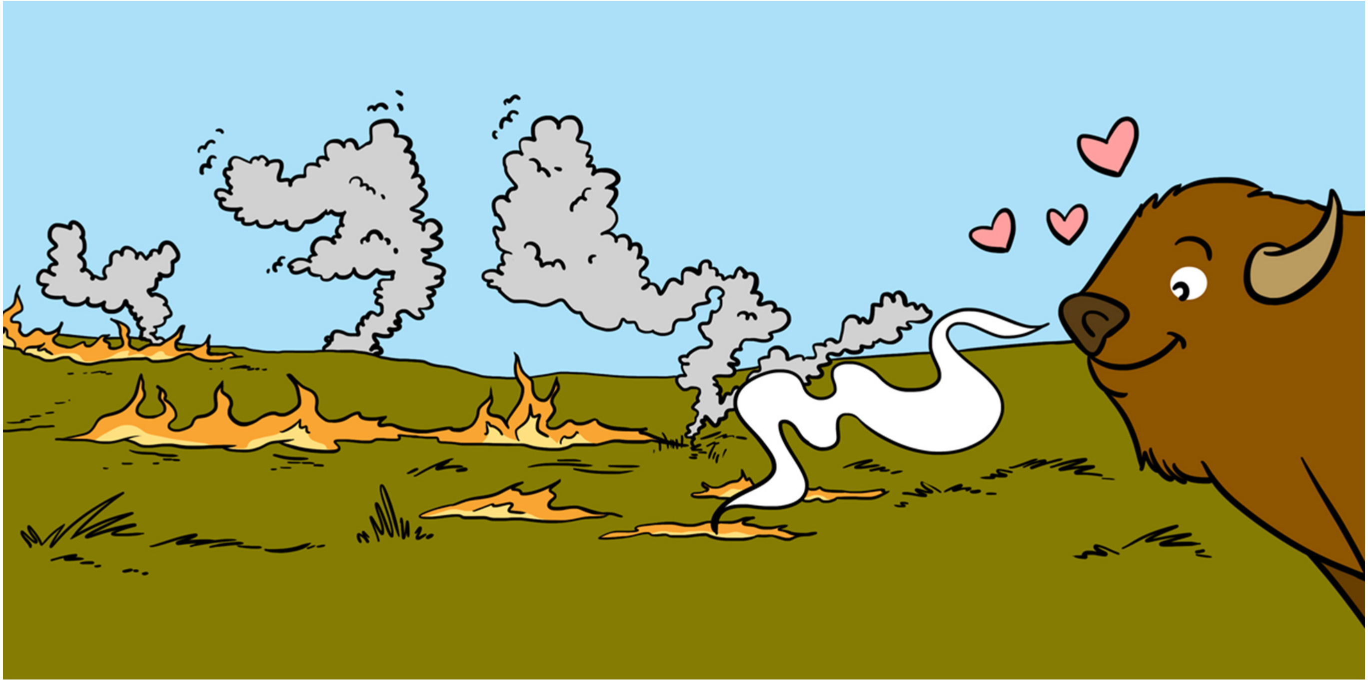

# EATING WHILE THE EATING'S GOOD: HOW FIRE CREATES A MAGNET FOR GRAZING ANIMALS

***Sherry A. Leis*[1*] *and Carol E. Baldwin*[2,3]**

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[2] *Agriculture, Natural Resources, and Community Vitality, Kansas State University, Manhattan, KS, United States*
[3] *Great Plains Fire Science Exchange, Manhattan, KS, United States*

YOUNG REVIEWERS:

HEADWATERS ACADEMY 8TH GRADE STUDENTS

AGES: 13-14

SKETCHY SCHOOL

AGES: 9-14

Tallgrass prairie is disappearing because farming and development have replaced it. This ecosystem is home to a unique group of plants, animals, and microbial life. The processes of fire, grazing by animals, and drought are important to the tallgrass prairie. They can influence each other and prairie life. For example, pyric-herbivory is the interaction of fire and grazing on the landscape. Burned areas attract herbivores (plant eaters) like a magnet. After fires, plant growth is nutritious and easy to find. Herbivores prefer grazing recently burned areas, creating patches of different habitats that support many other wildlife species, too. You can see pyric-herbivory in action at the Tallgrass Prairie National Preserve, where fire, cattle, and bison are a part of the preserve's management team! Healthy tallgrass prairie needs both fire and grazing.

## WHAT IS PRAIRIE?

Tallgrass prairie once covered much of central North America (Figure 1) [1]. Unfortunately, more than 90% of the prairie has been lost to cropland and development. We study the tallgrass prairie because of its important features and unique species. The prairie is fascinating and exciting, but when many people see a prairie for the first time, they only see grass. At first, the landscape may look empty and uninteresting but, as you look closer, an immense variety of life comes into focus. There are many different plant species, including grasses, wildflowers, sedges, and shrubs. Many of the plants are grasses like big bluestem, little bluestem, switchgrass, and Indiangrass. Wildflowers, like leadplant, heath aster, sunflowers, and milkweeds, are also important plants. Healthy prairies have many kinds of plants, but very few trees. The mixture of plants helps to create many habitats for wildlife. Deer, greater prairie-chickens, quail, grasshoppers, bees, and coyotes all depend on the tallgrass prairie. Bison no longer roam free in the tallgrass prairie, but they do live in ranches and parks, like the Tallgrass Prairie National Preserve in Kansas.

**ECOLOGICAL DISTURBANCE**

A short-term event or process that may cause the death of organisms or change the environment temporarily. Examples include drought, grazing, and fire, but not plowing for crop production.

The prairie is always changing because of ecological disturbances. **Ecological disturbances** are short-term events that change the plants, soil, water, or other organisms in an area for a short time. Grazing, fire, and drought (lack of rain) are examples of ecological disturbances than can often be beneficial [2]. The removal of grass leaves by grazing or fire is an example of a change that lasts for a short time (Figure 2). Ecological disturbances such as fire and grazing prevent tree growth while stimulating the germination and flowering of other plants and

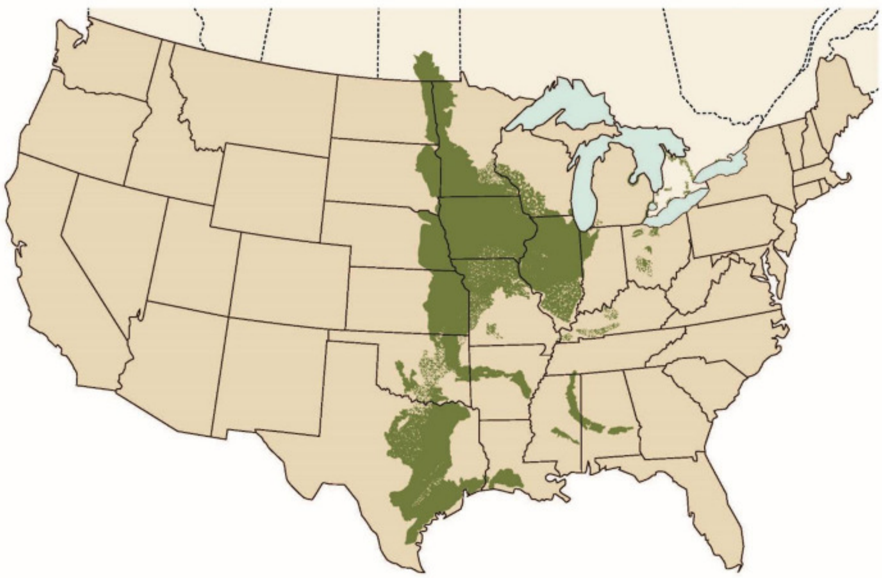

Figure 1

**Figure 1**

Map of tallgrass prairie prior to settlement by non-indigenous peoples (circa 1770). Less than 10% of this area remains as prairie today. Image used with permission from The Tallgrass Prairie Center, Cedar Falls, Iowa.

Figure 2

**Figure 2**

A prescribed burn at the Tallgrass Prairie National Preserve, Strong City, Kansas. The inset shows a closeup of the recently burned area. A grass blade (inside the hoop) began to emerge within a few days after the prescribed burn. Photo credit: Heartland Inventory and Monitoring Network, National Park Service.

the cycling of nutrients through the **ecosystem**. Prairies need these ecological disturbances to remain healthy.

**ECOSYSTEM**

The living and non-living parts of an area and their connections. Plants, animals, and other organisms interact with soil, rocks, water, light, and other parts of the landscape to survive.

## FIRE AND GRAZING ARE PRAIRIE PARTNERS

The attraction between fire and grazing is very strong [3]. This attraction is called **pyric-herbivory**. For example, cattle spend about 70% of their time grazing recently burned areas instead of unburned areas. The plants that regrow after a fire often have more key nutrients than the plants in unburned areas have. **Herbivores** can sense the best-tasting, highest-nutrition food that is also easy to munch on.

**PYRIC-HERBIVORY**

The interaction of fire and grazing. Herbivores tend to graze in recently burned areas rather than unburned areas. The attraction seems to be stronger in moist grassland like tallgrass prairie.

**HERBIVORE**

An organism that primarily eats plants.

**STANDING DEAD**

Above-ground plant stems that remain vertical even after they die.

The cycle of burning and grazing progresses through the seasons. Tall leaves and stems from the previous year (called **standing dead**) shade new spring growth and poke the animals' noses when they eat. Fire removes the standing dead, making the fresh growth easier to find. Burning reduces the shade from standing dead plants, which allows more efficient regrowth. Pyric-herbivory creates patches of short, burned-grazed plants next to patches of tall plants that are unburned and ungrazed. As fires are applied to various areas of the prairie, grazing shifts to newly burned patches. Areas that were previously burned and heavily grazed are left unburned, allowing the plants to regrow and rest (Figure 3).

The number of species that can live in a prairie is greatest when there are many habitat types available. Over time, pyric-herbivory provides a variety of habitats across the landscape, such as grasses of different heights, small patches of bare soil, and deep layers of old vegetation. For example, both killdeer and deer mouse are species that prefer bare ground in their habitats [3, 4]. Killdeer nest right on the bare soil and deer mice forage in open areas. Recently burned and grazed areas are important habitats for these animals. Henslow's sparrows and cotton

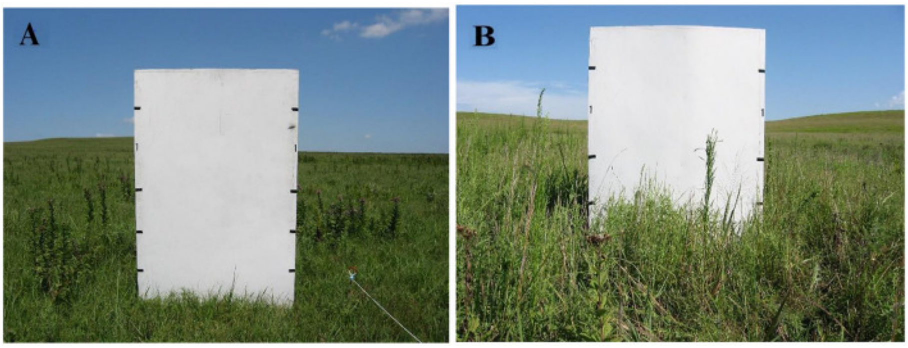


Figure 3

**Figure 3**

Photos from the Tallgrass Prairie National Preserve in 2009. **(A)** Tallgrass prairie burned in the prior month. Vegetation is short and relatively even in height, due to cattle grazing in the burned area. The white board shows the height of the plants, with black marks indicating 25 cm increments. Photos were taken 3 meters from the white board. **(B)** Tallgrass prairie burned 2 years prior. Vegetation is taller and more variable as it begins to recover from grazing and burning.

**LITTER**

Dead plant material laying on the soil surface.

rats, on the other hand, prefer areas with dense plants and litter. **Litter** is dead plant matter laying on the soil. Areas that have not been burned or grazed for a few years are ideal for these animals. Some animals, like greater prairie-chickens and quail, need more than one type of habitat, even during a single year. These birds need patches of short regrowth, bare ground, and tall grass with litter on the surface, all within their home range. Pyric-herbivory can create the patchy habitat that these prairie birds need.

Greater prairie-chickens are an example of an animal that is vanishing with the tallgrass prairie. Let us look further at their habitat needs. Early in the spring, male prairie-chickens "dance" to attract females. Mating dances occur in short grass or on bare ground, for maximum visibility. After mating, female prairie-chickens look for patches of unburned grass with dense litter to build nests. Tall plants and litter in unburned areas also conceal the hens and their chicks from predators like hawks and coyotes. As the tennis ball-sized chicks grow and begin to forage for food, they need areas that have lots of insects to eat and overhead cover to protect them from predators. The chicks are too small to move easily through the thick litter around the nest. That is why the burned areas are so important. Rapid plant growth after fire (a few weeks is all it takes) provides flowers and seeds that attract insects. Growing plant leaves provide cover, but chicks can move easily without litter blocking the way. Chicks can also find sunshine in burned areas when they need to dry off and warm up. Unburned areas are also valuable for winter refuge. On cold days, abundant litter and seeds for food help to keep the chickens warm. Healthy greater prairie-chicken populations need all these habitat types.

## THE FIRE-GRAZING INTERACTION IN ACTION

You can see pyric-herbivory at the Tallgrass Prairie National Preserve in Kansas, USA. The preserve protects a remnant of the tallgrass prairie ecosystem and explains the local ranching history. Staff use pyric-herbivory to protect the prairie and to tell the ranching story. Historically, ranchers burned the Kansas prairie before spring cattle drives. In the 1970s, burns shifted to earlier in the spring and cattle numbers increased. That new system created a more homogenous habitat type, meaning that the vegetation structure during the bird nesting season was very short and even like a lawn and some habitat types were missing. Later after cattle were sent to market, the plants grew taller and thicker, but evenly across the prairie.

In 2006, preserve managers again changed how fire and grazing were used. They began using pyric-herbivory to create a patchier prairie, instead of burning the whole preserve at once. Cattle and bison could then choose between grazing burned or unburned areas in their respective pastures. Researchers then observed the prairie plants and birds to see what changes occurred. Because some areas could now recover from grazing, bare ground decreased overall [5]. Bare ground was still greater in recently burned patches than in unburned patches. Pyric-herbivory led to a more balanced mix of habitat types.

Wildlife responded to these changes, too. Bird species that favored bare ground declined a bit, while birds that preferred denser vegetation increased. This patchy system also favored birds that are tallgrass prairie specialists instead of generalists [6]. Generalists are species that can live in many ecosystems. The increase in tallgrass prairie specialists is important because grassland-specialist birds are in decline in the USA. Providing more diverse habitat at the preserve helps grassland bird populations survive.

Pyric-herbivory also helps the land by decreasing the need for fences. Herbivores stay in the intended area because of their attraction to burned areas. When animals can choose what they graze, they select from a range of plants to meet their nutritional needs. The herbivores will move as they seek new burned areas with nutritious forage. Although fences can keep animals in designated areas, they are expensive and can interfere with wildlife movement. However, pyric-herbivory may not be a good fit for all prairies. It may not work well when the number of herbivores is too high or too low, or in very small prairies. Pyric-herbivory also functions differently in dryer climates. Fire is challenging to implement in some urban prairies, or those close to busy roads or smoke-sensitive businesses.

## A PRESCRIPTON FOR FIRE

Are you wondering how the fires are started? Wildfires are unplanned, lack objectives, and may be started by lightning, powerlines, or accidentally set by humans. **Prescribed burns** are different from wildfires because they are planned and purposeful. Great Plains Tribal Nations managed prairies with fire long before Europeans arrived [7]. Today, land managers continue to use prescribed burns to manage prairies.

**PRESCRIBED BURN**

Fires that are planned and ignited by humans; used for land management in natural areas.

Managers use prescribed fire to make the prairie ecosystem healthier. They also use a plan of treatment, called a burn plan, that is much like a medical prescription. The burn plan states the objectives, like improving wildlife habitat or the quality of plants available for animals to eat, and explains where and how the fire treatment will take place and what firebreaks will be used. Firebreaks are used to stop fire from crossing into unintended areas. For example, recently burned areas, roads, trails, streams, bare areas, and grazed areas can all stop fire. Burn plans also include lists of safe weather conditions, trained crews, and equipment.

## MORE TO LEARN

There is still much to learn about how animals and fire affect each other in the prairie. Pyric-herbivory may work differently in different prairie types, for example. We know that herbivores respond less intensely to burned areas in dryer ecosystems. The response of some plants to pyric-herbivory is also unknown. Underground, the soil is teeming with organisms about which we know very little, including their response to fire. You can become a scientist who uncovers new facts about the tallgrass prairie. You could also become a land manager who discovers new techniques to conserve the prairie. These are important jobs because they help to protect the prairie for the many organisms that call it home. Scientists and managers share what they have learned about prairies to inspire more people to protect these important places for the benefit of all living creatures including humans.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Sampson, F., and Knopf, F. 1994. Prairie conservation in North America. *Bioscience* 44:414–8.
2. Knapp, A. K., Briggs J. M., Hartnett D. C., and Collins S. L. (eds.). 1998. *Grassland Dynamics: Long-Term Ecological Research in Tallgrass Prairie*. Oxford: Oxford University Press.
3. Fuhlendorf, S. D., Harrell, W. C., and Engle, D. M. 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecol. Appl.* 16:1706–16. doi: 10.1890/1051-0761(2006)016[1706:shbtbf]2.0.co;2

4. Fuhlendorf, S. D., Townsend, D. E., Elmore, R. D., and Engle, D. M. 2010. Pyric-herbivory to promote rangeland heterogeneity: evidence from small mammal communities. *Rangel. Ecol. Manag.* 63:670–8. doi: 10.2111/REM-D-10-00044.1
5. Leis, S. A., and Morrison, L. W. 2018. *Long-Term Trends in Vegetation and Management Intensity: Tallgrass Prairie National Preserve 1995–2014*. Natural Resource Report NPS/HTLN/NRR-—2018/1582. Fort Collins, CO: National Park Service.
6. Peitz, D. G., and Kull, K. A. 2020. *Bird Community Monitoring at Tallgrass Prairie National Preserve, Kansas: Status Report 2001–2018*. Natural Resource Report. NPS/HTLN/NRR-—2020/2072. Fort Collins, CO: National Park Service.
7. Pyne, S. J. 2017. *The Great Plains: A Fire Survey.* Tuscon: The University of Arizona Press.

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## YOUNG REVIEWERS

### HEADWATERS ACADEMY 8TH GRADE STUDENTS, AGES: 13–14

Hi! We are the 8th grade class of 2021 at Headwaters Academy in Bozeman Montana. Bozeman is located just out of Yellowstone National Park. We have a small class of only 16 people, but it is great because we are able to travel together. Our class is very adventurous and athletic, we love spending time outdoors and spend a lot of time on the trails and slopes of the mountains surrounding us.

### SKETCHY SCHOOL, AGES: 9–14

We are from the Sketchy School, created during the pandemic for kids and families wanting to stay safe, and still be social while learning. We laughably call it Sketchy School because we meet in a warehouse and travel in a white van. We are very concerned about our planet, its animals, and how people treat each other. We are outdoor enthusiasts and athletes. We love animals. We enjoy reading, baking, writing, singing, dancing, eating, watching TV, and playing video games.

## AUTHORS

**SHERRY A. LEIS**

Sherry Leis is an ecologist with the National Park Service. She specializes in plants and fire ecology with emphasis on grassland ecosystems. Sherry is interested in how disturbances shape grassland communities. She has a master's degree in plant and soil science with emphasis in rangeland ecology and management as well as bachelor's degrees in anthropology and environmental biology. *sherry_leis@nps.gov

**CAROL E. BALDWIN**

Carol Baldwin is an extension associate at Kansas State University. She currently leads the Great Plains Fire Science Exchange, one of fifteen networks in the Joint Fire Science Program's national exchange network. Carol works to make science understandable for managers and others who work in grassland management and wildland fire. Carol's degrees are in range management (M.S. and Ph.D.) and production agronomy (B.S.), and she has 17 years of science outreach experience. She has also taught a university course and numerous guest lectures.

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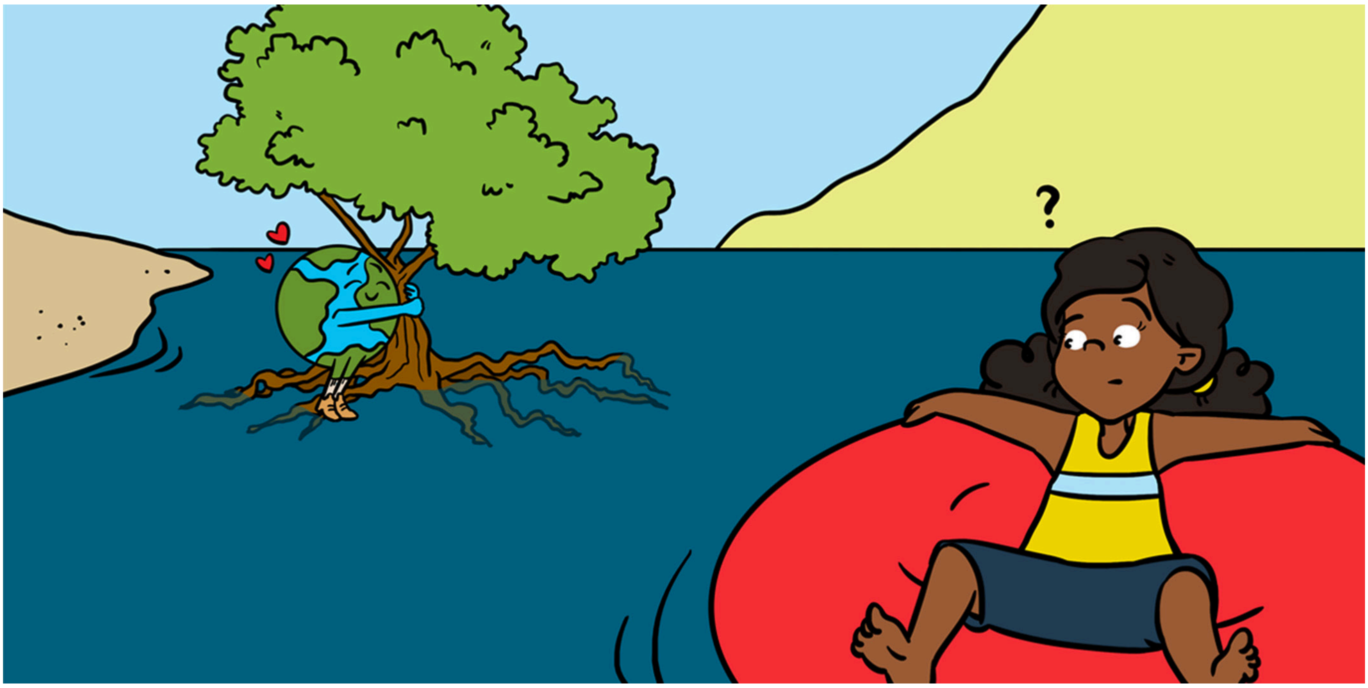

# MANGROVE MADNESS: WHAT ARE MANGROVES AND WHY DO WE CARE ABOUT THEM?

***Kevin R. T. Whelan**** ***and Michelle C. Prats***

*South Florida/ Caribbean Inventory & Monitoring Network, National Park Service, Palmetto Bay, FL, United States*

YOUNG REVIEWERS:

EMMA
AGE: 14

HEADWATERS ACADEMY 8TH GRADERS
AGES: 13–14

Mangrove communities are found in tropical regions of the world. They live along coastlines in the intertidal zone, where the land meets the sea. Mangroves provide many ecological services—a fancy term for benefits. They capture valuable sediments flowing into the ocean from streams, lower impacts from harmful substances, support many creatures, and prevent coastline erosion. At the heart of mangrove communities is the mighty mangrove tree. Mangrove trees have a unique system of roots and other structures to help them survive in a salty world. They tolerate regular flooding but can drown if they are under water too long. To adjust to rising sea levels, mangroves can bio-generate or capture materials to create soil. National Park Service scientists are studying this process. By building soil, mangroves capture and store carbon dioxide, which helps fight climate change. Mangroves are important to us all!

## WHAT ARE MANGROVE COMMUNITIES?

In tropical environments all over the world, mangrove communities consist of about 70 different species of trees, palms, shrubs, and ferns that live along the Earth's coastlines in the **intertidal zone**, which is where the ocean meets the land [1]. Often, they are found in **estuaries**—places where freshwater rivers flow into the ocean. Freshwater that arrives in estuaries often carries soil sediments, nutrients, and pesticides. Mangrove communities, also called mangrove forests, slow down the flow of this water and filter it, helping to capture sediments and decrease impacts from harmful substances like pollutants. Mangrove communities also shelter and support many creatures, including humans. In addition, they help prevent **erosion** by slowing down waves as they crash into the shoreline. At the foundation of mangrove communities are the mighty mangrove trees. Over thousands of years, mangrove trees have evolved unique traits that allow them to survive in a salty world.

**INTERTIDAL ZONE**

The area of the marine coastline that is either flooded by water at high tide or exposed to air at low tide.

**ESTUARY**

The place where freshwater flows into the ocean.

**EROSION**

The process of wearing away of the soil or rock by water, wind, or other natural agents over time.

## HOW DO MANGROVE TREES LIVE IN SALTWATER?

It is not normal for trees to grow in water, much less saltwater—but mangrove trees do it. So how *do* they do this? First, mangrove trees must deal with living in a lot of water, and then they need to figure out what to do with all the salt. Over time, mangroves have developed unique root systems that allow them to live in flooded habitats. Their roots are different from those of ordinary plants and have names like pneumatophores (pronounced new-mat-uh-fours), knees, aerial roots, and prop roots (Figures 1A,B). These special roots stick out of the water, which helps the trees breathe through special pores, called **lenticles**, that let in oxygen (Figure 1A). Other structures move the oxygen to the parts of the trees that are underwater. This unique root system prevents the trees from drowning.

**LENTICLE**

Special pores in woody plant stems or roots that allow gas exchange.

"Water, water, everywhere, Nor any drop to drink." Just like the sailor observed in "The Rime of the Ancient Mariner" poem by Coleridge (1798), ocean water is salty and unsafe for both humans and plants. Mangrove trees can handle salt in three ways: by blocking the salt from entering the roots, by letting the salt in and then sending it to older leaves that eventually die and fall off, or by letting the salt in and pushing it out through special salt glands on the surface of leaves, where it is washed away by rain [2]. Salt that the mangrove roots block out slowly builds up in the surrounding soil over time, making it saltier. This makes it harder for the mangroves to keep the salt out. Luckily, rainfall and ocean tides help move the extra salt back into the ocean. If this flushing process did not happen, mangrove communities would get so salty that even the mighty mangrove tree could not survive.

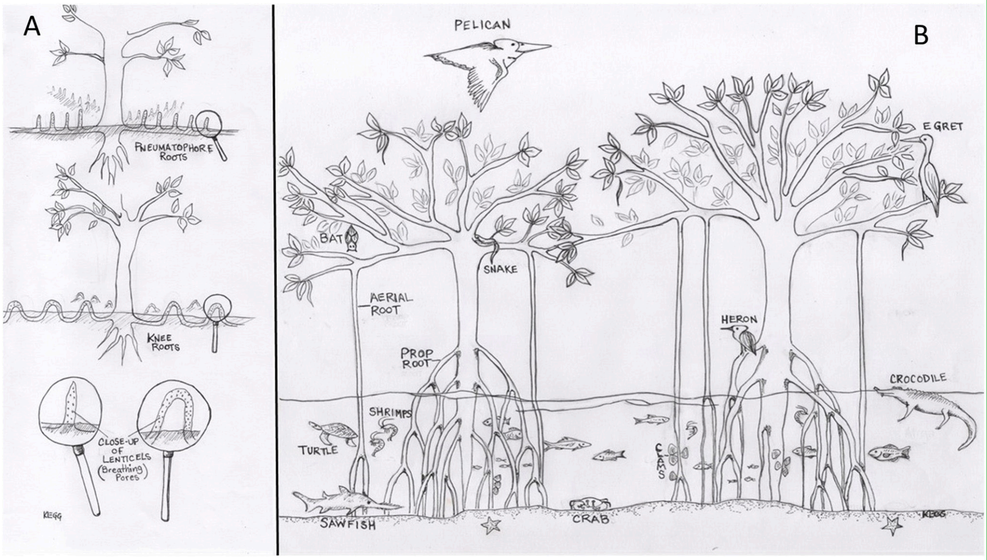


Figure 1

**Figure 1**

**(A)** Mangrove pneumatophores and knee roots, and a close-up of the lenticels (breathing pores) found on mangrove roots. **(B)** Mangrove trees with prop and aerial roots along with the animals found in the mangrove community when the area is flooded with water (Image credits: Kristin Legg).

## IT IS A GIVE-AND-TAKE MANGROVE WORLD

Healthy mangrove forests are not always flooded—water flows in and out (Figure 2). The amount of water and the length of time that water is present are constantly changing. Water levels can change one or two times a day, due to the tide cycle, and sometimes over several weeks to months due to seasonal rain events (monsoons), water pushed by the wind, or floods. As water comes into the mangrove communities, it brings in beneficial nutrients (like phosphorous) from the ocean. When the water flows out, it gets rid of materials that can be bad for the trees, like the extra salt. Water movement also brings oxygen to the tree roots and soil. In addition, leaves, nutrients, sediments, and other things that can be useful to the nearby ocean are carried away.

Shifting water levels also help mangrove communities to support many ocean creatures (Figure 2C). When the mangrove forest is flooded, the roots provide places for animals to eat and hide. Fish, crabs, shrimps, and other marine species come into the mangrove forests to find food. Even larger animals like the smalltooth sawfish, rays, crocodiles, and manatees use mangrove forests when they are flooded (Figures 1, 3). Once the water moves out, a whole different group of creatures arrives, searching for food on newly uncovered surfaces. It is common to see wading birds, raccoons, snails, lizards, and crabs like the mangrove tree crab and the fiddler crab, feeding in the mangrove forest mud (Figure 3). There is even a fish called the mangrove rivulus that can live in mangrove forests when there is no water at all. The rivulus fish has been found living inside dead mangrove logs for up to 60 days with no water [3]!


Figure 2

**Figure 2**

**(A)** Large black mangrove tree with numerous pneumatophores and adventurous roots coming out of the trunk, Biscayne National Park (Photograph credit: Kevin Whelan). **(B)** Large riverine mangroves in Tanjung Puting National Park, Kalimantan, Indonesia (Photograph credit: Craig Allen). **(C)** Corals, flat tree oysters, and sponges attached to red mangrove prop roots in Hurricane Hole, Saint John, US Virgin Islands (Photograph credit: Caroline Rogers). **(D)** Author standing on large prop root of a mangrove tree, Indonesia (Photograph credit: NPS).

## MANGROVE FORESTS ARE A FISH'S (AND OTHER SPECIES) BEST FRIEND

Without a doubt, mangrove forests support abundant wildlife. Many animals spend part of their lives, or their entire lifetimes, in mangrove communities. This is especially true for fish. In South Florida, U.S.A., the home of Biscayne National Park and other nearby national parks, an estimated 90% of commercially caught fish (fish that are caught and sold for a profit) and 75% of game fish (fish caught for fun) need mangroves for some part of their lifespan. In Malaysia, scientists have found over 119 different fish species in one single mangrove creek!

Figure 3

**Figure 3**

**(A)** Double-crested cormorants nesting in a mangrove tree, Biscayne National Park (Photograph credit: Robert Muxo). **(B)** American crocodile in a Florida mangrove forest (Photograph credit: Kevin Whelan). **(C)** Indonesian fisherman pulling in nets on Kumai Bay, Indonesia (Photograph credit: Kevin Whelan). **(D)** Bocourt Swimming Crab in the mangroves of Saint Croix, US Virgin Islands (Photograph credit: Kevin Whelan).

Clearly, mangrove forests ARE a fish's best friend, but other life forms benefit from mangrove forests as well. Mangrove roots provide a solid structure that organisms like sponges, sea fans, anemones, clams, oysters, and corals can attach to and live on (Figures 1, 2). At US Virgin Islands National Park, scientists recorded the same number of coral species in mangrove forests as they did on nearby coral reefs. That is amazing! In addition, the scientists found over 60 species of sponges attached to mangrove tree roots.

## MANGROVE SUPERHEROES: RISING SEA LEVELS AND CAPTURING CARBON DIOXIDE

Even the mighty mangrove will eventually drown if water levels do not vary enough. If the water is too deep for too long, mangrove seedlings drown. Without mangrove seedlings, there are no young trees to replace those that die. To adapt to rising sea levels within mangrove forests, mangrove trees can **bio-generate** materials to make **peat** (a soil made of partially decomposed leaves and roots) and/or capture natural materials to build up soil levels. During bio-generation, mangroves help capture and trap carbon dioxide ($CO_2$), making these trees important players in the fight against climate change.

**BIO-GENERATE**

The building blocks of a substance or process come from biologically made components.

**PEAT**

Soil formed from partially decomposed plant materials (leaves, roots, etc.) in wet, low-oxygen conditions.

Through photosynthesis, mangroves collect $CO_2$ from the atmosphere and lock it up for long-term storage in their peat soil. Mangrove forests are one of the most carbon-dense forests in the world, containing on average 1,023 metric tons of carbon per hectare [4]. What does this mean? Well, if an average passenger car uses a 75-L tank of gas, then it produces about 178 kg of carbon. So, each hectare of a mangrove forest stores about 5,750 tanks of gas in carbon. Now that is a lot to honk about!

## WHAT ELSE CAN PEAT TELL US?

Not only can peat sequester $CO_2$, but it can also help scientists understand how mangrove communities have survived over time. Mangrove communities have existed at the boundary between the ocean and the land, in places like Belize, for thousands of years! How do we know this? Well, scientists can gather a lot of useful information from studying the peat beneath the mangrove roots. Scientists took 12-meter-long **soil cores** out of the ground from a Belize mangrove forest. Back in the laboratory, they used microscopes and other machines and techniques to identify the types of material in the soil and how long they had been there. They found that the mangroves in Belize today are in the same spot as mangroves 8,000 years ago [5]! Who would have thought that dirt—oh sorry, peat—could tell us so much?

**SOIL CORE**

A vertical soil collection that samples down the soil column (profile). It is typically collected in a tube or cylinder.

To understand how mangrove forests are managing sea-level changes today, National Park Service scientists use information collected from soil-monitoring stations in mangrove forests in numerous national parks. These stations are sampled twice a year to see if the mangroves are generating peat or capturing enough soil to keep pace with the rising sea levels. And so far, mangrove forests seem to be doing their part!

## PROTECTING THE EARTH'S COASTLINES

By now, you have learned about the numerous **ecological services** mangrove forests provide. But did you know that mangrove communities are also extremely important in protecting Earth's coastlines? Their presence in the intertidal zone helps buffer shores from all sizes of waves—from small, rippling waves that can result in minor erosion, to massive waves from storm surges that can wipe out entire coastal ecosystems and human developments. As our Earth experiences more frequent and extreme storm events with climate change, mangrove communities are increasingly vital to preserving these fragile areas where the land meets the sea.

**ECOLOGICAL SERVICES**

Benefits that an ecosystem provides for humankind, such as oxygen, habitat for animals, place for recreation.

## CONCLUSION

Next time you visit a beach or go fishing, remember the valuable role of mangrove forests in keeping our coasts healthy. From sheltering and supporting ocean and land animals to keeping the Earth's shorelines intact, this important job is accomplished by the mighty mangrove!

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## REFERENCES

1. Duke, N., Ball, M., and Ellison, J. 1998. Factors influencing biodiversity and distributional gradients in mangroves. *Glob. Ecol. Biogeogr. Lett.* 7:27–47.
2. Hogarth, P. J. 1999. *The Biology of Mangroves*. Oxford: Oxford University Press.
3. Taylor, D. S., Turner, B. J., Davis, W. P., and Chapman, B. B. 2008. A novel terrestrial fish habitat inside emergent logs. *Am. Naturalist* 171:263–6. doi: 10.1086/524960
4. Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., and Kanninen, M. 2011. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* 4:293–7. doi: 10.1038/ngeo1123
5. Toscano, M. A., Gonzalez, J. L., and Whelan, K. R. T. 2016. "Sea level reconstructions from thick mangrove peat deposits in Florida, Belize and Panama – age and paleo elevations of basal peats vs. continuous sampling, and relationship to geophysical sea level models," in *The Mangrove and Macrobenthos Meeting* (St. Augustine, FL: University of Florida, Institute of Food and Agricultural Sciences).

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## YOUNG REVIEWERS

### EMMA, AGE: 14

Hi, my name is Emma. I live in Bozeman, MT. Some of my interests are earth sciences, biology, rocks and minerals. I also have multiple artistic hobbies including sculpting, painting, and sketching. This fall I will be heading into 9th grade.

### HEADWATERS ACADEMY 8TH GRADERS, AGES: 13–14

We are Headwaters Academy 8th grade students located in Bozeman Montana USA. Headwaters is a non-profit middle school with only 90 students, and only 27 students in the 8th grade. Headwaters mission is to educate young leaders for a changing world. We love being outdoors and base a lot of what we are learning about off of the nature around us. Our 8th graders are very lucky to be learning all about Mangroves, as well as editing the mangroves article.

## AUTHORS

### KEVIN R. T. WHELAN

Kevin R. T. Whelan is a scientist who monitors mangroves and other communities in the national parks in South Florida and the US Virgin Islands. The best part of his job is working in the field and observing nature. It is hot, buggy, and muddy in these parks, but they are also quite a beautiful place to experience. The hardest part of the job is getting folks to understand how the natural system works so they can make good decisions on how to help protect them into the future. *kevin_r_whelan@nps.gov

### MICHELLE C. PRATS

Michelle Prats monitors natural resources in the national parks of South Florida and the US Virgin Islands. One of her projects is measuring the change in soil elevation in mangrove communities. She also helps monitor fresh-water algae, nesting birds, and long-term forest health. One fun part of her job is traveling in boats, ATVs, and helicopters to areas that visitors do not normally see. One challenge is sharing data results quickly enough, so that it is useful to park managers. It is important that decisions are made based on good science. Michelle_Prats@nps.gov

EARTH AND ITS RESOURCES
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# NUTRIENTS IN MOUNTAIN LAKES: HOW MUCH IS TOO MUCH?

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[2] *Department of Environmental Sciences, University of California, Riverside, Riverside, CA, United States*

YOUNG REVIEWERS:

ADELAIDE
AGE: 7

LUKE
AGE: 10

ROWAN
AGE: 9

SILAS
AGE: 12

Yosemite, Kings Canyon, and Sequoia national parks protect over 1,200 mountain lakes. These lakes provide healthy homes for plants and animals and supply clean water to downstream communities. These clear blue lakes are high up in the mountains, where they receive very low amounts of nutrients from the watershed. Nutrients help living things grow and be healthy. However, human activities from communities upwind are adding nutrients into the air. These nutrients travel on air currents to remote watersheds *via* rain, snow, and dry particles. They increase lake algae growth, which disrupts the balance of plants and animals. We conducted experiments to determine the amount of nutrients it takes to increase algae growth. We compared these levels to current lake nutrient concentrations and found that over half of the lakes had concentrations that were below the determined early warning point and just under half were at levels of higher concern.

## WHY ARE WE WORRIED ABOUT TOO MANY NUTRIENTS IN MOUNTAIN LAKES?

Why are we worried about **nutrients**—are they not a good thing? We eat vegetables and fruits and add fertilizer to our gardens so that our bodies and our plants get the nutrients they need to grow and stay healthy. But the lakes in the Sierra Nevada mountains occur in rocky basins with normally low amounts of nutrients. The plants and animals living in these lakes are used to living in water with low nutrient concentrations. Although these lakes are in national parks, the park boundaries do not protect them from air pollution. Nutrients produced by industries, agriculture, and cars and trucks drift into mountain **watersheds** on air currents and are deposited *via* rain, snow, and dry particles (Figure 1). These pollutants travel from communities in California's Central Valley, the San Francisco Bay Area, and as far away as Asia [1, 2]!

Nitrogen is one of these pollutants. While nitrogen may be good for plants in our gardens, when too much nitrogen ends up in mountain lakes it can make the water less healthy and upset the balance of plants and animals that live there [3]. Nitrogen can increase the amount of **algae** in these lakes. When a large amount of algae dies and decays, this process can reduce the amount of oxygen dissolved in lake water. Animals like insects and frogs that live in the water need dissolved oxygen to breathe and survive. These insects and frogs are food sources for other animals such as birds, snakes, and shrews. Thus, changes in nutrients and algae can have cascading effects on the animals that live in the lakes and those that feed on them. Algae can also change the way lakes look—reducing their clarity and making them more green or murky [4]. We can keep track of changes in

**NUTRIENTS**

A substance used by organisms to survive, grow, and reproduce. Nitrogen is an important nutrient, as it is part of many proteins used by plants and animals.

**WATERSHEDS**

Land area that channels rainfall and snowmelt to streams and rivers, and eventually to lakes, bays, and oceans. Watersheds are separated by higher land areas like ridges.

**ALGAE**

Aquatic plants ranging from single-celled phytoplankton to multicellular forms like kelp. Algae contain pigments that allow them to use sunlight to make their own food from water and carbon dioxide.

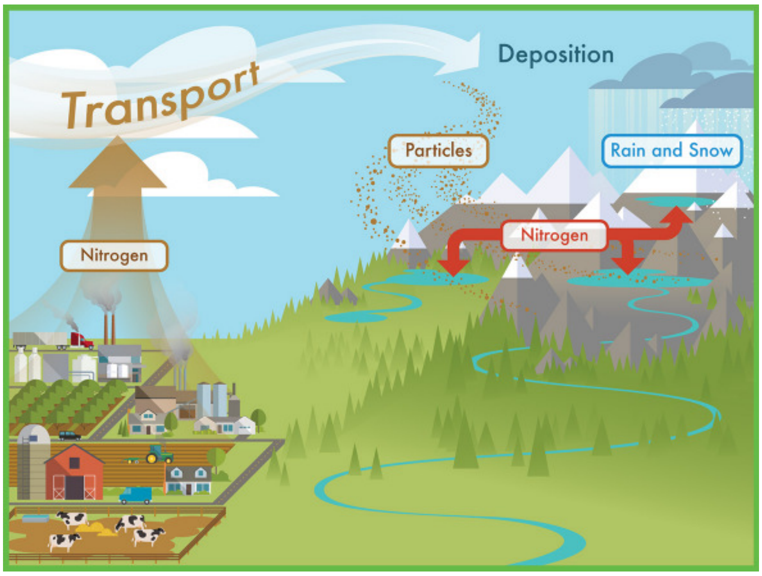


Figure 1

**Figure 1**

Sources of nitrogen include farms, vehicles, and industrial plants located in upwind communities. The nitrogen from these sources is transported on air currents up into the mountains. Here, it can fall into mountain watersheds as part of dry particles, rain, or snow.

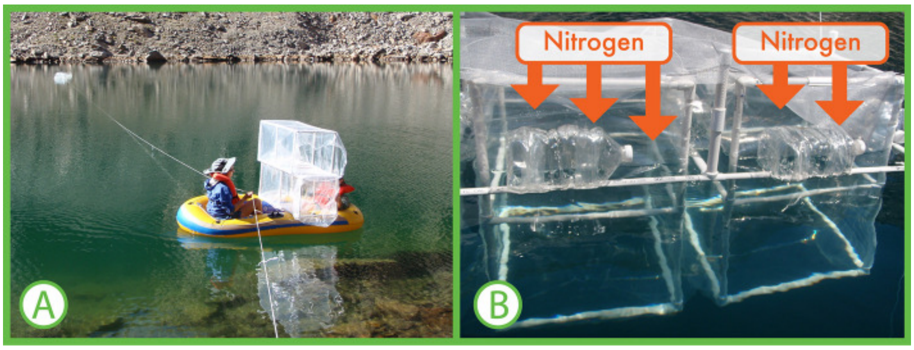


Figure 2

**Figure 2**

**(A)** We used small inflatable boats to carry and set up containers in the middle of the lake. Empty water bottles were used as flotation supports for the containers. **(B)** We filled the containers with lake water and added different amounts of nitrogen to each of them. This enabled us to develop numeric relationships between nitrogen and algae growth.

these lakes by monitoring them and doing research to answer specific questions about nutrients.

## TAKING THE PULSE OF MOUNTAIN LAKES

Scientists who work in the field of **limnology** are working hard to protect the mountain lakes in Yosemite, Sequoia, and Kings Canyon national parks. We and our crews of field scientists hike out to lakes every year to collect water samples and take scientific measurements. We monitor 76 lakes in the parks! **Nitrogen concentrations** are one measurement we collect. We can compare our nitrogen measurements each year to see if they are going up, going down, or staying the same. But we do not understand if these nitrogen amounts will cause too much algae to grow. We do not know how much nitrogen is too much. When a doctor measures your pulse, he or she can tell you if your heart rate is a healthy number, because doctors know how fast a healthy heart should beat. However, we do not know what that healthy number is for nutrients in mountain lakes.

**LIMNOLOGY**

The study of the chemistry, biology, and physics of inland waters. Similar to oceanography but performed in mainly freshwater environments.

**NITROGEN CONCENTRATIONS**

The mass or weight of nitrogen in 1L of water. We report nitrogen concentration using the units of parts per billion (ppb).

## HOW CAN WE TEST "HOW MUCH IS TOO MUCH?"

We developed experiments to help us answer how much nitrogen is too much for mountain lakes. We put large containers out in the middle of lakes and filled these containers with lake water (Figure 2). Any algae naturally living in each lake would also be captured in the containers with the lake water. We then added nitrogen to each container. We put a very small amount of nitrogen in the first container, and a slightly higher amount in the second container. We continued adding nitrogen in higher amounts until we had 15 containers. We waited 7 days to give the algae time to take in the nitrogen and grow. We collected water samples before and after the 7 days and measured the amount of algae in each sample.

We found that as we added more nitrogen, more algae grew (Figure 3). We used a graph to compare the nitrogen concentrations to the

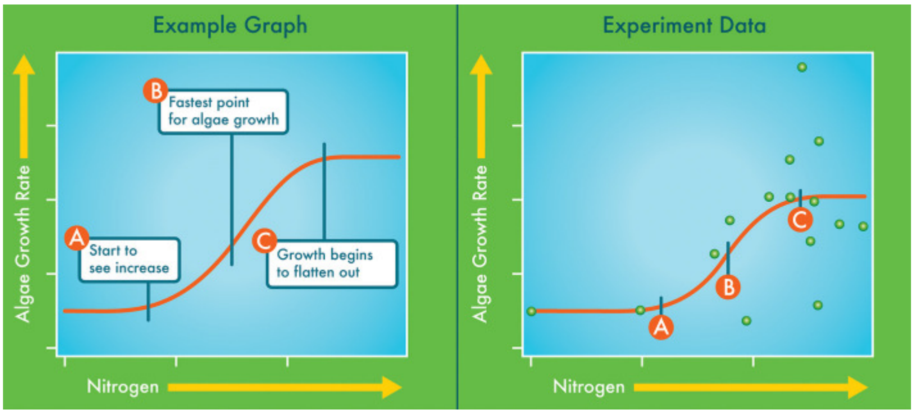


Figure 3

**Figure 3**

The graph on the left shows the general relationship between nitrogen and algae growth. The three levels of nitrogen that we examined are labeled A, B, and C along the curve. The graph on the right shows data from one of our experiments (green circles). The orange line shows the curve that fits our data. Our data allowed us to determine the nitrogen concentrations for points A, B, and C. For example, we observed increased algae growth when nitrogen reached 4–12 ppb.

amount of algae growth. The graph shows the amount of nitrogen present when algae first start to grow (Figure 3, point A). This is an early warning that we are starting to see too much nitrogen. The graph also shows when the algae start growing really fast (Figure 3, point B). There are too many nutrients at this point. Last, the graph shows when the algae growth is at its highest point and it starts to level out (Figure 3, point C). This means that there is more nitrogen than the algae can use—the algae cannot grow fast enough to keep up. At high nitrogen concentrations other nutrients like phosphorus can limit algae growth [5].

We want to pay the most attention to when nitrogen concentrations reach that first early warning point (Figure 3, point A). We learned from our experiments that we reach this point when nitrogen concentrations are between 4 and 12 parts per billion (ppb). This is a very low amount of nitrogen—a ppb is like adding a half teaspoon of dye to an Olympic-size pool! It takes very little nitrogen to make algae grow faster than we want. But by knowing what this amount is and paying attention early, we will have time to act and protect our mountain lakes. If we wait too long, the changes in nutrients and algae will upset the balance of plants and animals that live in these lakes.

## LOCATION MATTERS

We looked more closely at which lakes have higher nitrogen concentrations and learned that their locations on the landscape were important. Lakes found at the highest places of the Sierra Nevada mountains, or in rocky, steep watersheds, may have more nitrogen because few plants grow there. Plants take up and store nitrogen and reduce the amount of nitrogen that reaches streams and lakes. Water, and the nutrients in it, also travels more quickly down steep slopes. This means more nitrogen reaches the lakes that are located in areas with steep slopes surrounding them. Location is not everything, but it does matter for some lakes!

## THERE IS STILL TIME TO MAKE A DIFFERENCE

We compared the amounts of nitrogen we measured in the 76 lakes we monitor to the amounts we defined in our experiments and calculated the percentage of lakes that exceeded each level. We found that up to 13% of these lakes were below levels of concern (meaning they had healthy nitrogen levels), 37% had nitrogen concentrations that were at the early warning point (A), 29% were at the most rapid growth point (B), and 21% were at the high nitrogen point (C) where algae have more nitrogen than they can use. The good news is that over half of the lakes had nitrogen levels that were healthy or at the early warning point. So, while we are seeing too many nutrients in some lakes, many lakes are still healthy.

How can we use this information to reduce the amount of pollution reaching mountain lakes? As scientists, we can make sure that national park managers have the information they need to communicate about the health of these lakes to the public (that is you!) and to policymakers. The public and policymakers have the power to make decisions that will improve our air and water quality.

Is there anything you can do? Yes! The everyday choices that you make can help reduce pollution. For example, you can buy more food locally, such as from farmers' markets and local small farms, so it does not have to be transported from faraway places. You can try to use cars less often and bicycles and public transportation more frequently. Also, you can find out if your community is taking actions to protect air and water quality. Get involved! If you are interested in this topic and want to help, you can make a difference!

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## REFERENCES

1. Bytnerowicz, A., Tausz, M., Alanso, R., Jones, D., Johnson, R., and Grulke, N. 2002. Summer-time distribution of air pollutants in Sequoia National Park, California. *Environ. Poll.* 118:187–203. doi: 10.1016/S0269-7491(01)00312-8
2. Vicars, W. C., and Sickman, J. O. 2011. Mineral dust transport to the Sierra Nevada, California: loading rates and potential source areas. *J. Geophys. Res. Biogeosci.* 116:G1. doi: 10.1029/2010jg001394
3. Aczel, M. 2019. What is the nitrogen cycle and why is it key to life? *Front. Young Minds* 7:41. doi: 10.3389/frym.2019.00041
4. Goldman, C. R. 1988. Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada. *Limnol. Oceanogr.* 33:1321–33. doi: 10.4319/lo.1988.33.6.1321
5. Sterner, R. W. 2008. On the phosphorus limitation paradigm for lakes. *Int. Rev. Hydrobiol.* 93:433–45. doi: 10.1002/iroh.200811068

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## YOUNG REVIEWERS

**ADELAIDE, AGE: 7**
My name is Adelaide and I love to ski, camp, hike, and bike. I also love arts and crafts and my favorite color is blue. I love stuffed bears, cats, and dogs. I love to paint, and I want a dog. I love to be outside.

**LUKE, AGE: 10**

I like skiing, mountain biking, and fishing. I like legos and getting dirty. My favorite subject in school is math and I want to be a scientist when I grow up.

**ROWAN, AGE: 9**

I am starting fourth grade and my hobbies include playing soccer, Mindcraft, and Legos. My favorite subjects at school are History, Art, Science, and PE. I love swimming in lakes in the Sierra Nevada mountains.

**SILAS, AGE: 12**

I really like to ski and snowboard. I also really like hanging out with friends and playing video games. I love music, so I play piano and drumset. My favorite subject in school is language arts.

## AUTHORS

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Dr. Andrea M. Heard is a physical scientist with the National Park Service, Sierra Nevada Network (SIEN) Inventory and Monitoring Program. She is the lead for SIEN lake and river monitoring in Sequoia, Kings Canyon, and Yosemite national parks. These long-term monitoring projects inform the protection of aquatic ecosystems in our mountains and national parks. Dr. Heard's professional interests include water chemistry and hydrology. She also enjoys hiking (especially to mountain lakes!), camping, soccer, and sharing these pursuits with her family. *andi_heard@nps.gov

**JAMES O. SICKMAN**

Dr. James O. Sickman is a limnologist and hydrologist who investigates cycling of carbon, nitrogen, and phosphorus in lakes, rivers, and wetlands. He has been studying lakes and watersheds in the Sierra Nevada for almost 40 years, to understand how they are affected by major environmental problems such as acid rain, eutrophication, climate change, and surface-water pollution. Dr. Sickman is Emeritus Professor in the Department of Environmental Sciences at the University of California, Riverside.

**LINDA S. MUTCH**

Linda S. Mutch is a science communication specialist with the Sierra Nevada Network in the Inventory and Monitoring Division of the National Park Service. She works closely with her co-workers to communicate science findings to different audiences, from national park managers to the public. Together, they use web pages, newsletters, reports, publications, videos, posters, brief summaries, and presentations to share information about lakes, birds, forests, wetlands, and river-monitoring projects. Ms. Mutch previously worked as a forest ecologist and studied fire ecology and changes in forest health.

BIODIVERSITY
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# THE WILD AND WONDERFUL WORLD OF STREAM BUGS

*Trey Simmons[1*], Eric C. Dinger[2] and E. William Schweiger[3]*

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[2] *Klamath Inventory and Monitoring Network, National Park Service, Ashland, OR, United States*
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YOUNG REVIEWERS:

CLAREMONT MIDDLE SCHOOL

AGES: 11–12

MS. WARD'S AND MS. SHEIN'S 6TH GRADE SCIENCE CLASSES, PACIFIC CREST MIDDLE SCHOOL

AGES: 11–13

Under the surface of most streams a strange world exists, made up of hundreds of small critters called aquatic invertebrates. "Aquatic" means they live in the water and "invertebrate" means they have no backbones or even skeletons. Some have body parts that look like they came from an alien planet. Some have slippery bodies adapted to rushing stream water. These organisms play many important roles. Some live for up to 7 years and others live for as little as 2 weeks. Some eat slime growing on stream rocks and others eat leaves. Some, like the golden stonefly, even stalk and eat other invertebrates, like a tiger in a jungle. In national parks and around the world, scientists use these insects, worms, leeches, and mites to tell if the water is healthy. We can do this because certain stream invertebrates disappear if water is polluted, or if the stream habitat is degraded.

## WHAT ARE AQUATIC INVERTEBRATES?

Have you ever picked up a rock in a stream and looked at it? If you have, you have probably seen some bugs crawling on it. These bugs are called **aquatic invertebrates**. Aquatic invertebrates are mostly insects, but they also include worms, leeches, clams, snails, mussels, **crustaceans** (like crabs) and mites (tiny spiders) that live in the water. When people think about what lives in streams, rivers, and lakes, most think about fish, or maybe tadpoles. But invertebrates are much more important. They make up most of the **biomass** and most of the **biodiversity** in freshwater. There might be hundreds of kinds of invertebrates in a stream or lake, but only a few kinds of fish, and sometimes no fish at all.

Invertebrates live in almost every stream or lake on earth. They can live in extreme conditions, even hot springs that would scald your hand! In desert places like Death Valley National Park (California, United States) or Canyonlands National Park (Utah), invertebrates can live in temporary puddles. When there is water in the puddle, they hatch and grow quickly. Then they lay eggs that can survive when the puddle dries up. No matter where you look, if there is water, there are probably aquatic invertebrates. Although many invertebrates can swim, most of them spend their lives among the rocks or in the mud at the bottom of the stream. That is why we often do not notice them. Each species has its own unique **habitat** needs, so scientists can tell a lot about a stream by which aquatic invertebrates are there—or not there. For example, some like really cold, clean water, and others like warm, dirty water. In this article, we will focus mainly on aquatic insects, the largest group of aquatic invertebrates.

## LIFE CYCLE

Aquatic insects typically spend most of their lives as youngsters in the water (Figure 1A). They live only a short time as adult flying insects (Figure 1B). These youngsters are the **larva** stage of the insect's life. In the same way, a caterpillar is the larval stage of an adult butterfly. Larval insects transform into winged adults through **metamorphosis**. Metamorphosis is the process by which caterpillars transform into butterflies. The flying adults that emerge from the water live for only a few days or weeks. Because of their short lives, some adult aquatic insects do not even have mouths to eat with (Figure 1C)! The adult's main purpose is to lay eggs to create the next generation of insects. Males fertilize the eggs that are carried by females. How do males and females meet? To make it easier to find each other, the adults of a particular species emerge from the water at the same time. This is why you often see large swarms of aquatic insects flying around over a stream or lake.

**AQUATIC INVERTEBRATE**

Animals that do not have backbones, or even skeletons ("invertebrate") and that spend all or most of their lives in the water ("aquatic").

**CRUSTACEAN**

A type of invertebrate with a hard shell and more than 10 legs. Crustaceans include crabs, lobsters, crayfish, and roly-poly bugs.

**BIOMASS**

The total weight of all the organisms in a particular area, including all the plants and animals that live there.

**BIODIVERSITY**

All the different kinds of life found in a particular area, including all the animals, plants, and microorganisms.

**HABITAT**

A way to describe the natural home of an animal or plant. Each animal or plant prefers its habitat to be a certain way.

**LARVA**

A larva is an immature insect. Usually a larva looks very different from an adult insect. A larva changes into an adult through metamorphosis.

**METAMORPHOSIS**

The process by which a larva changes into an adult. Its body shape usually changes dramatically over a very short time. It may also grow legs or wings.

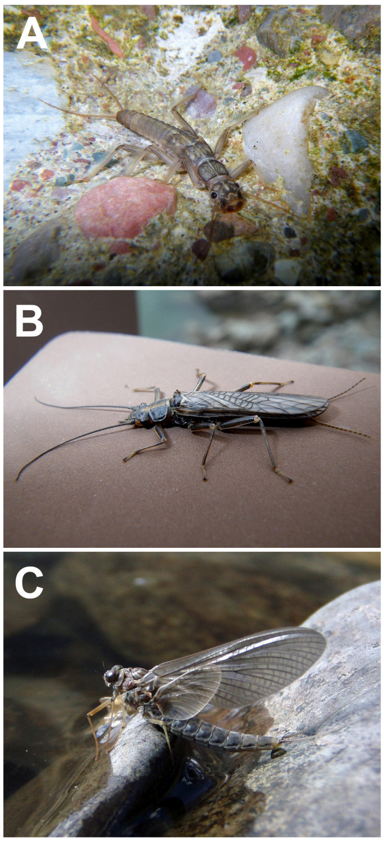

Figure 1

**Figure 1**

**(A)** A stonefly larva (about 3 cm long) on the bottom of a stream in Glacier National Park (Montana). **(B)** An adult stonefly, with awesome red eyes, resting on a rock. When it is resting, it keeps its wings flat. This giant one might be more than 6 cm long. **(C)** An adult mayfly emerging from the water right after metamorphosis. Many kinds of mayflies do not eat as adults and have no mouths. A mayfly sticks its wings straight up when it is resting. They are usually <3 cm long (Photograph credits: Joe Giersch, USGS).

Climate can have a big effect on how long an aquatic insect stays in a stream before emerging as an adult. Some midges (teensy flies that are annoying but do not bite) that live in really cold places like Gates of the Arctic National Park in Alaska might stay in the stream as larvae for up to 7 years before changing into adults. That is because it takes longer for them to grow in the cold. But in a warm place like Everglades National Park in Florida, those same midges might only live in the water for a few weeks, since they grow faster in the warm water.

## VARIETY AND SPECIAL ABILITIES

Aquatic insects come in all shapes and sizes. Some are really flat and streamlined to help them cling to rocks in strong current. Lots of mayflies and stoneflies have this shape (Figure 2A). Another kind of aquatic insect called a caddisfly builds a house out of tiny rocks or twigs or leaves (Figure 2B). Some caddisflies glue their house to a rock and stay put. Other caddisflies take their protective houses with them when they move around, like a snail does. When there is danger around, they pull themselves back inside to hide. Some aquatic insect larvae look like worms because they do not have any legs (Figure 2C). They grow legs when they turn into adults (Figure 2D).

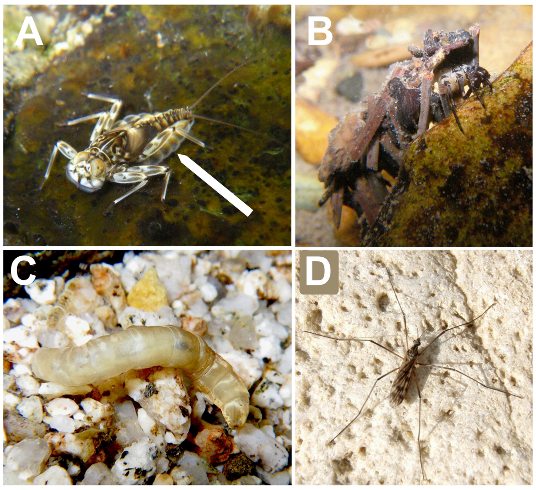


Figure 2

**Figure 2**

**(A)** A streamlined mayfly larva (about 2 cm long). Note the rounded gills that stick out along its body behind its back legs. The mayfly breathes through the gills and can use them as "suction cups" to stick to rocks. **(B)** A caddisfly larva (about 3 cm long) crawling across the bottom of a stream. Different kinds of caddisflies build their houses out of different things. The one in this picture used tiny sticks, but others use rocks or leaves. **(C)** A cranefly larva (about 4 cm long) is legless. It grows legs as an adult. **(D)** An adult cranefly (about 5 cm across) with really long legs (Photograph credits: Joe Giersch, USGS).

Have you ever seen insects that look like they are running around on top of the water? These are called water striders or water scooters. They have special long legs covered in tiny hairs that do not get wet. Their legs repel the water and that is why they can stay on top without sinking. They are also really fast! If a water strider were as big as you, it would be able to run across the water at over 320 kilometers per hour (or 200 miles per hour).

Most aquatic insects breathe through gills, like fish. But one peculiar kind, called a water boatman, breathes from an air bubble that it carries around with it under the water. Occasionally, it has to swim to the surface to refill its air bubble. Water boatmen are really good swimmers because their hind legs are shaped like flippers. Another aquatic insect that carries an air bubble is called a backswimmer. It is like a water boatman, except it swims upside down.

## EATING AND BEING EATEN

Aquatic insects eat all kinds of things, including each other, and all kinds of things eat them. Some aquatic insects are grazers—they eat the algae that grows on top of the rocks. Algae is what makes rocks in a stream feel slippery. Grazers are like the buffalo in Yellowstone National Park (Wyoming) eating grass. Some are scavengers—they eat the dead leaves that fall into streams and lakes and the fungus that grows on them. Scavengers are sometimes called shredders because they shred dead leaves into tiny pieces. If they did not, streams and lakes might fill up with leaves completely. Another kind of aquatic insect is called a collector. Collectors have nets that let them grab tiny bits of food out of the water as they float by. Some collectors build nets out of silk to catch their food (like a spider builds a spiderweb). Other collectors have built-in nets on their legs that they wave back and forth in the water to grab their food.

**PREDATOR**

An animal that kills and eats other animals. Most predators do not eat plants.

Some aquatic insects are **predators** that eat other aquatic insects. They can even eat tadpoles and small fish! Many of these predator insects stalk their prey like wolves in Glacier National Park (Montana), hunting for them amongst the rocks. Those super-fast water striders grab their prey on top of the water, stab them, and then suck out their juices. A dragonfly larva will ambush its prey like a crocodile. It waits until its prey gets close and then suddenly grabs it. Dragonflies have a special weapon that lets them do this: their lower jaws are really long and spring loaded, and they have sharp hooks. The jaw shoots out with lightning speed and snags the prey as it swims or walks by (Figure 3). Another predator insect is the giant water bug, which is also called the "toe biter"—can you guess why? This predator is big enough to hunt and eat small fish and tadpoles…or to bite your toes! Like the water strider, the giant water bug stabs its prey and sucks out the juices.

Figure 3

**Figure 3**

A dragonfly larva (right, about 4 cm long) catches and eats a mosquito larva (left, about 1 cm long) using its special spring-loaded jaw. Click here to watch! (Gif credit: Josh Cassidy/Deep Look, KQED).

What eats aquatic insects, besides other aquatic insects? Lots of animals do! Fish are probably the most important predator of aquatic insects—they can eat a lot of them. That is one reason that aquatic insects spend most of their time underneath rocks in a stream—it makes it harder for fish to catch them. Fish also eat lots of flying adult insects that settle on the surface of the water. Besides fish, many other animals eat aquatic insects, including tadpoles, frogs, salamanders, baby alligators, birds, bats, and spiders. There is even a tiny mammal called the water shrew, found in mountain parks like Olympic National Park (Washington) and northern ones like Glacier Bay National Park (Alaska), that can swim and dive for aquatic insects. People mostly do not eat aquatic insects, but we do eat other kinds of aquatic invertebrates, like crayfish and mussels.

## HEALTHY AQUATIC INSECTS, HEALTHY STREAMS

Aquatic invertebrates are extremely important to freshwater ecosystems. They come in different shapes and sizes, eat different things, and lead many different types of lives. Each aquatic invertebrate is specially adapted to its environment. When the environment changes, so do the kinds of invertebrates that live there. Scientists in national parks use these differences to understand what is happening in these ecosystems [1]. If a stream changes from a healthy environment to one that is unhealthy, for example as a result of pollution from industrial chemicals, the kinds of invertebrates that live there will also change. Some kinds do not mind polluted water, while other kinds might die in it. By going to a stream and observing the invertebrates, scientists can determine whether it is polluted or otherwise damaged, and what is causing the problem. This can help with efforts to clean up the stream and to restore its water quality. Lots of countries around the world use invertebrates to measure stream health in this way.

## REFERENCES

1. Dinger, E. C., Schweiger, E. W., and Simmons, T. 2022. How healthy is a stream? Ask the stream bugs. *Front. Young Minds*. doi: 10.3389/frym.2022.716591

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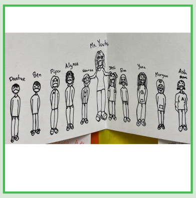
## YOUNG REVIEWERS



**CLAREMONT MIDDLE SCHOOL, AGES: 11–12**
We are 6th grade scientist kids from the heart of Oakland, and we like anime, playing music, making art, being in in-person school, and reptiles. Not necessarily in that order!


**MS. WARD'S AND MS. SHEIN'S 6TH GRADE SCIENCE CLASSES, PACIFIC CREST MIDDLE SCHOOL, AGES: 11–13**

These 6th graders live along the foothills of the Cascade Mountains of Central Oregon, and in the Deschutes River watershed. This is traditional homelands to the Tenino, Warm Springs, Wasco, Klamath, Paiute, Molalla, and Yahooskin Tribes. Typical to contemporary times in Central Oregon, these Young Minds reviewers enjoy many outdoor activities including running around playing with friends or while playing organized after-school sports, keeping up with their friends on social media apps, and staying busy with their families on weekends.

## AUTHORS


**TREY SIMMONS**

Trey Simmons is an aquatic ecologist working in the Central Alaska Network Inventory and Monitoring Program 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 time. 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 was not working, Trey loves skiing and hiking and playing with his dog Regan. *trey_simmons@nps.gov

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Eric C. Dinger is an aquatic ecologist for the National Park Service Klamath Inventory and Monitoring Network, 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, sometimes rock climbing or running as well.

**E. WILLIAM SCHWEIGER**

E. Willian Schweiger is the principal ecologist for the National Park Service Rocky Mountain Inventory and Monitoring Network. He is the lead for developing and implementing multiple long-term ecological monitoring protocols in six national parks in the northern and southern Rocky Mountains. He also collaborates with other scientists to support long-term goals to keep these parks healthy. When not doing science, he likes to race cars, play Ultimate Frisbee, and get lost in the wilderness.

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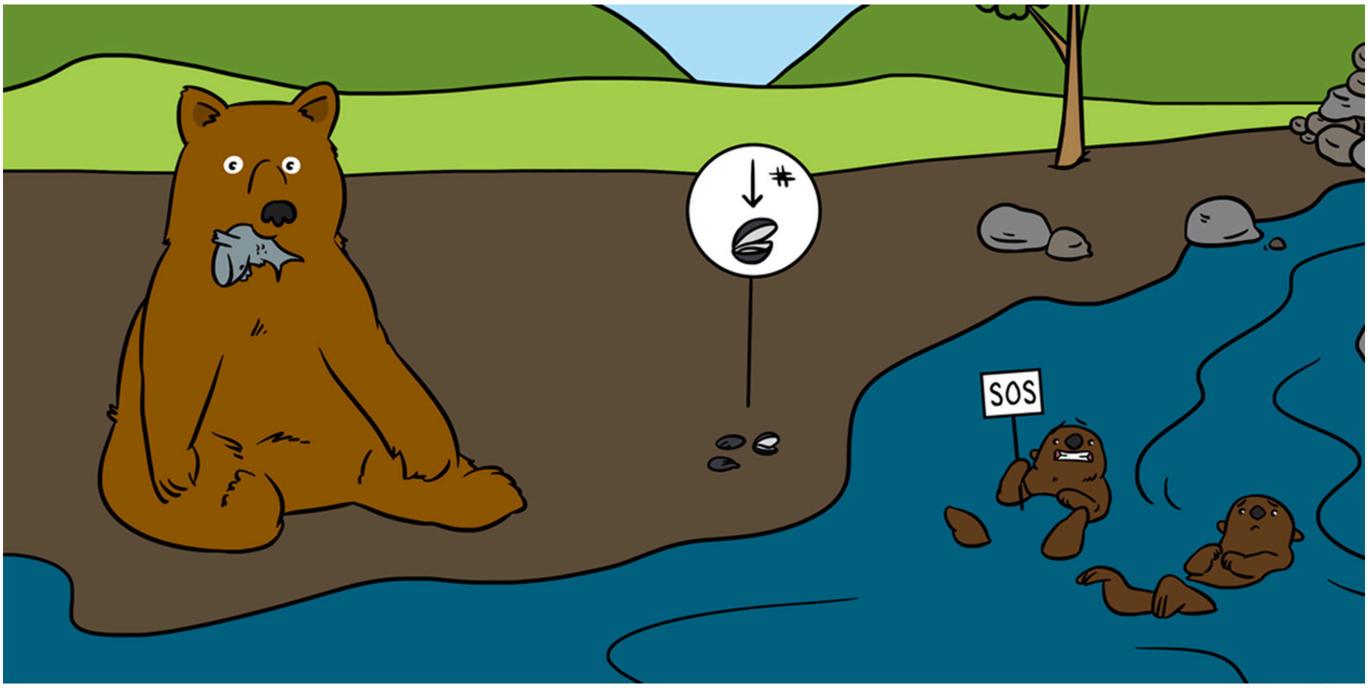


# WHERE LAND AND SEA MEET: BROWN BEARS AND SEA OTTERS

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YOUNG REVIEWERS:

HEADWATERS ACADEMY
7TH GRADE
AGES: 12–13

ZION
AGE: 13

In Katmai National Park, Alaska, USA, we have seen changes in the number of brown bears and sea otters. The number of animals of a species a habitat can support is called carrying capacity. Even though bears live on land and sea otters live in the ocean, these two mammals share coastal habitats. Bears eat salmon, other fish, plants, clams, and beached whales. Sea otters feed on clams and other marine invertebrates. All these foods are influenced by the ocean. Recently, we have seen fewer bears but more sea otters! What changed? Many things, but several observations point to the ocean. There are fewer

**salmon, whales, and clams, so bears rely more on plants for food. Fewer clams mean sea otters must work harder to find food. Our studies are helping us to understand how and why carrying capacity for a given species may change over time.**

## INTRODUCTION

National parks along Alaska's coastlines are some of the most remote, undeveloped, and wild places on the planet. It is here, in Katmai National Park and Preserve (Figure 1), that we can see the natural world and how it changes over time and across ecosystems. We can ask questions about how many animals live here, what they eat, and how the populations are changing. Two species, brown bears and sea otters, are used as **vital signs** to help us monitor the overall health of the park. If we think of vital signs just like we do for our bodies—for example, a strong, regular heartbeat is one indication of good health—we can use bears and sea otters as vital signs to check on the health of Katmai. You can think of the number of animals in the park like the park's heartbeat—when the park's heartbeat is strong, the park has just the right number of bears and sea otters, but if the number of bears or sea otters decreases, it might be a sign that the park is not well. So, how many brown bears and sea otters can live at Katmai? In **ecology**, this concept is called **carrying capacity**, which means the number of individuals of a species an ecosystem can support. This article will describe Katmai's carrying capacity for both brown bears and sea otters, how and why it has changed over time, and how these

**VITAL SIGNS**

Signals that can be used to gauge the health of an individual (a pulse rate or temperature), a population (abundance) or an ecosystem (number of species present).

**ECOLOGY**

The study of how different organisms interact with each and their environment.

**CARRYING CAPACITY**

The ability of a habitat to support a given number of a particular species. Carrying capacity can change over time as the habitat changes.

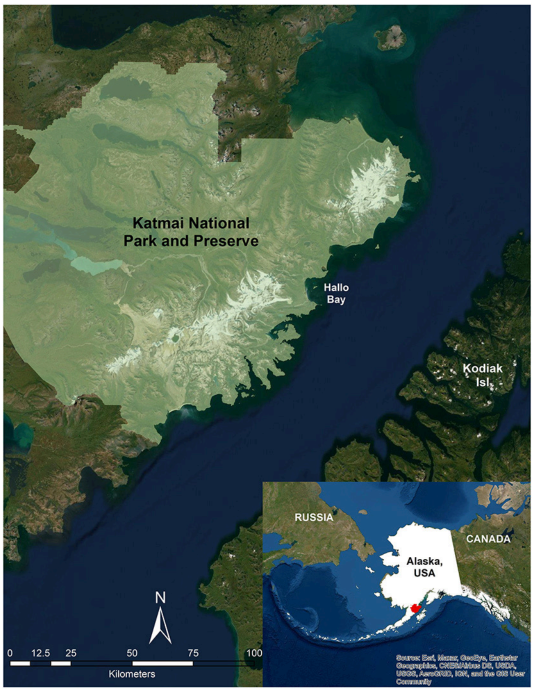


Figure 1

**Figure 1**

Katmai National Park and Preserve is located along the coast of Alaska, USA. Alaska is the northernmost state in the USA, shares a border with Canada, and is a close neighbor to Russia. Katmai is the red dot on the white Alaska map (inset). The larger map is a zoomed-in view of Katmai, which is just west of Kodiak Island, in the Gulf of Alaska.

changes might continue to occur [1]. All this information helps us to understand the overall health of the ecosystems in Katmai.

## BEARS AND SEA OTTERS

**TERRESTRIAL**

Describes an organism or object that resides on land.

**MARINE**

Describes an organism or object that resides in salt water (oceans).

Surprisingly, the habitats of bears and sea otters overlap more than you might think. Bears eat some of the same foods sea otters eat, like clams! But bears and sea otters also use different spaces: bears are primarily on land (**terrestrial**), and sea otters are primarily at sea (**marine**). Studying them both can tell us about each habitat as well as how the habitats are linked, so we get a better sense of the health of the park's different ecosystems.

Brown bears are the largest terrestrial mammals in North America, with some bears weighing more than 1,000 pounds! After more than 300 years of over-hunting and habitat loss, the range of brown bears in North America has decreased drastically, but Alaska still has healthy brown bear populations. Bears are especially healthy in Katmai because so many types of food are available. Bears catch salmon in the summer and fall, and they eat washed-up whale carcasses when they find them, to fatten up. All that fat helps the bears prepare for hibernation as winter approaches. They also dig up clams and catch fish on the tidal flats and eat grasses in tidal meadows [2]. The amounts of these foods that are available to bears helps determine the carrying capacity of their environment.

Sea otters can weigh up to 100 pounds and live near the coast in the North Pacific Ocean. In the 1800s, sea otters were hunted for their fur and went extinct along the Katmai coast by the early 1900s. Without sea otters to eat them, some of the otters' favorite foods, like clams, crabs, and urchins, increased in size and number [3]. Once sea otters were protected, they returned to Katmai and had lots of food to eat. At first, all the extra food helped the sea otter population to grow. But once they ate most of the extra food, the number of sea otters went down a bit and now appears to have settled at a level that their food supply can support. That is carrying capacity at work!

## THINGS WE LEARNED

Over the past 20 years, the number of bears counted along the Katmai coast has decreased by about 66%. The bears' diets also changed over this same time, from about two-thirds salmon and one-third plants in the 1990s to one-quarter salmon and three-quarters plants in recent years. What happened? One change is that salmon used to be more plentiful. Between 1978 and 2006, nearly a million salmon returned every year to spawn along the Katmai coast. Over the 10 years that followed, only about half as many salmon returned. In 2018, scientists counted more **sedges**, a favorite coastal plant that bears like to eat,

**SEDGES**

A grass-like plant that grows in wet ground, like tidal meadows.

than were counted in 2008. Lower numbers of salmon likely decreased the carrying capacity for bears along the Katmai coast, even though there were more sedges to eat. Why? Well, salmon have more calories than sedges, and so it takes more sedges than salmon to fatten up a bear. But individual bears remain healthy, there are just fewer of them being seen (Figure 2) [4].

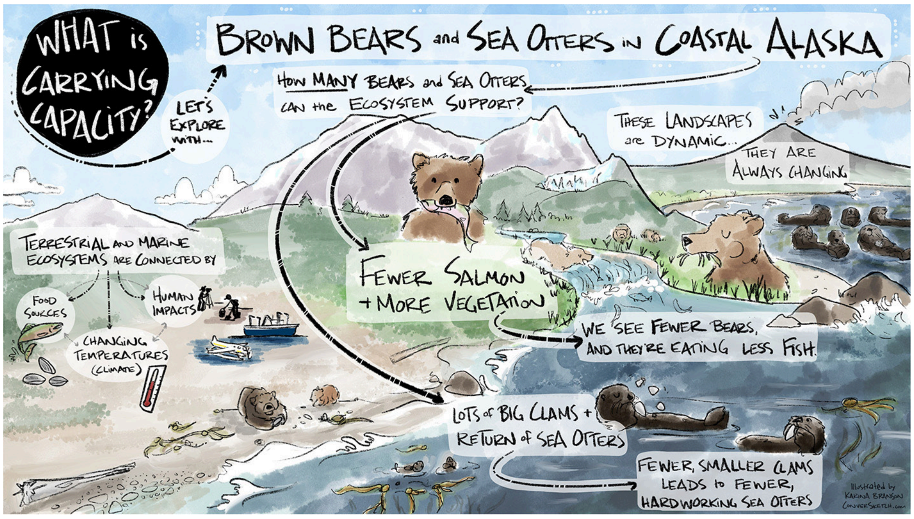

Figure 2

**Figure 2**

The carrying capacity of the Katmai ecosystem changes over time, for both brown bears and sea otters. Marine and terrestrial ecosystems are linked by rivers. Freshwater, sediments, and nutrients flow from the land to the ocean. Changing ocean temperatures, sea-level rise, and fish like salmon that grow in the ocean return to the rivers, linking the marine ecosystem to the terrestrial ecosystem. Human impacts take place across all ecosystems (Image credit: Karina Branson—CoverSketch, LLC).

Sea otters came back to the Katmai coast around 1950. Their population size peaked in 2012 at 8,600 when there was a lot of extra food, but today there are about 6,000 sea otters (a 30% decline). In addition to counting sea otters, scientists also measure how much food the otters eat. In 2006, because food was still abundant and easy to find, the average sea otter could eat lots of food in a short time, but this plentiful food did not last. From 2006–2019, we measured how many clams there were, and found that the number of clams went down following the peak in the sea otter population! Fewer clams meant the sea otters had to spend more time looking for food, and this eventually led to a reduced carrying capacity for sea otters along the Katmai coast [5] (Figure 2).

## DRIVERS OF CHANGE

What else might have changed the carrying capacity for brown bears and sea otters? Currently, there are no cities on the Katmai coast, but human activities still affect the carrying capacity of Katmai for both bears and sea otters. For example, because of whaling in the 1900s, there are now fewer whales in the ocean [6]. That means fewer whales wash ashore for bears to eat. Since whale carcasses have lots of blubber and provide lots of energy for bears, the loss of whales reduces the carrying capacity of the coast for bears.

**FOOD WEB**

All the linkages in an ecosystem that relate to food. A food web links consumers and producers together.

**PLANKTON**

Organisms that cannot swim against a current of water. Most plankton are microscopic and can be plant-like or animal-like.

Although Katmai is a remote wilderness, both the ocean and the land will still feel the effects of a changing climate. As the planet warms, glaciers are melting and the rivers that salmon need are changing. As the ocean warms, the whole **food web** may be impacted. There may be less **plankton** (or different plankton) to feed the small fish that salmon eat. Less plankton also affects the clams and mussels that sea otters eat. A changing climate will probably shift the carrying capacity of Katmai for brown bears and sea otters again, as well as for the plants and animals that call Katmai home.

We have also seen a change in the number of people that visit Katmai. Before 1990, for example, few people visited the coast in Hallo Bay, but lately more than 3,000 visitors come to the bay each year by plane or boat. They come to watch brown bears and to see sea otters. Since hunting is not allowed in the park, bears have become less fearful of humans, but they are wary, and large numbers of visitors might affect where bears go. If too many people are watching the bears at their favorite places, the bears may not stay to eat as much as they would if people were not there. In this case, the carrying capacity may change—not because less food is available but because more people are visiting (Figure 2).

## CONCLUSION

We expect some changes in an ecosystem to have a larger effect than others on the carrying capacity of that region for a given species. For example, in Alaska's coastal habitats, salmon may be the most important food for brown bears. We expect larger numbers of salmon to increase the number of bears and fewer salmon to decrease the number of bears. In contrast, we expect decreasing numbers of clams to have a small effect on the region's carrying capacity for bears because clams make up a small part of the bears' diet. But fewer clams could have a large effect on the sea otter carrying capacity because otters like to eat lots of clams. In another example, we expect that fewer whale carcasses would tend to have a negative effect on bears, but little effect on sea otters because sea otters do not eat whale carcasses. One thing that has not changed is the size and general health of the bears. This presents a riddle. We would expect that, as food becomes less abundant or nutritious, the bears' physical condition and size should diminish. However, we think that bears may adjust their abundance and stay healthy as opposed to keeping the same numbers of individuals with potential declines in overall health. This example is an indication of how animals may adjust their numbers in response to changes in carrying capacity.

As scientists, we will continue to study brown bears, sea otters, and other species at Katmai to see how they interact and how their populations change over time (Figure 3). Both bears and sea otters live in dynamic environments. Environmental changes can be natural or caused by humans. The ability of these species to adapt to change allows them to stay healthy as individuals and as populations. Because of the important role these mammals play by interacting with many other species, bears and sea otters are good indicators of ecosystem health. Thus, they serve as effective vital signs for "taking the pulse" of Katmai.

Figure 3

**Figure 3**

**(A)** A brown bear eating salmon (NPS Photograph/K. Jalone). **(B)** A crew collecting data on salt marsh/sedge vegetation (NPS Photograph/M. Shepherd). **(C)** A brown bear eating sedges. **(D)** A brown bear eating a clam. **(E)** A scientist collecting sea otter foraging data. **(F)** A sea otter. **(G)** A sea otter eating a clam. **(H)** Brown bears eating a whale carcass (NPS Photograph/J. Erlenbach). (C-G credits: NPS Photograph/J. Pfeiffenberger).

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## REFERENCES

1. Coletti, H., Bowen, L., Ballachey, B., Wilson, T. L., Waters, S., Booz, M., et al. 2022. The mysterious case of the missing razor clams. *Front. Young Minds* 10:715425. doi: 10.3389/frym.2022.715425
2. Smith, T. S., and Partridge, S. T. 2004. Dynamics of intertidal foraging by coastal brown bears in southwestern Alaska. *J. Wildl. Manag.* 68:233–40. doi: 10.2193/0022-541X(2004)068[0233:DOIFBC]2.0.CO;2
3. Riedman, M. L., and Estes, J. A. 1990. *The Sea otter (Enhydra lutris): behavior, ecology, and natural history*. Biological Report 90. U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.
4. Erlenbach, J. A. 2020. *Nutritional and Landscape Ecology of Brown Bears (Ursus arctos)* (Ph.D. Dissertation). Washington State University, Pullman, WA, USA.
5. Coletti, H. A., Bodkin, J. L., Monson, D. H., Ballachey, B. E., and Dean T. A. 2016. Detecting and inferring cause of change in an Alaska nearshore marine ecosystem. *Ecosphere* 7:e01489. doi: 10.1002/ecs2.1489
6. Springer, A. M., Estes, J. A., van Vliet, G. B., Williams, T. M., Doak, D. F., Danner, E. M., et al. 2003. Sequential megafaunal collapse in the North Pacific Ocean: an ongoing legacy of industrial whaling? *Proc. Natl. Acad. Sci. U. S. A.* 100:12223–8. doi: 10.1073/pnas.1635156100

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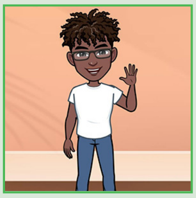
## YOUNG REVIEWERS

### HEADWATERS ACADEMY 7TH GRADE, AGES: 12–13

The 7th grade class of Headwaters Academy, with all of its eccentricities, is a humorous and adventuresome community. Our class is made up of great backgrounds of both sport and mind. Our community, built to create leaders and learners for a changing future, has allowed us to thrive and develop in our beautiful ecosystem, though it allows us to look upon the world in a different way: to know what should be and how to improve upon what is.



### ZION, AGE: 13

Zion loves to play video games on the weekend and loves all things Marvel. His favorite subject is Math and his favorite food is spaghetti with meatballs. Zion plays baseball, football, and soccer, but enjoys working in the community garden more than anything.

## AUTHORS

### HEATHER COLETTI

Heather Coletti is a marine ecologist for the National Park Service. She has studied nearshore marine ecosystems, in particular sea otters and their prey, since 2001. Her favorite part of her job is to be in the field, which includes living on a boat, conducting lots of coastal surveys and watching sea otters. She also hopes her work contributes to marine conservation. For fun, Heather likes to spend time with her family cross-country skiing and mountain biking in Alaska. *heather_coletti@nps.gov

### GRANT HILDERBRAND

Grant Hilderbrand is a wildlife biologist who studies brown bears and wolves. He is interested in how these animals are impacted by and shape their environments. He currently leads the natural resource team for the National Park Service in Alaska.

### JAMES BODKIN

James Bodkin was a research biologist with the US Geological Survey from 1977 until his retirement in 2012. Nearly all of his career was spent studying the biology and ecology of sea otters from California to Russia, but mostly in Alaska. Jim continues to study sea otters and nearshore marine ecosystems in Alaska and Washington while residing in Port Townsend, WA.

### BRENDA BALLACHEY

Brenda Ballachey is a scientist with the US Geological Survey in Anchorage, Alaska. Her research has included studies of physiology, toxicology, and genetics in both wildlife and domestic livestock. She spent many years exploring the effects of the 1989 *Exxon Valdez* oil spill on sea otters and continues to study sea otters and the nearshore areas where they live. When not working, she loves to be outdoors, exploring nature, or to curl up with a good book.

## JOY ERLENBACH

Joy Erlenbach is a wildlife biologist specializing in bears. She is primarily interested in why bears do the things they do—including what they eat and where they spend their time. She currently works in Kodiak Alaska for the US Fish and Wildlife Service.

## GEORGE ESSLINGER

George Esslinger is a zoologist at US Geological Survey in Alaska. His research focuses on sea otters and understanding the nearshore ecosystem they live in. He enjoys working and playing with all forms of water, from boating and diving to skating and skiing.

## MICHAEL HANNAM

Michael Hannam is an ecologist for the National Park Service in Alaska, where he studies changes in plant communities in southwest Alaska, and explores new ways to find patterns in data. Dr. Hannam has studied marine plants and helped with research on prairie dogs and black-footed ferrets. For fun, Michael likes to hike, ski, and cook fancy food.

## KIMBERLY KLOECKER

Kimberly Kloecker is a USGS marine ecologist at the Alaska Science Center. She grew up playing in Lake Erie and was inspired to study marine biology by family trips to marine parks. Her work centers on sea otter health, population status, and behavior. She has two favorite types of workdays: sitting on shore with a spotting scope, stopwatch, and data sheet watching sea otters forage and working with students of all ages. In her spare time, she hikes and paddles with her teens but will drop everything to give belly rubs to her adopted kitties, Cha-Cha and Rhumba.

## BUCK MANGIPANE

Buck Mangipane is the natural resource program manager for Lake Clark National Park and Preserve. Trained as a wildlife biologist, he has taken part in research and monitoring of caribou, Dall's sheep, brown bears, black bears, wolves, moose, and bald eagles. In his current role, he facilitates scientific research in the park that ranges from describing ocean currents to completing an acoustic inventory. Working in his 20th year at the park, he continues to be fascinated by wildlife ecology. Outside of work he enjoys fly-fishing and biking with his wife Lindsey and dog Stanley.

## AMY MILLER

Amy Miller is an ecologist with the National Park Service. She has worked since 2004 as a plant ecologist and supervisory ecologist with the Inventory & Monitoring Program, Southwest Alaska Network, where she has focused on the effects of climate and disturbance on vegetation communities, including coastal marshes. In her spare time, Amy enjoys skiing and hiking in the nearby mountains.

## DANIEL MONSON

Daniel Monson is a research wildlife biologist who works with sea otters and is interested in the role otters play in structuring the nearshore marine ecosystem where they live. He enjoys observing otters as they forage and interact with their environment, diving into their world to assess the abundance of their prey, and even capturing sea otters to assess their health and study their physiology. Dan works for the USGS, Alaska Science Center in Anchorage, AK but has conducted fieldwork throughout the sea otter's range.

**BENJAMIN PISTER**

Benjamin Pister is the director of resource management at Kenai Fjords National Park. His job is to preserve the natural and cultural resources of the park for the education, inspiration, and enjoyment of current and future generations. By training he is an intertidal ecologist with a Ph.D. in biology and loves to study all things in the ocean—but especially invertebrates! When not working, he enjoys fishing, hunting, gathering, and spending time outdoors in Alaska with his kids.

**KELSEY GRIFFIN**

Kelsey is a wildlife biologist working for the National Park Service in Alaska. She is interested in understanding the roles that species play in their ecosystems and how we can inspire people to protect parks and natural areas through science. She studies many species, everything from birds and bats to bears and wolves. She enjoys exploring new areas, hiking and skiing with friends and family, and watercolor painting.

**KELLY BODKIN**

Kelly Bodkin is a special education teacher with over 14 years of experience working with students with autism, social emotional behavioral disorders, multiple health impairments, Down's syndrome, visual impairments, and learning disabilities. Kelly is inspired by the creativity, determination, positivity, and potential of each student she has worked with. She is currently pursuing her doctoral degree in special education. She has also participated in many field projects related to sea otters in Alaska.

**TOM SMITH**

Dr. Tom Smith has worked as a federal research scientist at the USGS Alaska Research Center and presently at Brigham Young University as a professor of wildlife management. His research is largely focused on bear ecology, human-bear conflict, and ways that we can live in harmony with bears. Current projects include four species of bears: black, brown, polar, and sloth. Dr. Smith serves on the Polar Bear Specialist Group, an international body tasked with conserving polar bears.

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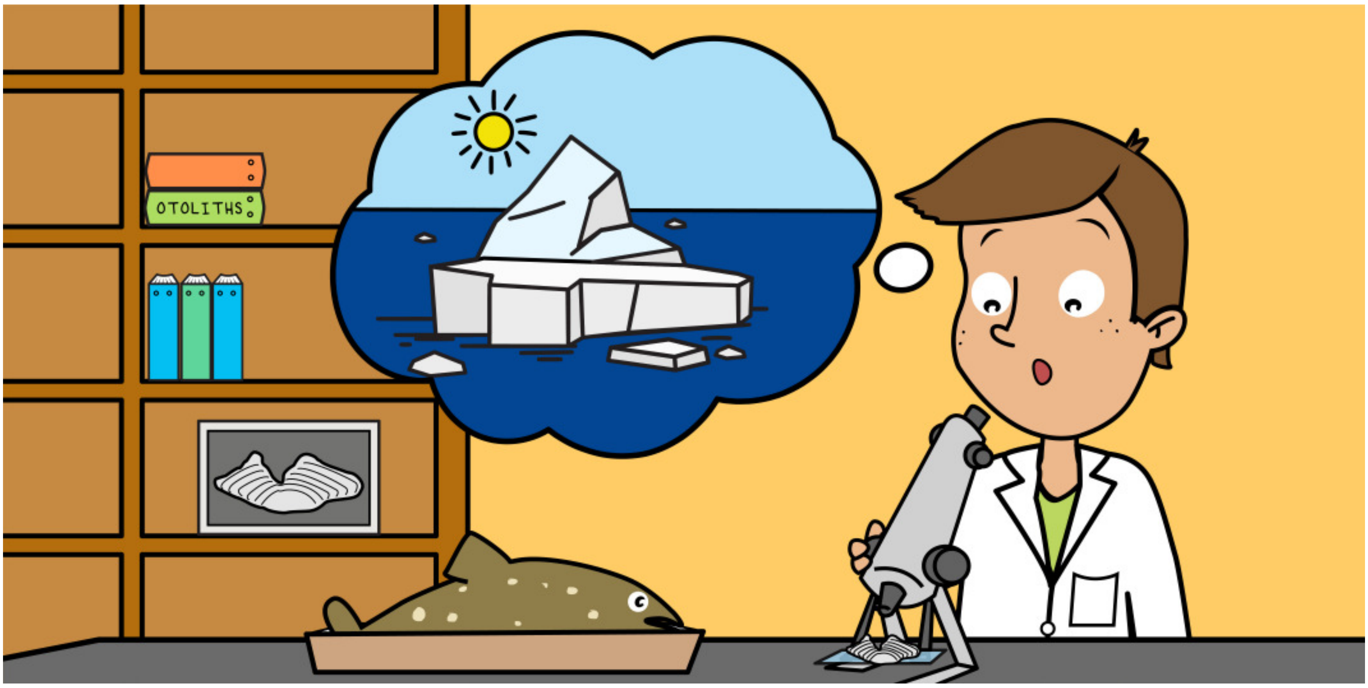


# FISH EAR STONES OFFER CLIMATE CHANGE CLUES IN ALASKA'S LAKES

*Krista K. Bartz[1*], Vanessa R. von Biela[2], Bryan A. Black[3], Daniel B. Young[4], Peter van der Sleen[5,6] and Christian E. Zimmerman[2]*

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YOUNG REVIEWERS

7TH–8TH FRESHWATER BIOLOGY CLASS

AGES: 12–14

Otoliths, also known as ear stones, are small body parts that help fish with hearing and balance. Like tree rings, otoliths form one light and one dark band per year, creating rings. These rings can be measured to understand fish growth. The wider the ring, the greater the growth. In our study, we used otoliths to understand how one fish species—lake trout—responds to rising temperature in the state of Alaska. We found that warmer spring air temperature and earlier lake ice melt were related to faster lake trout growth. This finding is consistent with other studies that link warmer water temperature and earlier lake ice melt to increased plankton in Alaska's lakes. Together, these findings suggest that climate-driven increases at the bottom of the food web might benefit top predators like lake trout. However,

the relationship between warmer temperature and faster growth may not last.

## THINGS WITH RINGS

Have you ever noticed the rings on a cross-cut tree trunk? Counting those rings can tell you the age of a tree. This is because each ring is made of two parts: a light-colored band of wood that formed in the spring and early summer, and a dark-colored band of wood that formed in late summer and fall. Therefore, a light band and a neighboring dark band represent 1 year of life for a tree.

But age is not the only thing revealed by tree rings. The width of the rings contains information about the growth of a tree and the environmental conditions it experienced. This is because trees respond to conditions like temperature, moisture, and **nutrients**. In warmer, wetter years, trees tend to grow more, and their rings are wider than in colder, drier years. Similarly, trees tend to grow more in years when nutrients like fertilizers are plentiful in the soil. Because trees stay in one place and grow for many years, their rings offer a record of conditions in that place over time.

**NUTRIENTS**

Chemicals that provide materials needed by living things to survive, grow, and reproduce. The nutrients that often limit growth at the bottom of lake food webs are nitrogen and phosphorus.

Believe it or not, other organisms also form rings every year that they live. For example, corals and clams create yearly growth rings in their skeletons and shells. Some fish also do so, within their scales and ear stones. Ear stones—also called **otoliths**—are small, flat structures that help fish with hearing and balance (Figure 1). They are located just under the brain in a fish's skull. Like tree rings, otoliths form one light and one dark band per year, creating a ring. These rings can be counted to determine fish age. They can also be measured to understand fish growth. The wider the ring, the greater the growth in a single year.

**OTOLITHS**

Small structures used by vertebrates for balance and hearing. In fish, otoliths grow by adding new layers of seashell-like material year after year, throughout life.

## WHAT CONTROLS FISH GROWTH?

Fish grow faster or slower depending on how old they are and how well their environment meets their needs. Like humans, fish grow more slowly as they age. They also grow more slowly when they lack nutrients and energy from food. Unlike humans, fish grow more slowly in cold temperatures. The reason for this is simple. Most fish are **ectothermic** or cold-blooded, so their body temperatures are controlled by the water temperatures around them. When water temperatures are cold, everything in an ectotherm's body slows down, including its breathing, digestion, and growth.

**ECTOTHERMIC**

Cold-blooded. An ectothermic animal is one whose internal body temperature depends on external heat sources for warmth.

In our study, we used otoliths to explore the growth of one fish species—lake trout. We wanted to know how lake trout growth responds to temperature and nutrients. We were particularly interested

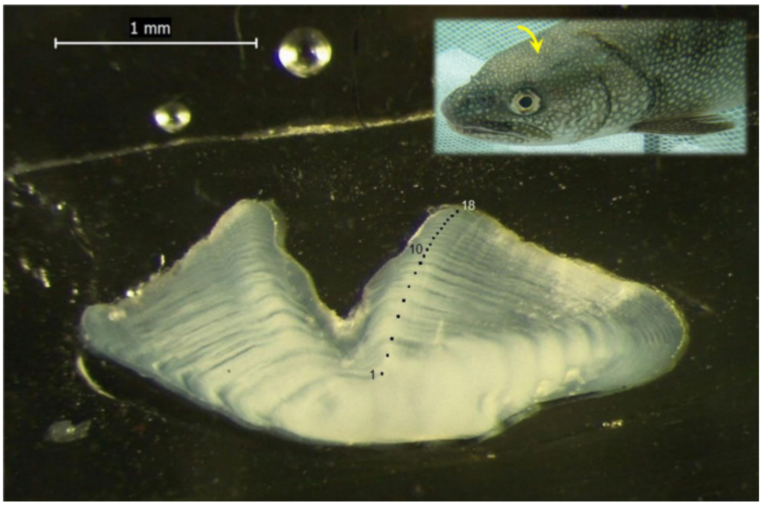



Figure 1

**Figure 1**

A magnified cross-section of an otolith from an 18-year-old lake trout. The black dots mark the edges of the rings. Rings for years 1, 10, and 18 are labeled. The white line shows the scale for this otolith (2.4 cm on the page is 1.0 mm in real life), and the yellow arrow shows its approximate location in a lake trout.

in lake trout from Lake Clark National Park & Preserve in southwest Alaska, USA.

## WHY STUDY LAKE TROUT IN LAKE CLARK?

Lake trout are top predators that thrive in cold, deep lakes. We focused on this species for two main reasons. First, we chose lake trout because they are common in Alaska. This makes them easier to find than rarer species. Second, we chose lake trout because they have long lifespans (20+ years). This means their otoliths contain a longer record of growth than other common fish species in Alaska, like sockeye salmon.

Lake Clark National Park & Preserve is known for its cold, deep lakes and surrounding wilderness. Human impacts, like buildings and roads, are scarce inside park boundaries. However, like the rest of Alaska, the park is experiencing climate change. Average annual air temperature in Alaska is warming about twice as fast as the world-wide pace [1]. Warmer air temperature is shortening the number of days that lakes have ice in winter [2]. Both air temperature and lake ice affect the conditions experienced by fish.

The park is also known for the thousands of sockeye salmon that **spawn** there. Salmon begin and end their lives in fresh water. Between those endpoints, they gain most of their body weight in the ocean, where the waters are high in nutrients. When salmon return to fresh water to spawn and die, their bodies are like bundles of nutrients delivered from the ocean. Some scientists think that those bundles of salmon nutrients help other freshwater fish grow faster [3].

**SPAWN**

Reproduce, by adult salmon, through building a gravel nest, laying eggs in the nest, and fertilizing the eggs.

## WHAT WAS OUR QUESTION AND APPROACH?

Lake trout are long-lived fish that prefer cold, deep lakes. Lake Clark National Park & Preserve has lots of cold, deep lakes, plus nutrients from dead salmon. However, Alaska's changing climate is warming its lakes. Therefore, we asked whether lake trout grow faster or slower in warmer years, and whether sockeye salmon nutrients affect lake trout growth as well.

To study this, we caught 240 lake trout from 7 lakes, during the summers of 2004, 2011, 2012, and 2013. All the lakes had cool waters with low levels of nutrients. However, they differed in one basic trait: only 4 lakes were accessible to salmon. The other 3 lakes were upstream of barriers to salmon migration, like waterfalls.

After catching the lake trout, we removed their otoliths by dissection. We then used a multi-step process to count and measure the otolith rings. First, we covered each otolith with a gel that dried to a hard, clear block. Next, we cut the blocks with a special saw, to obtain a slice about as thick as a fingernail from the middle of each otolith. Then, we glued the otolith slices to glass microscope slides and photographed the slides using a camera attached to a microscope. The microscope made each otolith slice look 40 times bigger in the photograph than in real life.

Using the magnified photographs, we counted the otolith rings to age each fish. We also assigned a year of formation to each ring by counting backward from the year we caught the fish. Then, we measured the ring widths on the photographs. By the end of this multi-step process, we had measured 964 otolith rings. Although 964 seems like a lot, it is fewer than expected because only 80 of the 240 fish had distinct otolith rings.

Next, we used **statistical models** to summarize the 964 ring widths from the 80 lake trout into a single width per year, applicable to all lake trout in our study. We called that summarized version our master growth record because it applied to many different fish, like a master key that opened many different locks. The master growth record showed years when fish grew less than average, about average, and more than average. It included years from 1990 to 2011.

**STATISTICAL MODEL**

A math "sentence" that compares two or more different pieces of information as numbers or categories to see *if* and *how* they are related.

Finally, we compared the master growth record to temperature, ice, and salmon **data** from the same years. This was challenging because these types of data were not measured at each of our study lakes that far back in time. Therefore, we used the best available data from other sources. For temperature, we used monthly average air temperature at a weather station near one study lake (Lake Clark). For ice, we used the date when lake ice melted at another study lake (Telaquana Lake). For salmon, we used the number of adult sockeye salmon returning to spawn downstream of those two lakes. Using these datasets, we

**DATA**

A group of facts, like numbers, measurements, or observations. The word "data" is the plural form of the word "datum," which is a single fact.

analyzed the relationships between lake trout growth, temperature, ice, and salmon.

## WHAT DID WE FIND?

We found that lake trout grew faster in warmer years. In particular, lake trout grew faster in years with warmer air temperatures in April (Figure 2). This pattern existed in February and July too but was not as strong. Lake trout also grew faster in years with earlier dates of lake ice melt. However, we did not see a pattern between lake trout growth and salmon. Lake trout did *not* grow faster in lakes with salmon compared to lakes without salmon. In lakes with salmon, lake trout did *not* grow faster in years with more spawning salmon.

## HOW DO OUR FINDINGS FIT WITHIN THE "BIG PICTURE"?

Our study found that lake trout grow faster in years with warmer air temperature in April because warmer air causes earlier lake ice melt. Warmer air and earlier melt probably increase spring water temperature at the lake surface toward the 9°C preferred by lake trout. At this preferred temperature, lake trout can eat more and grow more without overheating, if food is available.

Interestingly, more food might be available in warmer years (Figure 3). Other studies in nearby lakes have shown that **plankton** counts increase with warmer surface water and earlier spring melt [2, 4]. Warmer springs are also linked to higher counts and faster growth of

**PLANKTON**

Tiny organisms that drift near the surface of a body of water, like a lake or ocean. These organisms may be plant-like phytoplankton or animal-like zooplankton. Zooplankton eat phytoplankton.

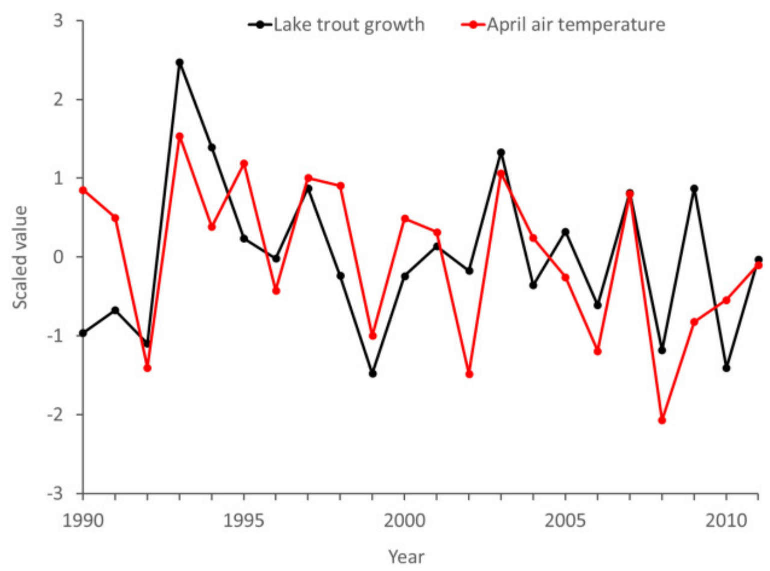


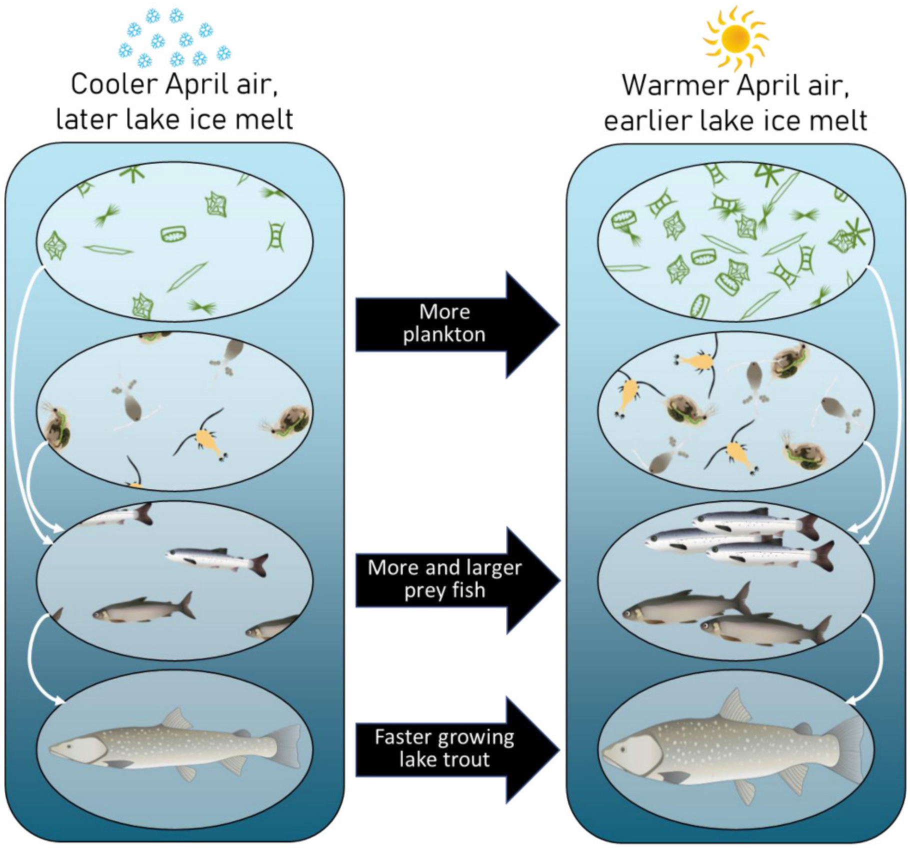

Figure 2

**Figure 2**

Our master growth record (black line) compared with average April air temperature (red line) for years 1990–2011. Both variables were scaled to a mean value of 0 and a standard deviation of 1 to make their original units of measure (millimeters of growth and degrees Celsius) equal. You can see that lake trout growth (in black) and April air temperature (in red) track each other across years.

**Figure 3**

Diagram of a simple lake food web showing phytoplankton, zooplankton, prey fish, and predator fish under two possible scenarios: cooler and warmer springs. We expect that warmer springs lead to higher plankton counts, increased numbers and size of plankton-eating fish, and faster growing lake trout.




small plankton-eating fish, like young sockeye salmon [4, 5]. And guess what likes to eat young sockeye salmon as prey? Lake trout!

These results suggest that lake trout in Lake Clark National Park & Preserve might be climate change winners. They can benefit from the increased food linked to warmer water near the lake surface, while still having the option to use cooler water at deeper depths if they need to slow down their bodies to conserve food. These results hold true with or without the added nutrients from salmon. Whether these results will hold true over time, as climate warming continues, remains a question.

## ACKNOWLEDGMENTS

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## ORIGINAL SOURCE ARTICLE

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## REFERENCES

1. Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., et al., eds. 2018. "Fourth national climate assessment, volume II – impacts, risks, and adaptation in the United States," in: *Chapter 26, Alaska* (Washington, DC: U.S. Global Change Research Program). p. 1185–241. doi: 10.7930/NCA4.2018.CH26
2. Carter, J. L., and Schindler, D. E. 2012. Responses of zooplankton populations to four decades of climate warming in lakes of southwestern Alaska. *Ecosystems* 15:1010–26. doi: 10.1007/s10021-012-9560-0
3. Wipfli, M. S., Hudson, J. P., Caouette, J. P., and Chaloner, D. T. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. *Trans. Am. Fish. Soc.* 132:371–81. doi: 10.1577/1548-8659(2003)132<0371:MSIFE S>2.0.CO;2
4. Schindler, D. E., Rogers, D. E., Scheuerell, M. D., and Abrey, C. A. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in Southwestern Alaska. *Ecology* 86:198–209. doi: 10.1890/03-0408
5. Rich, H. B., Quinn, T. P., Scheuerell, M. D., and Schindler, D. E. 2009. Climate and intraspecific competition control the growth and life history of juvenile sockeye salmon (Oncorhynchus nerka) in Iliamna Lake, Alaska. *Can. J. Fish. Aquat. Sci.* 66:238–46. doi: 10.1139/F08-210

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## YOUNG REVIEWERS

### 7TH–8TH FRESHWATER BIOLOGY CLASS, AGES: 12–14

We are the 7th/8th grade mixed class of 2021 at Gruening Middle School in Eagle River, Alaska, just a few miles north of Anchorage. We have a relatively small class of only 21 people who work well together. Our class is an eclectic bunch made up of many students from military families and a few Native Alaskans. We all are proud to live in Alaska and enjoy the many resources and adventures available just out our front doors.

## AUTHORS

### KRISTA K. BARTZ

Krista Bartz is an aquatic ecologist with the National Park Service Southwest Alaska Inventory and Monitoring Network. There, she oversees long-term monitoring of freshwater indicators in three southwest Alaska parks—a job she began in 2013. The indicators include water quality, water quantity, and fish contaminants. She has two children, ages 9 and 12. *Krista_Bartz@nps.gov

### VANESSA R. VON BIELA

Vanessa von Biela is a research fish biologist at the U.S. Geological Survey Alaska Science Center. Her areas of expertise include both freshwater and marine ecology, with topics as diverse as kelp in marine fish food webs, heat stress in migrating adult salmon, and arctic ecology. She started working for the USGS in 2007 and completed her PhD in 2015. She has 3 children, ages 7, 5 and 5 (twins!).

### BRYAN A. BLACK

Bryan Black is an associate professor at the University of Arizona's Laboratory of Tree-Ring Research. His work focuses on growth rings formed in the hard parts of marine and freshwater species. He uses the rings to understand patterns in growth, sometimes across multiple species. He also links the patterns in growth to climate and other variables. He has one child, age 10.

### DANIEL B. YOUNG

Dan Young is a fish biologist with the National Park Service and has been affiliated with Lake Clark National Park and Preserve since 1999. During that time, he has collected data on the abundance and timing of sockeye salmon returning to spawn in the park. He has also studied less popular species, like least cisco and humpback whitefish. He has two children, ages 16 and 18.

### PETER VAN DER SLEEN

Peter van der Sleen is a researcher and lecturer at the Wageningen University in the Netherlands. His research activities include studies in tropical, temperate, and arctic regions, and involve trees and fishes. Across these biomes and organisms, his main focus has been on growth, and how growth rates are influenced by environmental conditions. He has two children, ages 4 and 6.

**CHRISTIAN E. ZIMMERMAN**

Chris Zimmerman is the director of the U.S. Geological Survey Alaska Science Center. He has worked there since 2001 in various roles, including research fish biologist, leader of the Fish and Aquatic Ecology Program, and leader of the Water, Ice and Landscapes Dynamics Office. In his spare time, Chris enjoys being a private pilot.

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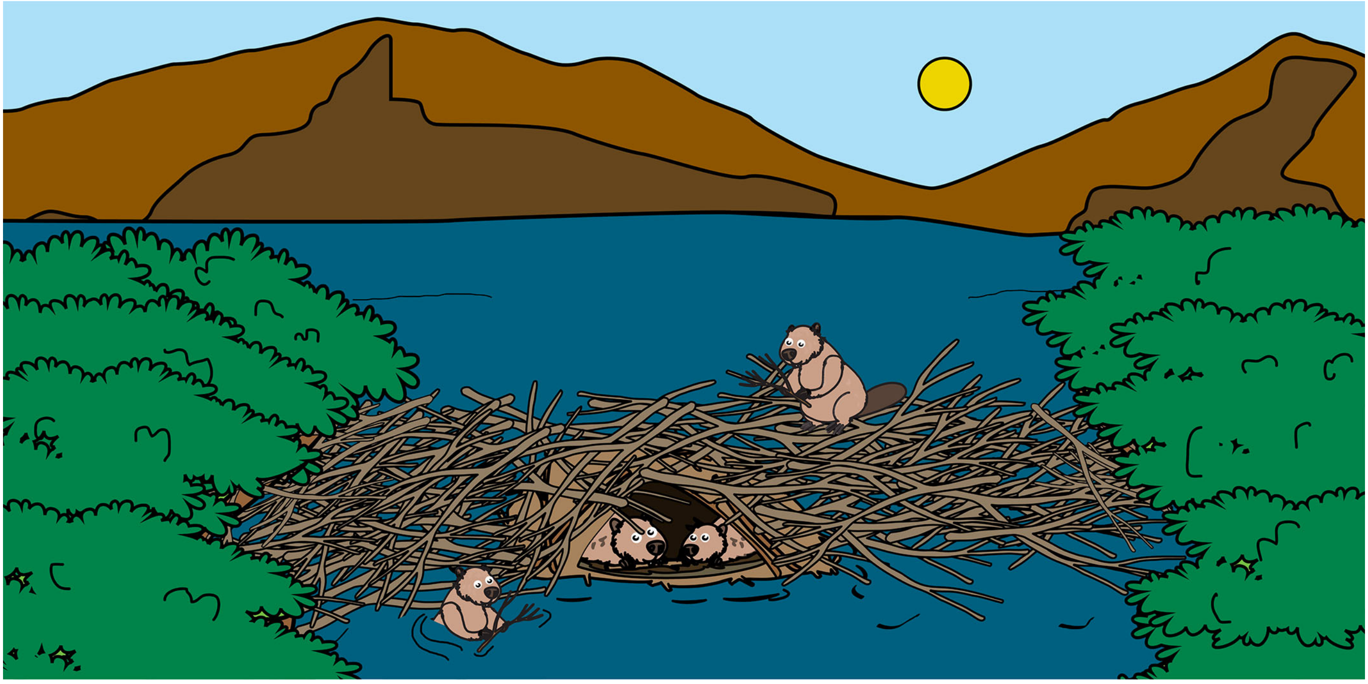

# HOW BEAVERS ARE CHANGING ARCTIC LANDSCAPES AND EARTH'S CLIMATE

***Jonathan A. O'Donnell*[1*], *Michael P. Carey*[2], *Brett A. Poulin*[3], *Ken D. Tape*[4] and *Joshua C. Koch*[2]**

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YOUNG REVIEWERS:

DREW
AGE: 11

SPRINGHILL SCHOOL
AGES: 10–14

Beavers build dams that change the way water moves between streams, lakes, and the land. In Alaska, beavers are moving north from the forests into the Arctic tundra. When beavers build dams in the Arctic, they cause frozen soil, called permafrost, to thaw. Scientists are studying how beavers and the thawing of permafrost are impacting streams and rivers in Alaska's national parks. For example, permafrost thaw from beavers can add harmful substances like mercury to streams. Mercury can be taken up by stream food webs, including fish, which then become unhealthy to eat. Permafrost thaw can also move carbon (from dead plants) to beaver ponds. When this carbon decomposes, it can be released from beaver ponds into the air as greenhouse gases, which cause Earth's climate to warm. Scientists are trying to keep up with these busy beavers to better understand how they are changing Arctic landscapes and Earth's climate.

## BEAVERS ARE ECOSYSTEM ENGINEERS

Beavers are ecosystem engineers that build dams. The dams change the way water moves between streams, rivers, lakes, and the land around them. Beaver dams in streams block the flow of water, making ponds that flood nearby soils (Figure 1). Scientific studies of beaver ponds in the western United States and Canada show that beavers can impact water quality. Beavers can change the amounts of nutrients (which act like fertilizers), carbon (from dead plant material), and harmful substances (like mercury) in streams and lakes [1]. Beavers can

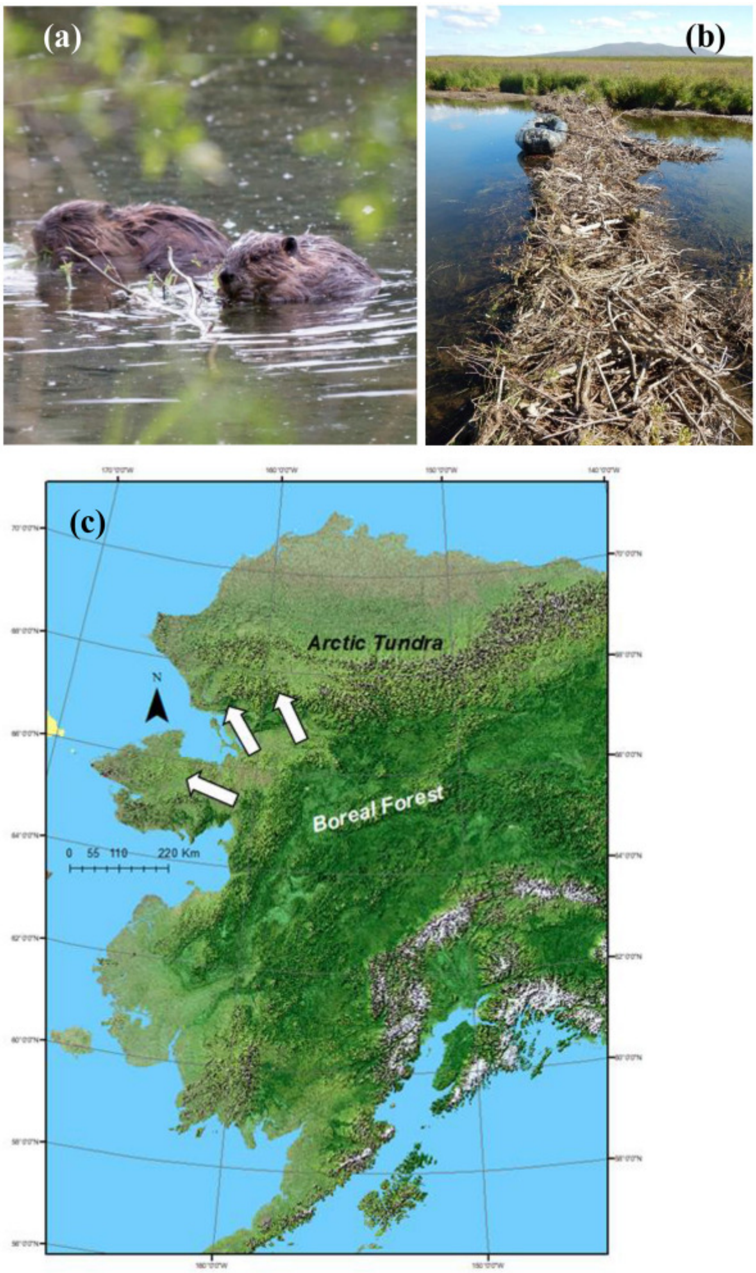


Figure 1

**Figure 1**

**(a)** Two beavers eating shrub branches in a pond near Glenallen, Alaska. **(b)** A beaver dam in Alaska's Arctic is made of small branches and twigs from shrubs. **(c)** In the past, beavers lived in regions with larger trees, like Alaska's forests (dark green on map). However, climate change has caused shrubs to grow in the Arctic tundra (light green), where there was previously mainly grass and moss. Beavers are moving north from the forests to the Arctic tundra in northwest Alaska (white arrows) and are using these shrubs to build dams (Photo credit: Ken Tape; map: https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1691).

also cause the spread of diseases like Giardia (sometimes called beaver fever). This disease makes people sick if they drink unfiltered water from streams. Beavers also create habitats for fish and wildlife, and they can also affect landscapes by encouraging growth of vegetation and limiting the spread of wildfires. Given all of this, there is good reason why people use the phrase "busy as a beaver"!

**BOREAL FOREST**

A large, forested region in the Northern Hemisphere. The boreal forest is dominated by conifer trees, like spruce and pine. Boreal trees and soils store lots of carbon.

**ARCTIC TUNDRA**

The region north of the boreal forest. Arctic tundra ecosystems are cold, with small plants (such as moss and lichen) and permafrost soils.

## BEAVERS ARE MOVING NORTH IN ALASKA

Beavers typically live in regions with forests. They use trees, branches, mud, and rocks to build dams and lodges. In Alaska, beavers have mainly lived in the **boreal forests** in the lower part of the state. But scientists recently discovered that beavers are moving north, beyond Alaska's boreal forests and into the **Arctic tundra** [2]. Using satellite images, researchers can see that, over the last 30 years, beaver ponds have increased in northwest Alaska (Figure 2). Beavers are moving into new habitat in Alaska's Arctic national parks, including Bering Land Bridge National Preserve, Cape Krusenstern National Monument, and Noatak National Preserve.

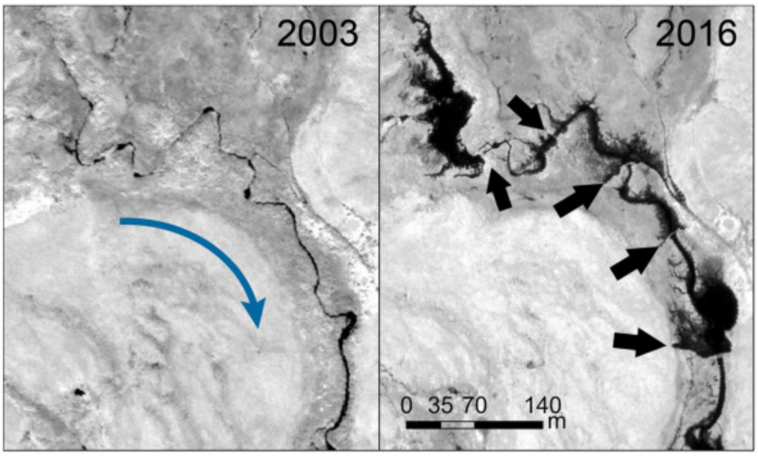


Figure 2

**Figure 2**

Satellite pictures showing the effects of beavers on an Arctic stream in northwest Alaska. The blue arrow shows which direction the stream flows. In 2003, there were no beavers and the stream channel was small. By 2016, beavers had built several dams (each black arrow points to a dam), creating a number of large beaver ponds [Image credits: Quickbird (2003; Digital Globe Inc.) and Worldview 2 (2016)].

Beaver numbers have changed due to both trapping and climate change. In the 1800s, people used to trap beavers for their valuable fur, which kept the number of beavers in the region low. By the 1900s, new laws slowed beaver trapping, which caused the number of beavers to increase. In the past, the Arctic was too cold and lacked both beaver food and the large sticks needed for building their homes and dams. But the climate is warming rapidly in Alaska—much faster than in the rest of the United States. As it gets warmer, trees and shrubs can grow farther north. This new growth provides the wood beavers can use to build dams and lodges. Other mammals, like snowshoe hares and moose, are also moving north as Earth's climate warms and shrubs grow bigger. **Climate models**—or computer simulations—predict that Alaska's climate will continue to warm for tens of years into the future.

**CLIMATE MODELS**

Complex computer programs that use math to understand Earth's climate. Climate models can be used to study how land, air, and oceans interact to affect the climate.

As a result, scientists believe that the number of beavers will continue to increase, and they will expand throughout the Alaskan Arctic. Scientists from the US Geological Survey, the National Park Service, and the University of Alaska Fairbanks are currently studying beavers to understand how they are changing Arctic lands and waters.

## DO BEAVERS CAUSE PERMAFROST TO THAW?

Beaver ponds in the Arctic are different from beaver ponds in the rest of the US due to the presence of **permafrost**. Permafrost, or frozen soil, is an important feature of Arctic regions like Alaska. Permafrost forms in cold climates. Most permafrost has remained frozen for hundreds or even thousands of years. But recent climate warming in the Arctic is causing permafrost to thaw. Perhaps permafrost is not permanent after all! When permafrost thaws, the ice melts, water flows away, and the ground surface can collapse. In Arctic towns and cities, permafrost thaw can also cause houses to collapse and roads to break.

**PERMAFROST**

Soil that has remained frozen for at least two straight years, although most permafrost has been frozen for much longer.

**THERMOKARST**

When icy permafrost soils thaw, the ground surface can collapse. This process is known as thermokarst.

New beaver ponds flood the surrounding Arctic permafrost soils. During summer, the relatively warm pond water causes the permafrost to warm and rapidly thaw in a process known as **thermokarst** [3]. This permafrost thaw can occur beneath ponds, making ponds deeper over time. Permafrost thaw can also happen around the edges of ponds. This increases the surface area of beaver ponds as the pond banks thaw, collapse, and erode over time (Figure 3). It is clear how beaver ponds can change the land and streams. How can they impact water quality and climate change?

Figure 3

**Figure 3**

Aerial view of a beaver pond in the tundra. The picture shows a large beaver dam (white arrows) that blocks water from flowing downstream. You can see how the pond floods nearby soils. The pile of sticks in the middle of the pond is the beaver lodge, their home (Photo credit: Ken Tape).

## BEAVER EFFECTS ON WATER QUALITY AND FISH

Permafrost stores large amounts of **organic carbon** and nutrients. Think of carbon and nutrients as food for stream plants and **algae**. Algae grow attached to rocks and wood or they float in the water. Algae and other water plants make up the base of the food web. They support bugs, fish, and all other animals that eat plants. For example, moose are often spotted eating plants out of beaver ponds. When carbon and nutrients are frozen in permafrost, it is like storing food in a freezer. When permafrost thaws, it is like you are transferring the food from the freezer to the refrigerator. When the food thaws, it can be eaten, or it can decompose.

As we discussed earlier, beavers can cause permafrost soils to thaw by building ponds. In that way, beavers cause the release of carbon and nutrients from permafrost into ponds and streams. Water quality is a measure of how safe that water is for people or an ecosystem[1]. Scientists do not yet know the consequences of beaver ponds on water quality and stream food webs. A recent study found carbon from thawing permafrost in the muscles of Arctic fish species. Species called Arctic Grayling and Dolly Varden had **permafrost carbon** in their muscles because it was in their food [4]. Permafrost carbon enters the food web through algae and moves up the food chain through bugs to fish. It is possible that beaver ponds are a great place for some fish species because permafrost carbon can support their growth and energy needs.

One concern of scientists, national park managers, and fishermen is the release of mercury, a metal, from thawing permafrost into beaver ponds. In addition to carbon and nutrients, permafrost stores large amounts of mercury. Some forms of mercury are toxic and can be taken up by stream food webs. To better understand this release of mercury, we visited beaver ponds in northwest Alaska to make scientific observations and collect water and fish samples. Our research on Arctic beaver ponds in national parks shows that beaver ponds can be "hotspots" for toxic mercury. For instance, we found that toxic forms of mercury can account for up to 80% of total mercury in beaver pond sediments. If people eat fish with high amounts of mercury, it can negatively affect their health. Therefore, it is important to determine if beaver ponds are causing mercury to accumulate in Arctic fish.

## CAN BEAVERS IMPACT EARTH'S CLIMATE?

When permafrost thaws and carbon moves from the freezer to the refrigerator, this thawed carbon can also move from the soil to the air. Soil bacteria can decompose the thawed carbon, similar to the way animals chew and digest food. By doing so, these bacteria produce the greenhouse gases carbon dioxide ($CO_2$) and methane ($CH_4$). These

### ORGANIC CARBON

Carbon that forms from living things, such as plant or animals. In the Arctic, soils store lots of organic carbon.

### ALGAE

Simple plants that grow in streams and lakes. Unlike many land plants, algae do not have stems, roots, or leaves. "Algae" is plural, and the singular term is "alga."

[1] For more information about water quality, see: https://www.usgs.gov/special-topic/water-science-school/science/water-quality-information-topic.

### PERMAFROST CARBON

Carbon, or dead plant material, stored in permafrost. When permafrost thaws, large amounts of carbon can be released into the air as greenhouse gases.

greenhouse gases are the main reason why Earth's climate has been warming so quickly over the last 40–50 years. Beaver ponds and other shallow Arctic lakes release lots of methane to the atmosphere [5]. We expect that permafrost will continue to thaw and more carbon will be released to the atmosphere as beavers move north. By adding more greenhouse gases to Earth's atmosphere, beavers may be contributing to Earth's warming climate! However, scientists do not know how large of an impact beavers will have on climate. We will continue to study these ecosystems to better understand the importance of beavers to the Arctic and to Earth's climate.

As ecosystem engineers, beavers have a large effect on ecosystems. Now that beavers have moved north into the Arctic tundra, their effects could be even greater. The combination of beavers and permafrost thaw makes tundra streams exciting places to study. It is important to understand the effects of these changes throughout the food web, to the climate, and to people. We are just now beginning to understand all the different things that change when beavers make a tundra stream their home. In the future, we will collect more water and fish samples to better understand the effects of beavers on mercury and greenhouse gases. Now, scientists are as busy as beavers.

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## ORIGINAL SOURCE ARTICLE

Tape, K. D., Jones, B. M., Arp, C. D., Nitze, I., and Grosse, G. 2018. Tundra be dammed: beaver colonization of the Arctic. *Glob. Change Biol.* 24:4478–88. doi: 10.1111/gcb.14332

## REFERENCES

1. Naiman, R. J., Johnston, C. A., and Kelley, J. C. 1988. Alteration of North American streams by beaver. *Bioscience* 38:753–62. doi: 10.2307/1310784
2. Tape, K. D., Jones, B. M., Arp, C. D., Nitze, I., and Grosse, G. 2018. Tundra be dammed: beaver colonization of the Arctic. *Glob. Change Biol.* 24:4478–88. doi: 10.1111/gcb.14332
3. Jones, B. M., Tape, K. D., Clark, J. A., Nitze, I, Grosse, G., and Disbrow, J. 2020. Increase in beaver dams controls surface water and thermokarst dynamics in an Arctic tundra region, Baldwin Peninsula, northwestern Alaska. *Environ. Res. Lett.* 15:075005. doi: 10.1088/1748-9326/ab80f1
4. O'Donnell, J. A., Carey, M. P., Koch, J. C., Xu, X., Poulin, B., Walker, J., et al. 2020. Permafrost hydrology drives the assimilation of old carbon by stream food webs in the Arctic. *Ecosystems* 23:435–53. doi: 10.1007/s10021-019-00413-6

5. Turetsky, M. R., Abbott, B. W., Jones, M. C., Walter Anthony, K., Olefeldt, D., Schuur, E. A. G., et al. 2020. Carbon release through abrupt permafrost thaw. *Nat. Geosci.* 13:138–43. doi: 10.1038/s41561-019-0526-0

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## YOUNG REVIEWERS

**DREW AGE: 11**
Hi, I am Drew! I love science, especially animals, dinosaurs, and the Museum of the Rockies. My favorite sport is soccer, I love to fish, and skiing is awesome. My Gramps got me hooked on birds, and my family calls me eagle eye.

**SPRINGHILL SCHOOL, AGES: 10–14**
We are a one room schoolhouse just north of Bozeman, Montana. We have 14 students currently in grades one through eight. We are a school who operates as one team even though we have many different grades. Our older students often step in as "mini teachers" and help younger students understand difficult concepts and complete challenging activities. This allows our students to grow in their leadership abilities and develop skills in teamwork.

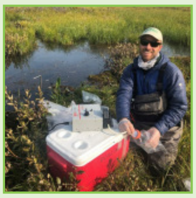
## AUTHORS


**JONATHAN A. O'DONNELL**

Jonathan A. O'Donnell is an ecologist with the National Park Service in Anchorage, Alaska. He monitors streams, rivers, and lakes in the Arctic. He also conducts research to understand how climate change is impacting Arctic ecosystems. In his free time, Jon enjoys camping with his family, skiing, and playing guitar. *jaodonnell@nps.gov

**MICHAEL P. CAREY**

Mike P. Carey is a Research Fish Biologist at the U.S. Geological Survey Alaska Science Center in Anchorage, AK. He works in Arctic and Subarctic ecosystems to understand how changes from climate warming and invasive species influences aquatic food webs. He is particularly interested in understanding how changing ecosystems influence fish communities that live in the rivers and lakes or use these habitats at different stages of their life. When he is not thinking about fish you can find him skiing or mountain biking trying to keep up with his kids.



**BRETT A. POULIN**

Brett A. Poulin is an assistant professor and scientist at the University of California, Davis. His work aims to understand how the chemistry of water influences chemicals and metals that are toxic to humans and wildlife. He uses this information to guide the management of environments to improve them and understand how these environments will respond to new pressures (e.g., climate change). He gets excited about his work because he can make measurements at the small scale of atoms and relate his observations to processes at the scale of ecosystems.

**KEN D. TAPE**

Ken D. Tape is an Arctic ecologist. He studies how the landscape is responding to climate warming, and how these changes affect an assortment of wildlife. Lately he has studied the impact of beaver colonization on aquatic and terrestrial environments of the Arctic.

**JOSHUA C. KOCH**

Josh C. Koch studies water for the United State Geological Survey in Alaska. He went to school until he was 32 years old to get the training needed to do his job. He measures the amount of water flowing in streams and rivers and the volume of water in lakes. Josh measures how water flow and volume change in time and looks at the chemistry of the water to understand where the water has been and how it is used by ecosystems.

EARTH AND ITS RESOURCES
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# PERMAFROST AND DRAINING LAKES IN ARCTIC ALASKA

***David K. Swanson*** *

*U.S. Department of the Interior, National Park Service, Fairbanks, AK, United States*

YOUNG REVIEWERS:

ZEPHYR
AGE: 12

ZOE
AGE: 13

In the Arctic, the ground is frozen most of the year. Only the top layer of soil thaws each summer. This frozen ground, called permafrost, contains a lot of frozen water (ice). There are many small lakes in the Arctic, in low spots formed from melted ice. But melting ice does not just create lakes, it can destroy them too. Melting permafrost can create gullies that let the water drain out of a lake. Most lakes in the Arctic are far from where people live, so we watch them using pictures taken from satellites. Recently, we have seen the water drain out of many lakes, which can affect plants and animals. We measure the number and size of drained lakes caused by thawing permafrost to understand how the Arctic is changing.

## WHAT IS PERMAFROST?

**PERMAFROST:** Ground that stays frozen year-round.

**Permafrost** is ground that stays frozen all year round. It forms in places with cold climates where the ground freezes so deeply in the winter that it stays frozen through the summer. Only the ground near the surface thaws in the summer. The part that thaws is called the

**ACTIVE LAYER:**

Ground above permafrost that thaws during the summer.

**active layer**. That is where the action is: plant roots can grow, water can soak in, the soil can even slide downhill. Below the active layer is the permafrost, which stays solidly frozen all year long.

As summer progresses, the ground thaws from the surface downward. By the end of summer, the thaw slows down and eventually stops. When winter comes, the active layer freezes again.

Permafrost prevents water from snowmelt or rain from soaking deep into the ground. Where the ground is flat, the soil is often waterlogged and there are many lakes and ponds. The plants that grow in these environments are specially adapted to cold, wet soils. On hillslopes and in rocky areas, water can drain from the soils even when there is permafrost below. These dry places support different kinds of plants, and animals can dig burrows there, too.

**CONTINUOUS PERMAFROST ZONE:**

Regions of the Earth where permafrost covers most (more than 90%) of the land area.

**DISCONTINUOUS PERMAFROST ZONE:**

Regions of the Earth where permafrost is present but covers less than 90% of the whole land area.

## WHERE CAN WE FIND PERMAFROST?

Permafrost is found in the cold parts of the world. Large parts of Canada and Alaska have permafrost (Figure 1). Our map shows two permafrost zones that depend on how much of the land is underlain by permafrost. In the **continuous permafrost zone** permafrost is present nearly everywhere. In the **discontinuous permafrost zone**, permafrost is missing in warm places, such as sunny hillslopes. In the Arctic—the part of the world so far north that it is too cold for trees to live—most of the land has continuous permafrost.

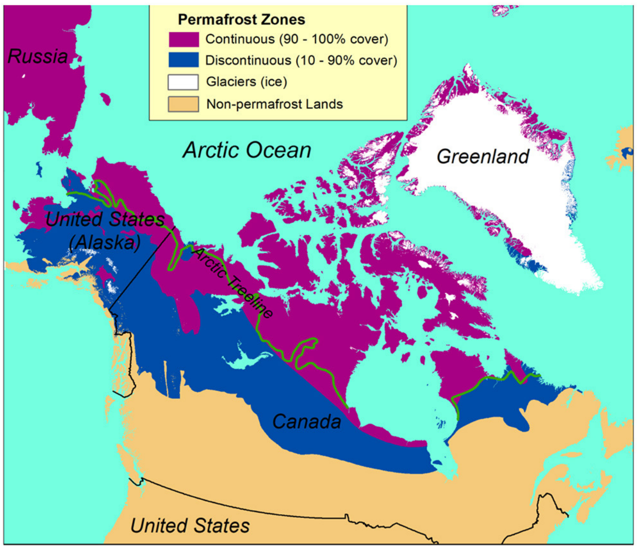


Figure 1

**Figure 1**

Permafrost map of North America. The colors represent zones that differ in how much land area is underlain by permafrost: continuous permafrost (90–100% permafrost cover) and discontinuous permafrost (10–90% permafrost cover). [Figure credit: simplified from Brown et al. [1]].

## ICE IN THE GROUND

Permafrost usually contains ice, known as ground ice. Where the ground is mostly sand and gravel, ground ice usually fills just the spaces between the grains. Where the ground is solid rock, ice is usually found only in the cracks in the rock. Where the ground is made of very small particles like silt and clay, ground ice is the cement that holds the ground together. Ground ice can also exist as masses of nearly pure ice. The most common kind of pure ice in permafrost is **ice wedges**, which create a distinctive pattern of polygons on the landscape (Figure 2). Ice wedges appear wedge-shaped when seen from the side, and when seen from above they form a network that follows the polygon outlines.

**ICE WEDGE:**

Ice in the ground that forms by repeated freezing and thawing. A contraction crack in permafrost fills with meltwater that freezes to form a wedge.

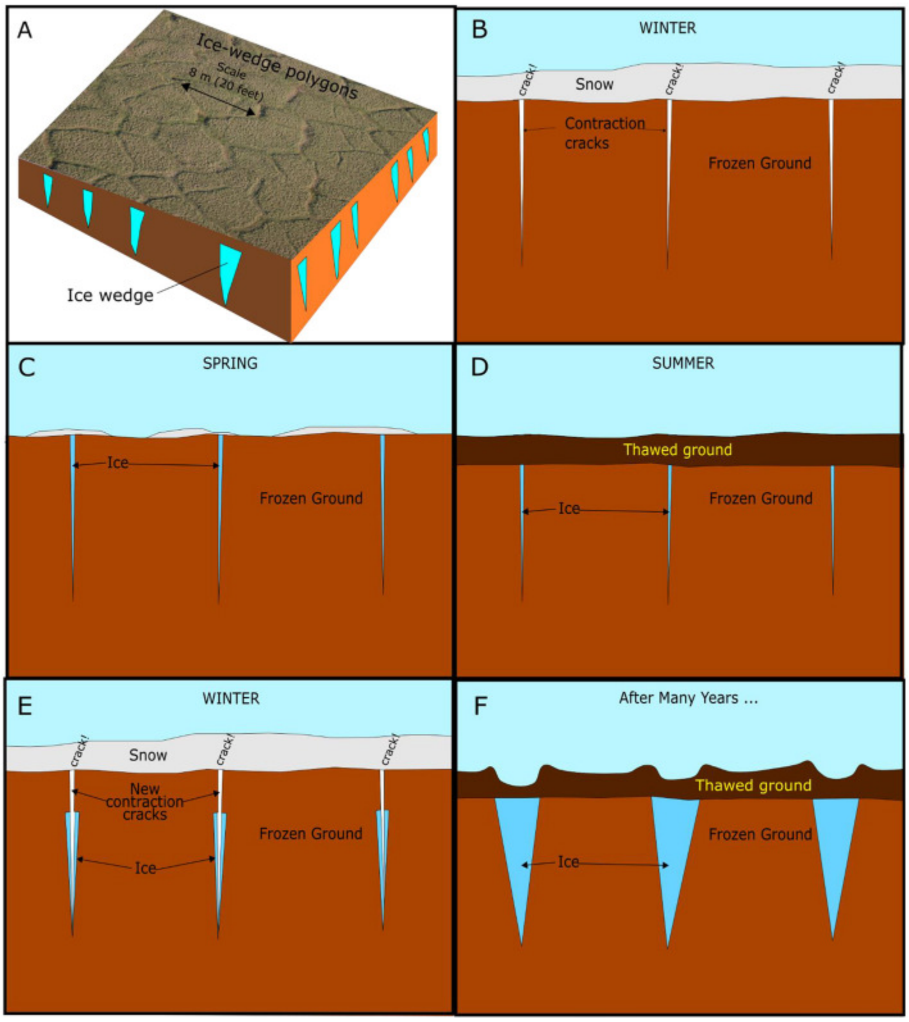


Figure 2

**Figure 2**

The formation of ice-wedge polygons. **(A)** An image from above showing ice-wedge polygons on the surface and the ice wedges underground. **(B–F)** The steps in the formation of ice wedges, as seen from the side. In winter the ground cracks, then in the spring the cracks fill with meltwater that freezes and lasts through the summer. In the following winter, the ground cracks in the same place and the wedge grows wider.

The way that ice wedges form was first discovered over 100 years ago [2]. Ice wedges form in permafrost by freezing and thawing over many years' time. In the winter, the permafrost and the frozen active layer form a solid mass that contracts (shrinks) as it gets colder. If it contracts enough it will crack, usually in a pattern of polygons that reminds us of cracks in dried mud. Mud cracks also form by contraction as the mud dries. The difference is that the ice-wedge polygons are much larger than mud-crack polygons. Ice-wedge polygons are usually about 5–10 m (16–33 feet) across (Figure 2). When winter ends, the snow melts but the ground is still cold and the cracks are still open, so water flows into the cracks and freezes. Down in the permafrost, this narrow wedge of ice survives the summer thaw. The crack is a weak spot that is likely to crack again in the future, so the ice wedge will grow wider over time. In some places the wedges grow so wide that over half of the ground near the top of the permafrost is made of ice wedges. When permafrost contains a lot of ice it is called **ice-rich permafrost**.

**ICE-RICH PERMAFROST:**

Permafrost that contains so much ice that it sinks or flows when it thaws.

## PERMAFROST THAW LAKES

Ice-wedge polygons are one of many unique permafrost landforms. Another permafrost landform closely tied to ice-wedge polygons is the **thaw lake** (Figure 3). Thaw lakes were first given this name and described over 70 years ago [3]. They form when ice-rich permafrost thaws in flat, wet environments. Thawing of permafrost causes the ground surface to sink down. In places with many large ice wedges, the ground can sink enough to form a basin for a lake, which is then called a thaw lake. Thawing of permafrost can begin with just a small pond. The water in the pond warms up by absorbing energy from the sun, causing ground ice below and next to the pond to thaw. Over time the pond becomes bigger and deeper, absorbing more energy from the sun and melting more ice. This process drives itself to speed up as time goes on. Thaw lakes are usually shallow, but they can grow to be more than 1 km (half a mile) across.

**THAW LAKE:**

A lake that formed where the land sank due to melting of ice in the ground.

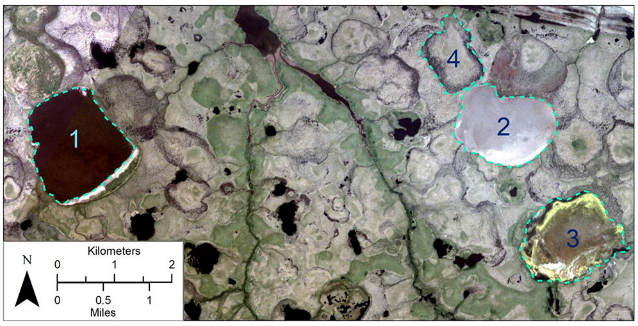


Figure 3

**Figure 3**

Thaw lakes in Bering Land Bridge National Preserve, Alaska, on a satellite image taken in July 2019. Lake (1) was still full of water, and appears black. The circle at (2) outlines the mud bottom of a former lake that drained just before the image was taken. The circle at (3) outlines a lake that drained in 2018, and vegetation has begun to grow on the lake bottom. The circle at (4) outlines a lake that drained long ago. The outlines of many other drained lakes are visible; all drained before our earliest aerial photographs from the 1950s.

The banks of thaw lakes do not hold back the water very well. Water from the lake can quickly cut a trench by melting the ground ice and washing away the soil. Water can flow out of the lake through a new trench, draining most of the water in just a few days. In places with thaw lakes, you can often see the outlines of lakes that drained both recently and long ago. These are most easily seen on pictures taken from airplanes or satellites (Figure 3). The study of the earth using

**REMOTE SENSING:**

The study of land or objects from a distance using cameras or other instruments. An example is the study of the Earth using images taken from satellites.

images taken from above is called **remote sensing**. Remote sensing is very useful for the study of permafrost in remote places like the far north. It is especially interesting to study images taken at different times to see what changes have happened.

Many thaw lakes have drained in northern Alaskan parks in recent years. National Park Service scientists use satellite images taken every summer to measure the number and size of drained lakes caused by thawing permafrost, and to determine the year when they drained. We use computers to examine hundreds of satellite images. We found that 18 lakes drained in 2018 and 22 in 2019, while no more than 10 had ever drained in any single year since 2000. There are fewer lakes now than there were on the earliest historical images that we have (photographs from airplanes), which were taken 70 years ago [4–6]. In the northern plains of Bering Land Bridge National Preserve, the area of lakes is now almost 20% less than it was 20 years ago [6].

The weather in the northern Alaska parks has been warmer and snowier than normal in the past few years [7]. This has made it easier for new gullies to form and drain the lakes. The recent unusual weather is probably due to both natural year-to-year variations combined with long-term climate change. For centuries, lakes in the Arctic have been forming and draining [8]. However, climate change is probably causing them to drain more often now than they did in the past. When the climate warms, ice wedges that were solidly frozen in permafrost are more likely to melt and create new gullies and small ponds.

When lakes drain, they can no longer provide homes for water birds such as loons and ducks. On the other hand, animals can graze the lush new vegetation that grows on the bottoms of drained lakes. We have seen caribou, geese, and even grizzly bears grazing on drained lake bottoms. We will keep studying drained lakes to help us understand how the loss of lakes affects the plants and animals that live in the Arctic. Permafrost is very vulnerable to change as the climate warms. Draining lakes are just one example of how thawing of permafrost is changing the Arctic.

## FUNDING

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## REFERENCES

1. Brown, J., Ferrians, O., Heginbottom, J. A., and Melnikov, E. 2002. *Circum-Arctic Map of Permafrost and Ground-Ice Conditions, Version 2*. Available online at: `https://nsidc.org/data/ggd318` (accessed April 6, 2021).

2. Leffingwell, E. K. 1915. Ground-ice wedges: the dominant form of ground-ice on the north coast of Alaska. *J. Geol.* 23:635–54.
3. Hopkins, D. M. 1949. Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska. *J. Geol.* 57:119–31.
4. Jones, B. M., Grosse, G., Arp, C. D., Jones, M. C., Walter Anthony, K. M., and Romanovsky, V. E. 2011. Modern thermokarst lake dynamics in the continuous permafrost zone, northern Seward Peninsula, Alaska. *J. Geophys. Res. Biogeosci.* 116:G00M03. doi: 10.1029/2011JG001666
5. Swanson, D. K. 2019. Thermokarst and precipitation drive changes in the area of lakes and ponds in the National Parks of northwestern Alaska, 1984–2018. *Arct. Antarct. Alp. Res.* 51:265–79. doi: 10.1080/15230430.2019.1629222
6. Swanson, D. K. 2020. *Monitoring of Water Surface Area in Alaska's Arctic National Parks: Update With 2019 Data*. *Natural Resource Data Series NPS/ARCN/NRDS—2020/1263*. Fort Collins, CO: National Park Service. Available online at: `https://irma.nps.gov/DataStore/Reference/Profile/2272062` (accessed May 28, 2020).
7. Swanson, D. K., Sousanes, P. J., and Hill, K. 2021. Increased mean annual temperatures in 2014–2019 indicate permafrost thaw in Alaskan national parks. *Arct. Antarct. Alp. Res.* 53:1–19. doi: 10.1080/15230430.2020.1859435
8. Jones M. C., Grosse G., Jones B. M., and Walter Anthony, K. 2012. Peat accumulation in drained thermokarst lake basins in continuous, ice-rich permafrost, northern Seward Peninsula, Alaska. *J. Geophys. Res. Biogeosci.* 117:16. doi: 10.1029/2011JG001766

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## YOUNG REVIEWERS

**ZEPHYR, AGE: 12**

My name is Zephyr and I live in a small country town in the mountains in Oregon. I am in seventh grade. In my free time I like to explore the land around me and build with Legos. I also have a small dog named Zella who I like to play with.

**ZOE, AGE: 13**

My name is Zoe, I am 13. I was born and raised in Central California. I like sports, art, and cooking. Social Studies and Math are my favorite subjects. I got into science in kindergarten. In my free time, I love to make jewelry and read! I have played basketball for 7 years! When I am not playing basketball I am playing outside with my sister. When I am older I want to be an architect and room designer.

## AUTHOR

**DAVID K. SWANSON**

Dr. Swanson became interested in science as a young boy and went on to study geology, soils, and plants in college and graduate school. He has worked as a scientist for different U.S. Government agencies since 1988. He currently is responsible for monitoring natural changes in the five large national parks in northern Alaska. *david_k_swanson@nps.gov

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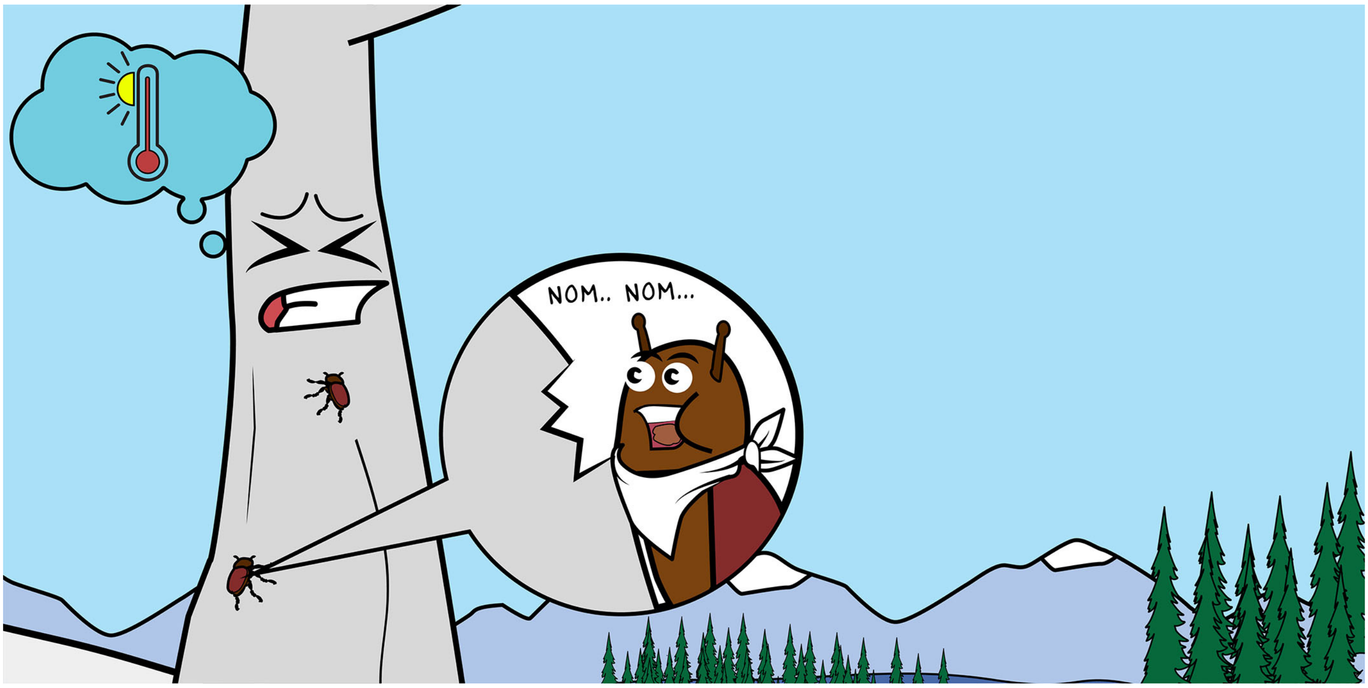


# TROUBLE IN THE FOREST: WHITEBARK PINE TREES, MOUNTAIN PINE BEETLES, AND CLIMATE CHANGE

***Alzada Roche*[1], *Erin Shanahan*[1*] *and Jonathan Nesmith*[2†]**

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YOUNG REVIEWERS:


AYA
AGE: 10


NICOLE
AGE: 15

Have you ever hiked up a mountain and felt a frosty wind blowing across your face? You might need to button up your jacket to visit this place, but here, whitebark pine trees are right at home. Whitebark pines thrive in the highest forests of western North America. In these environments, whitebark pines help other, less-hardy species to establish, grow, and survive. For this pine, chilly mountaintops provide a refuge from insects, disease, and competition with other trees. Yet as our climate changes, whitebark pines no longer have the cold on their side. They are dying at alarming rates, and one of the biggest killers is a tiny bark beetle. How is climate change helping this little insect munch through huge swaths of forest? National Park Service scientists use long-term monitoring studies to unravel this complicated relationship. This information guides resource managers entrusted with protecting whitebark pines.

## HOW DOES CLIMATE CHANGE AFFECT COLD-ADAPTED SPECIES?

You may have heard that climate change will contribute to the extinction of many species over your lifetime. But have you thought about why? For some species, the environment is going to get too warm too fast for them to live: think of a goldfish in a bowl of hot water. For most other species, the interaction between climate change and survival is more complex. While some species will suffer in warmer temperatures, others may thrive. And this difference in survival can throw off the natural balance in an ecosystem.

Whitebark pine trees are found in cold, high-elevation forests across western North America (Figure 1). They are adapted to live on mountain slopes and ridges at the upper limits of where trees can survive. Warmer temperatures are not always harmful to whitebark pine trees. Like many plant species, whitebark pines can grow faster if conditions are warmer. But frequent periods of warmer temperatures favor mountain pine beetles, which can be a serious threat to whitebark pine health. By studying the relationship between whitebark pines and mountain pine beetles, scientists can determine how climate change influences certain aspects of whitebark pine survival. This information can also help us learn about the potential effects of climate change on other plant species.

## WHITEBARK PINES ARE AN IMPORTANT SPECIES

The whitebark pine is a **keystone species**. This means that these trees are very important to other species within the ecosystems where they grow. Whitebark pines produce nutritious seeds that provide fat and calories for grizzly and black bears, squirrels, and birds (Figure 2). When trees produce a lot of cones, well-fed grizzly bears can give birth to more cubs [1]. With higher body fat, bears also have an increased chance of survival through the winter. Grizzly bears are top predators and will eat just about anything, but whitebark pine seeds are one of their favorite foods!

**KEYSTONE SPECIES**

A species that greatly influences the wellbeing of many other species in its ecosystem. Like the keystone in a rock archway, if this species is removed, the system collapses.

Whitebark pines also have a special relationship with Clark's nutcrackers. This loud, gray bird collects whitebark pine seeds throughout the summer and fall, burying them in little holes in the ground. Stored seeds, or caches, supply food for the birds during the long winter months. Fortunately for whitebark pines, the birds cache more seeds than they need to eat. Many of these forgotten seeds sprout into new trees. Clark's nutcrackers like to hide their seeds in forest openings, particularly in areas that have been burned by wildfires. Because of this behavior, whitebark pines are often the first trees to grow back after a wildfire. This type of relationship, in which two species benefit from one another, is known as **mutualism**.

**MUTUALISM**

A type of relationship between different species in which both organisms benefit. Some examples include bees and the flowers they pollinate, and helpful bacteria inside the human digestive system.

**Figure 1**

Locations of whitebark pine trees in western North America. The black lines show the boundaries of Yellowstone, Grand Teton, Sequoia, Kings Canyon, and Yosemite National Parks, and the yellow line outlines the Greater Yellowstone Ecosystem.

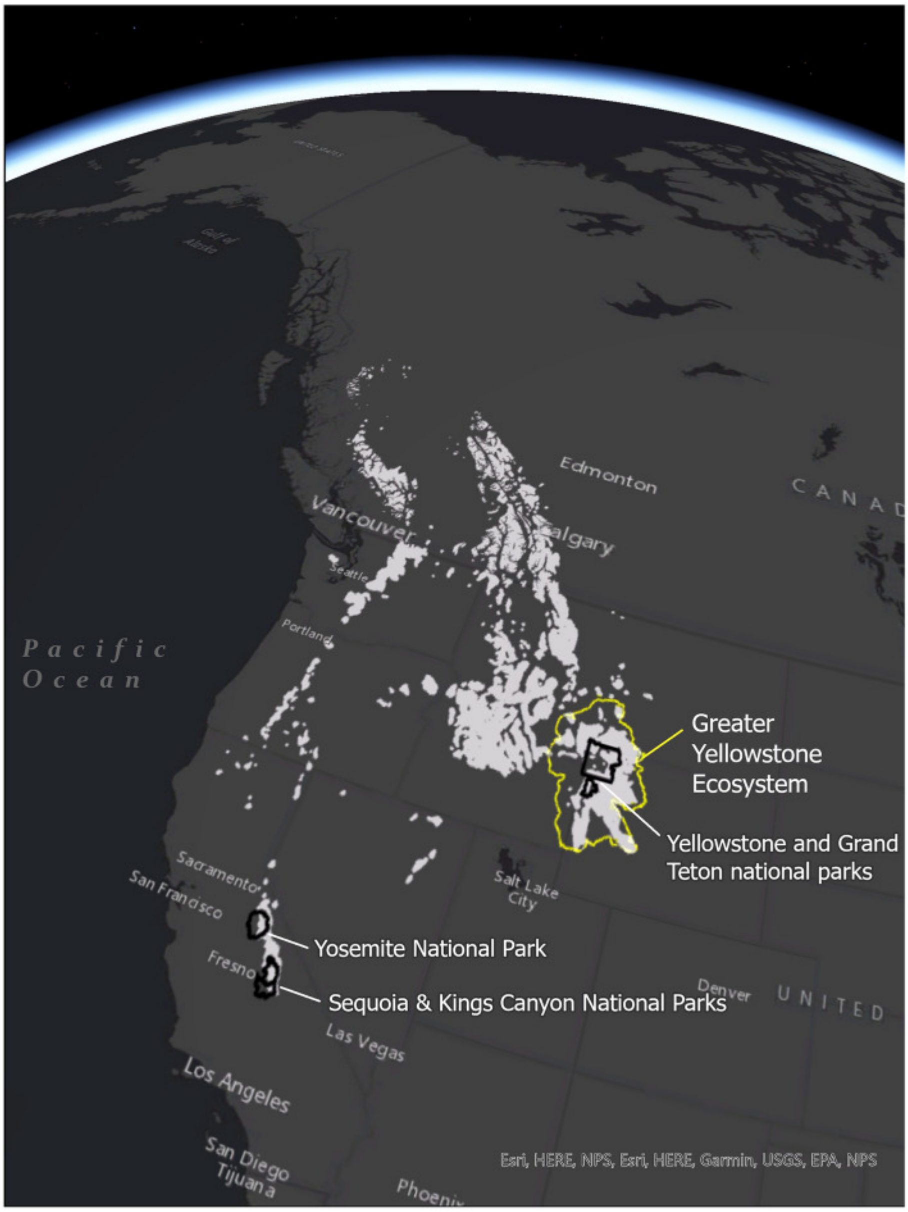


Figure 1

As a whitebark pine seed sprouts and develops into a mature tree, its roots stabilize and enrich the soil. After several years, the tree creates a welcoming environment where other less hardy plants can establish and grow. Shade from its wide-spread branches allows the snow underneath to melt more slowly over the spring and summer, which provides a steadier source of water for plants, animals, and people downstream.

It is common to find whitebark pine trees that are over 400 years old. The oldest one we know of is about 1275 years old! In their lifetime, these ancient trees may have withstood insect outbreaks, wildfire, and drought. They have witnessed generations of people come and go.


Figure 2

**(A)** This whitebark pine tree could be several 100 years old. **(B)** The Clark's nutcracker is the primary disperser of whitebark seeds. **(C)** Grizzly bears depend on fat and calories from whitebark pine seeds to survive the winter. **(D)** Squirrels use their sharp teeth to cut cones down from the high branches. Bears often raid their piles of cones for a meal! **(E)** Whitebark pine pinecones are dark purple and sticky with sap. **(F)** Areas where many trees have died are known as "ghost forests." Image credits: **(A,E,F)** Authors' own. **(B)** Walter Siegmund. Creative Commons License. https://commons.wikimedia.org/wiki/File:Pinus_albicaulis_7025.JPG. **(C)** Jim Peaco, NPS. Creative Commons License. https://www.flickr.com/photos/yellowstonenps/35472673145. **(D)** BlueCanoe. Creative Commons License. https://commons.wikimedia.org/wiki/File:Eastern_Gray_Squirrel_Sciurus_carolinensis_Lake_Juanita_WA.jpg.

But now, they are dying at an alarming rate. Where these majestic guardians of the mountains once thrived, "ghost forests" now stand. How did these mighty trees die after surviving for so long? One reason is that there is a wee beetle living in the forest, and it has a teeny, tiny mouth but a terrible bite.

## MOUNTAIN PINE BEETLE—TINY AND HUNGRY

Mountain pine beetles may be small, but they have a huge effect on forests! The **life cycle** of mountain pine beetles includes egg, larva, pupa, and adult stages. Most of that life cycle is completed underneath the bark of host trees, which are trees that mountain pine beetles like to reproduce in and eat—including whitebark pines. Adult beetles swarm a tree and chew a network of paths inside the bark. Next, female beetles lay their eggs in the paths. After about 2 weeks, the eggs hatch into larvae. The hungry larvae dig horizontal channels in the living tissue under the bark, where they feed and develop. This stops the flow of water and nutrients, killing the tree. Once the larvae change into pupae and finally into adult beetles, they emerge from under the bark and fly to new trees to start the cycle again.

**LIFE CYCLE**

The developmental changes an organism goes through during its life. For mountain pine beetles, the life cycle consists of egg, larva, pupa, and finally adult stages.

Whitebark pines and mountain pine beetles have lived in mountain environments for thousands of years. For most of that time, temperatures have kept them in balance. While whitebark pines are found at higher regions that are usually colder, beetles are normally more abundant at lower elevations, where temperatures are warmer. Where whitebark pines grow, beetle populations commonly

**ENDEMIC**

A constantly maintained level of an organism in a particular geographic area. Mountain pine beetles are usually constantly present in western forests but at low numbers.

**EPIDEMIC**

A large increase in the number of organisms in an area. In the case of mountain pine beetles, the number of beetles increased substantially in western forests over several years.

stay at **endemic** levels, which means the typical, low numbers of beetles. Fewer beetles mean fewer trees are killed. However, when temperatures rise, beetle populations can explode to **epidemic** levels, meaning unusually high numbers of beetles. It is natural to see occasional beetle outbreaks in the forest, but recent outbreaks have been larger, lasting longer, and occurring at higher elevations.

## A BEETLE OUTBREAK IN THE GREATER YELLOWSTONE ECOSYSTEM

The Greater Yellowstone Ecosystem is a vast, wild area in the northern Rocky Mountains. It includes Yellowstone and Grand Teton National Parks. In the early 2000s, National Park Service scientists and land managers noticed a dramatic increase in mountain pine beetle populations in this region. By the mid-2000s, beetle numbers had reached epidemic levels. This outbreak continued for several years. When it was over, about 75% of the large, older whitebark pine trees were dead [2].

The National Park Service uses long-term monitoring programs to study whitebark pine health. Park scientists collect data from the same trees, year after year. At each visit, they record whether trees are alive and healthy, diseased, infested with beetles, or dead. Park scientists also look at climate conditions such as air temperature and other factors that affect tree health.

Using the data collected during the mountain pine beetle outbreak, park scientists discovered what triggered the epidemic. Above-average temperatures were recorded in high mountain areas for several years in a row, which allowed beetle populations to expand into whitebark pine habitat and increase to epidemic levels. Higher temperatures speed up the mountain pine beetle's life cycle. Under colder conditions, the beetle life cycle might take two or even 3 years to complete. However, in warmer conditions, the beetle's life cycle happens faster, in as little as 1 year. Mild temperatures also mean that more beetles survive the winter. More beetles born in the summer plus more surviving through the winter adds up to a massive population explosion (Figure 3)!

Historically, the cold climate in whitebark pine habitats has safeguarded the trees from widespread beetle attacks. But as temperatures continue to warm, mountaintops may no longer offer the same protection they once did for whitebark pines.

## STILL MORE TO LEARN

In Yosemite, Sequoia, and Kings Canyon National Parks, park scientists have also been monitoring the health of whitebark pines. Interestingly,

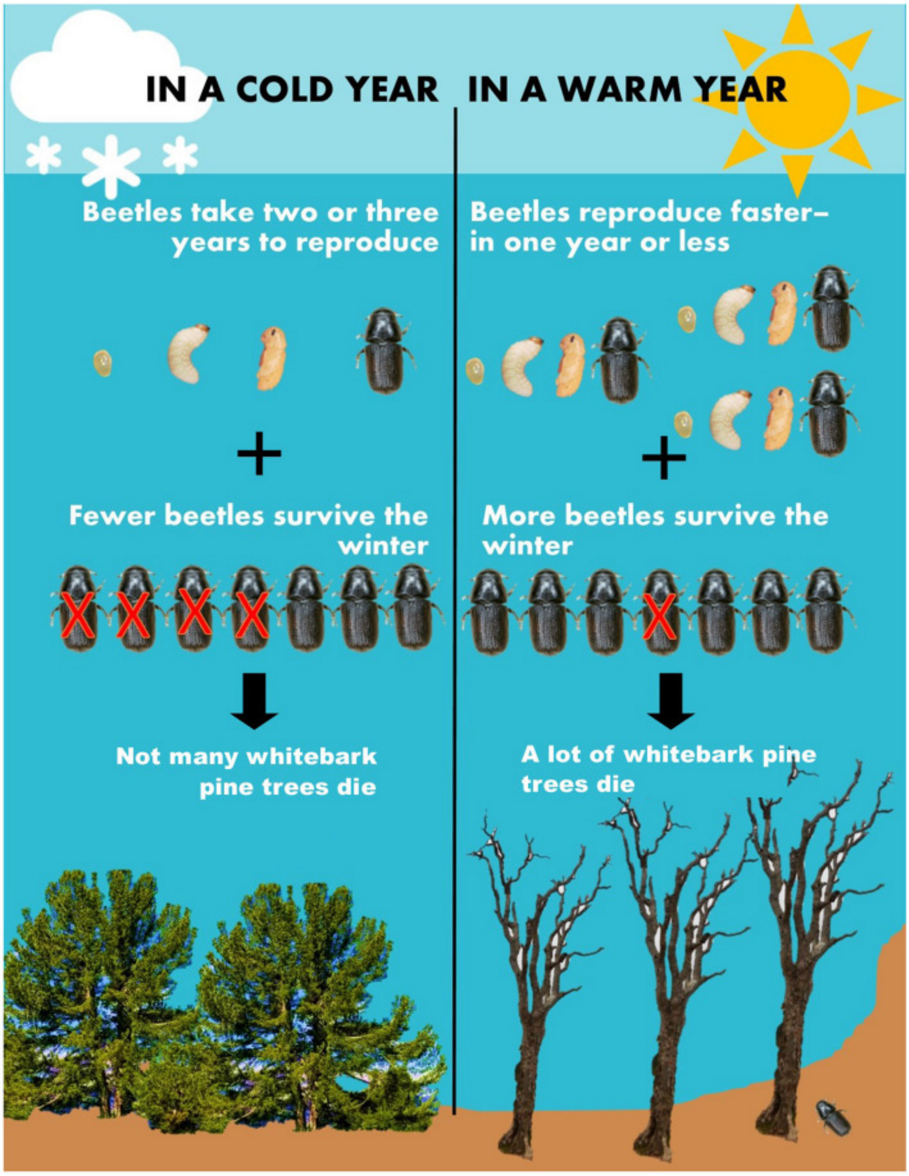


Figure 3

**Figure 3**

When temperatures remain cold over many years, it typically takes beetles 2–3 years to change from an egg to an adult beetle. Colder winters tend to kill more beetles. As a result, fewer beetles are present in the forest and lower numbers of whitebark pines die from beetle attacks. When temperatures are warmer than usual year after year, the beetles' life cycle speeds up, and more beetles can live through warmer winter months. With loads of hungry beetles flying around the forest, a lot of whitebark pines die. Image credits: Beetle and larvae: USDA Forest Service—Region 2—Rocky Mountain Region, USDA Forest Service, Creative commons license. Bugwood.org. Live tree: Erin Shanahan, NPS. Dead Tree: A-wiki-guest-user. Creative Commons License. https://commons.wikimedia.org/wiki/File:Dead_tree_in_Horton_Plains.jpg.

these parks did not have big beetle outbreaks like the ones in Yellowstone and Grand Teton National Parks. California parks differ from the parks in the Greater Yellowstone Ecosystem in several ways, including climate. Currently, we do not know why the trees there are healthier. Do you have a hypothesis for why the whitebark pine populations in these areas are different? If so, it would be a good topic for a research project! Studying other whitebark pine populations can help park scientists understand how climate change is affecting our high-elevation forests across the West.

## HOW CAN WE SECURE A FUTURE FOR WHITEBARK PINES?

By now you may be wondering whether it is even possible for whitebark pines to survive. Forest managers hope so. If whitebark pine populations disappear from the mountaintops, it will have a huge impact on the community of plants and animals that live there. Squirrels, bears, and Clark's nutcrackers will have to look elsewhere for food. Snow will melt sooner without the shade of the pines' branches. And the plants and soil that whitebark pines shelter will have to face the harsh conditions on their own.

Fortunately, there are many people working to preserve this important species. Scientists from the National Park Service and land managers from other U.S. government agencies are working hard to protect and restore whitebark pines. While they may not be able to stop climate change and keep mountaintops cold, they are taking important actions. Using what we have learned about the complicated relationship of whitebark pines, mountain pine beetles, and climate change, managers are focusing their efforts on tasks like collecting and planting seeds in places that might stay colder in the future, defending trees from wildfires, and protecting trees from beetle attacks. Most importantly, they are also educating the public about the ecosystem value of whitebark pines and the impacts of global warming. By working together, park scientists, and land managers will continue to fight for this amazing tree species.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Schwartz, C. C., Haroldson, M. A., White, G. C., Harris, R. B., Cherry, S., Keating, K. A., et al. 2006. Temporal, spatial, and environmental influences on the demographics of grizzly bears in the greater yellowstone ecosystem. *Wildlife Monogr.* 161:1–8. doi: 10.2193/0084-0173(2006)161[1:TSAEIO]2.0.CO;2
2. Shanahan, E., Irvine, K. M., Thoma, D., Wilmoth, S., Ray, A., Legg, K., et al. 2016. Whitebark pine mortality related to white pine blister rust, mountain pine beetle outbreak, and water availability. *Ecosphere*. 7:e01610. doi: 10.1002/ecs2.1610

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## YOUNG REVIEWERS

**AYA, AGE: 10**

Aya wants to study marine biology. She wants to specialize in sharks and rays. Her favorite subjects in school are reading, writing, math, and music. In her free time she likes to read books, try out challenging puzzles, train for track and cross country, and play the violin.

**NICOLE, AGE: 15**

Hi! I am Nicole and my favorite hobbies are reading, running, playing the violin, and spending time outdoors. I am interested in Anthropology and hope to do something close to nature.

## AUTHORS

**ALZADA ROCHE**

Alzada Roche is a biological science technician with the National Park Service. She has transformed her childhood passions of climbing trees and scooping up tadpoles into a career in science. She loves swimming in cold water, climbing high mountains, learning new languages, and cooking with her friends.

**ERIN SHANAHAN**

Erin Shanahan is a vegetation ecologist for the National Park Service's Greater Yellowstone Inventory and Monitoring Network. She has been the protocol lead for the Interagency Whitebark Pine Monitoring Program since its inception in 2004. Through her work monitoring whitebark pines, she has had the privilege to visit some of the most magnificent areas throughout the Greater Yellowstone Ecosystem.

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**JONATHAN NESMITH**

Jonathan Nesmith is a forest ecologist with interests in understanding interactions among forest structure, condition, and disturbance agents including insects and disease, fire, and climate change. When he is not working, he enjoys camping, backpacking, and generally trying to keep up with his two daughters.

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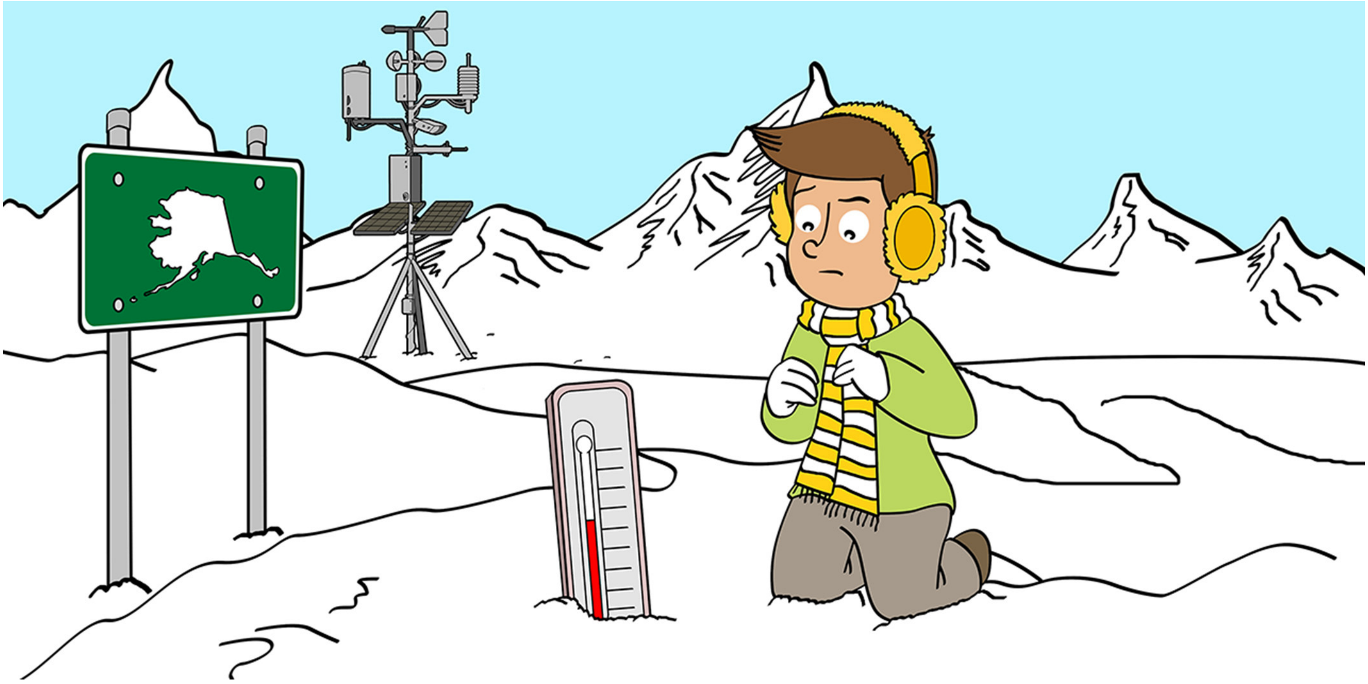

# TWO DEGREES MATTERS

**Pamela J. Sousanes**[*†]**, Ken Hill and David K. Swanson**

*National Park Service, Fairbanks, AK, United States*

YOUNG REVIEWERS:

ARIA
AGE: 9

MOAB CHARTER SCHOOL
AGES: 11–12

How do you tell if someone is not well? You take the person's temperature. If it is too warm, something is not quite right. We care about how the weather and climate are changing in Alaska's national parks, so we continuously take their temperatures. We have dozens of weather stations in remote locations in the northern Alaska parks that run continuously, powered by the sun. Over the past several years, we found that the air and ground temperatures have been warmer than normal. Plants, animals, and people get used to living in their environments. They thrive within an expected temperature range. Things get out of whack when the environment that organisms are accustomed to changes. In northern Alaska, warming of just a few degrees can cause ice to melt and formerly frozen ground to thaw. Once the ground thaws, the ice changes to water and the landscape changes.

## WEATHER AND CLIMATE, WHAT IS THE DIFFERENCE?

We want to know how changes in air temperature impact Alaska's national parks. Alaska's parks are large, and they span several different


Figure 1

**Figure 1**

Alaska is a large state with large national parks! We took a close look at temperatures in the northern Alaska parks, including the parks in the Arctic and in central Alaska (the parks in light green).

**CLIMATE ZONES**

Geographical regions based on average temperature and average rainfall.

**CLIMATE**

The general weather conditions found in a particular place.

**WEATHER**

The state of the atmosphere at a place and time with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness.

**climate zones**. When we refer to **climate**, we are talking about the average weather over a long period of time, generally 30 years. To put it in more practical terms, the clothes you decided to wear today are based on the current **weather**. The clothes you have in your closet (sweaters, boots) are based on the *climate* that you live in. The climate varies depending on where you are on Earth. The closer to the north or south pole you get, the less warmth you get from the sun because it is low in the sky. In the middle of the winter near the poles, the sun does not rise at all! As a result, the average temperatures generally get colder as you move away from the Equator. The Alaskan parks we studied are all above 60° north latitude and some are even north of the Arctic Circle, at 66° north latitude (Figure 1). Up here, summers are short, winters are long and cold, and snow blankets the ground for more than 6 months of the year.

## OCEANS HOLD THE HEAT

Ocean temperatures are also cooler near the poles. Alaska is a big state surrounded by water, with the Pacific Ocean to the south and the Arctic Ocean to the north. Several of our parks are along the coast and are influenced by ocean temperatures. During the winter months, the Arctic Ocean freezes, and the sea ice keeps nearby lands cool. Along the southern coast of Alaska, the Pacific Ocean remains ice free. This moderates the cold winter months and keeps the temperature of nearby lands warmer.

## THE LAND OF SNOW AND ICE

Snow, ice, and frozen ground define these parks. A temperature increase of a few degrees means that snow and ice start to melt. Alaska and other high-latitude environments are undergoing rapid change due to warming temperatures [1]. Alaska's four warmest years on record all occurred between 2014 and 2019. During this period, the ocean temperatures surrounding Alaska were much warmer than normal. This meant that the ice froze later, melted earlier, and was thinner when it was present [2]. Remember that the ice keeps things cool, so when there is no ice, air temperatures are much warmer. Alaska national parks are feeling the heat more than other national parks in the USA [3].

Much of the **Arctic** has **permafrost**, which is ground that is frozen year-round. One of the telltale signs of warming in the Arctic is slumping and oozing ground from thawing permafrost. People have lived in these northern lands for thousands of years. Entire communities are built on frozen ground. As the ground begins to melt, houses and buildings start to sink and fall over. People here hunt (caribou, moose, seals, and whales) and fish (salmon and crab) for food. They use snowmobiles to travel across frozen rivers and the frozen ocean. Without ice, it becomes harder and more dangerous to find food. Everything they hunt for and the way they hunt is based on a cold Arctic.

**ARCTIC**

The northern most region of the Earth known for its extreme cold climate. An important feature is permanently frozen ground and seasonally varying snow and ice cover.

**PERMAFROST**

A combination of soil, rocks, and sand that is held together by ice. The soil and ice in permafrost stay frozen all year long.

## HOW CAN WE MEASURE CLIMATE CHANGE?

We have weather stations in the Alaska national parks that record data year-round. By collecting data every day, we can figure out the average temperature for the whole year. If we keep collecting data year after year, we can track changes in air temperature, ground temperature, and snow depth over time. It is impossible to have enough weather stations to measure the temperature at every location. So, we have computer models that use math to estimate temperatures where we cannot measure them. The models suggest that the ground temperature is very close to freezing in large portions of the northern Alaska parks [4]. Because the temperatures of the air and the ground are related, we know that warming air temperatures mean the ground is also warming.

But there is another important element to consider—snow! Snow is on the ground for more than half of the year in these parks. By measuring snow depth, we can figure out when the snow arrives in the fall, when it melts in the spring, and how much is on the ground throughout the snow season.

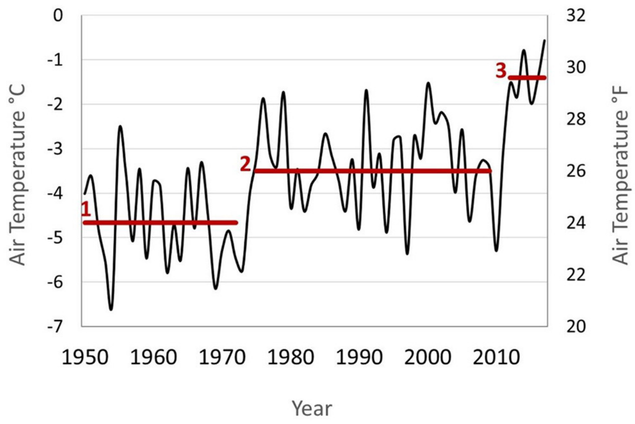


**Figure 2**

Warming temperatures in northern Alaska national parks over the past 70 years. Notice the cooler period up until the mid-1970s (red line 1), a shift to a warmer period (line 2), and the most recent increase to the warmest temperatures (line 3). The recent 2°C of warming puts the temperature of the northern Alaska parks closer to 0 C or 32°F, the temperature at which snow or ice change to water.

## AIR TEMPERATURES ARE WARMING

We found that recent air temperatures in and around the parks are the warmest on record. By looking at the average yearly temperatures over the past 70 years, we can see how much warmer it is now compared to the climate of the past (Figure 2). The average annual temperature in the earlier decades was about −5°C (24°F). Then there was a shift to warmer temperatures in the mid-1970s. Over the next four decades, the average temperature was stable and averaged about −3°C (26°F). That is still cold enough to keep things frozen. But, in 2014, air temperatures increased again by 2°C! This was not a gradual warming, but another sudden upward shift. The average temperature in recent years was about −1°C (30°F), much warmer than it has been in the last 70 years [5]. The temperature increase was not the same in every park. The Arctic parks warmed by almost twice as much as the central Alaska parks.

## WARM AIR, WARM GROUND

We found that the central Alaska parks have already started to thaw, even though they have not warmed as much. This is because these parks were warmer to begin with. The permafrost in those parks is relatively warm and already on the edge of thawing. So, when the temperature went up a few degrees, the ground started to melt. We estimate that about one-third of the permafrost in the central parks is thawing now.

The air temperatures in the Arctic parks near the coast warmed the most. The sea ice formed later in the fall and melted earlier in the spring, and the open ocean kept these parks warmer than normal. Even though the ground is colder in the Arctic parks, during this recent warm period some soils rose above the freezing point and started to thaw. At some Arctic weather stations near the coast, permafrost began to thaw. We predict that about half of the permafrost on park lands

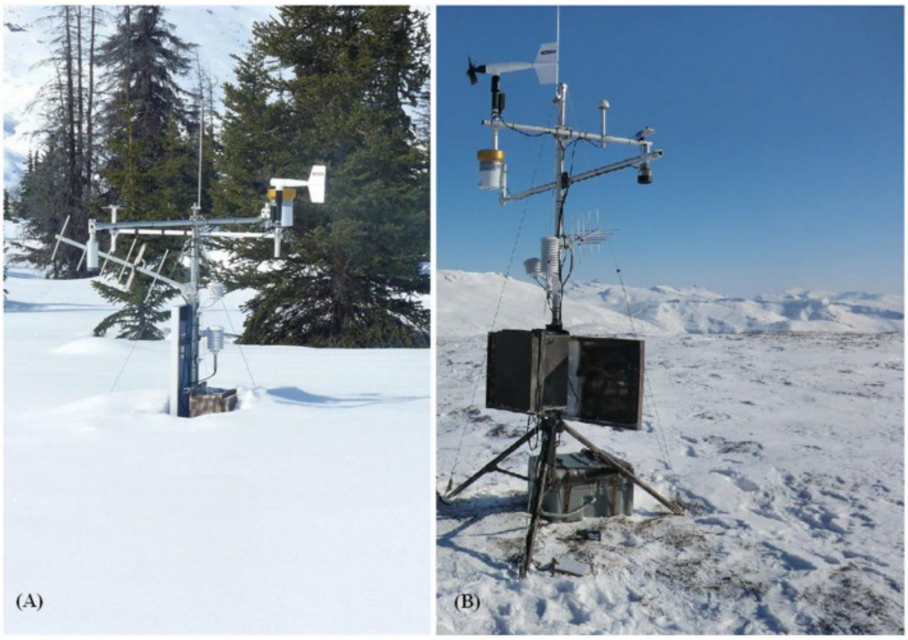


Figure 3

**Figure 3**

**(A)** Tebay weather station in Wrangell-St. Elias National Park (in central Alaska) under a deep blanket of snow, and **(B)** Pamichtuk weather station in Gates of the Arctic National Park (an Arctic park) with very little snow. Thanks to the thick, insulating snow layer, warmer winter temperatures at Tebay did not affect the ground temperature nearly as much as they did at Pamichtuk.

near the coast are vulnerable to thawing. This has never happened in modern history.

## SNOW MATTERS

Snow covers the ground throughout the winter months and can help insulate it. Where the blanket of snow is deep, the frozen permafrost is protected from warmer winter air. When there is not any snow, the warmer air can warm the ground and cause the permafrost to thaw. This is a slow process that occurs over years and decades. But snow is an important consideration for permafrost stability in a warming climate.

In general, the Arctic parks receive less snow than the central Alaska parks. Also, a lot of snow in the Arctic is blown away by wind. Figure 3 shows a typical mid-winter scene at a central Alaska park and an Arctic park weather station. Since winter air temperatures were warmer and the ground did not have much snow insulation, the ground warmed the same amount as the air in the Arctic parks. By comparison, the ground warmed by only half as much as the air temperatures in the central Alaska parks, where there was more snow.

## TWO DEGREES MATTERS

Two degrees of warming means that things have started to melt. The recent warming is particularly troubling in the Alaska national parks where snow and ice are the main features of the landscape. As the permafrost thaws, the ground sinks, trees tip over, and new ponds form as the ice in the soil melts. Roads get bumpier, and they can be blocked by landslides. More trees and shrubs will grow, and the animals that eat them, like moose and beavers, will become more common. But the Arctic wildlife that has adapted to the cold and snowy climate will not do as well. If the snow arrives later, animals like the snowshoe hare, which turns white to blend in with the snow, will stand out against the bare ground. The snow provides a winter habitat for small animals like Arctic ground squirrels. It also keeps larger animals like bears toasty in their winter dens. Polar bears, like people, need sea ice as a platform to hunt. As temperatures climb above freezing and ice and snow melt, it will impact the entire system of plants, animals, and people in northern Alaska.

Share this story with your friends and family. Let them know that a few degrees of warming *does* matter. Also, tell them that there are things all of us can do to help keep the temperatures of Alaska's parks down. Turn off your computer when you are not using it. Flip the light switch off when you leave the room. Do not leave the faucet running while you brush your teeth. Ride your bike or walk instead of asking your parents for a ride. These are a few simple ways to conserve energy in your everyday life, and they can help make a difference for the future of Alaska's parks.

## ORIGINAL SOURCE ARTICLE

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## REFERENCES

1. Markon, C., Gray, S., Berman, M., Eerkes-Medrano, L., Hennessy, T., Huntington, H. P., et al. 2018. "Alaska," in *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, *Vol. II* (Washington, DC: U.S. Global Change Research Program), 1185–241.
2. Thoman, R. L., Bhatt, U. S., Bieniek, P. A., Brettschneider, B. R., Brubaker, M., Danielson, S. L., et al. 2020. The record low Bering Sea ice extent in 2018: context, impacts, and an assessment of the role of anthropogenic climate change. *Bull. Am. Meteorol. Soc.* 101:S53–8. doi: 10.1175/BAMS-D-19-0175.1
3. Gonzalez, P., Wang, F., Notaro, M., Vimont, D. J., and Williams, J. W. 2018. Disproportionate magnitude of climate change in United States National Parks. *Environ. Res. Lett.* 13:104001. doi: 10.1088/1748-9326/ aade09
4. Panda, S. K., Marchenko, S. S., and Romanovsky, V. E. 2016. *High-resolution permafrost modeling in the arctic network of national parks, preserves and monuments*. Natural Resource Report NPS/ARCN/NRR-2016/1366. Fort Collins, Colorado: National Park Service. Available online at: `https://irma.nps.gov/DataStore/Reference/Profile/2237720`.

5. Swanson, D. K., Sousanes, P. J., and Hill, K. 2021. Increased mean annual temperatures in 2014–2019 indicate permafrost thaw in Alaskan national parks. *Arct. Antarct. Alp. Res*. 53:1. doi: 10.1080/15230430.2020.1859435

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## YOUNG REVIEWERS

**ARIA, AGE: 9**

I live next to Yellowstone. My dad is a scientist and my mom is a tour guide. We can go into Yellowstone whenever we want!

**MOAB CHARTER SCHOOL, AGES: 11–12**

We are a unique human sixth grade class in Moab, Utah. We consist of seven students with interests such as rocks, Minecraft, longboarding, cosplay, animals, and dirt biking. Our favorite subjects are math and science and we also like doing community service projects. We enjoy living in and exploring the desert of southern Utah.

## AUTHORS

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frontiers FOR YOUNG MINDS

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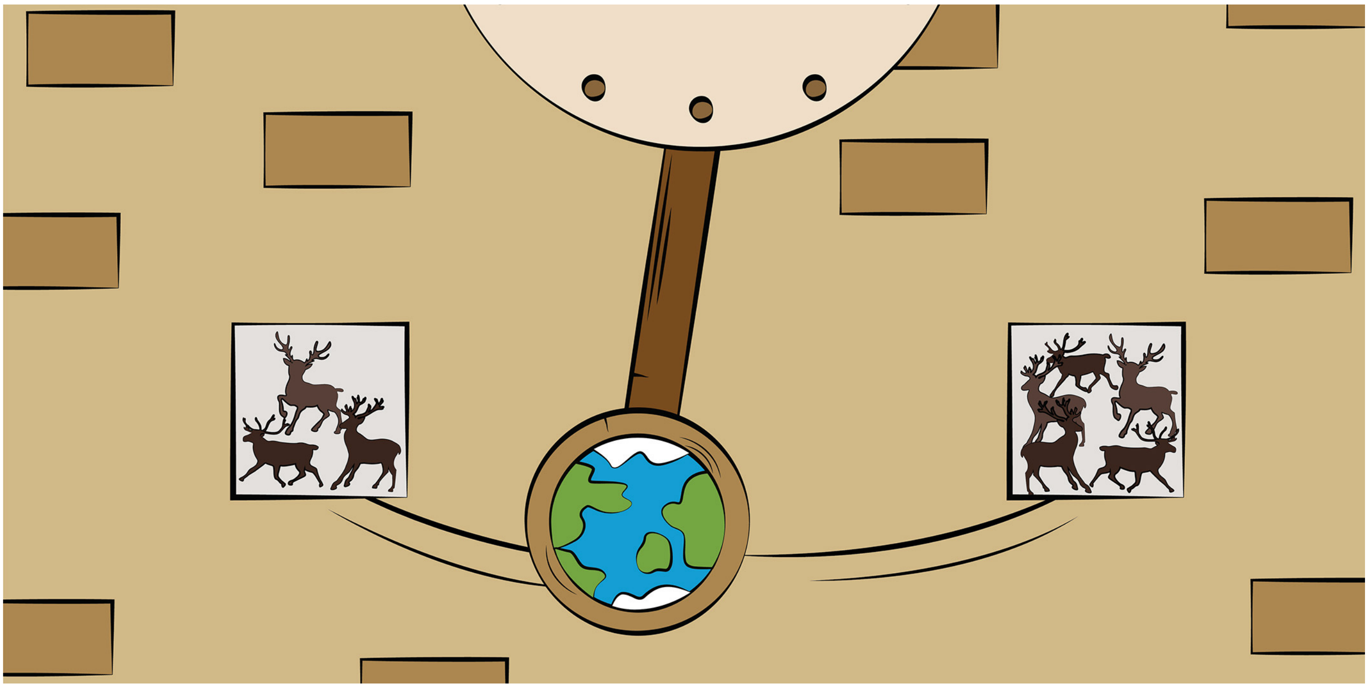

# WHAT GOES UP MUST COME DOWN: THE INFLUENCE OF CLIMATE ON CARIBOU POPULATIONS

*Kyle Joly**

*Gates of the Arctic National Park and Preserve, National Park Service, Fairbanks, AK, United States*

YOUNG REVIEWERS:

ALESSANDRO
AGE: 14

LUCY
AGE: 14

Wildlife populations naturally go up and down. Oscillation is the term used for this pattern of highs (when there are many animals) and lows (when there are few). When the number of births is greater than the number of deaths, then populations grow. If deaths exceed births, populations decline. Caribou in the Arctic have dramatic population oscillations. The number of caribou can grow very high and also decrease to very few. Large-scale, long-lasting weather oscillations are one reason for this pattern. Knowledge of the connection between wildlife populations and climate oscillations is important to help conserve species like caribou and to better understand how climate change will impact wildlife.

## INTRODUCTION

Caribou are a member of the deer family that live in northern regions across the world (Figure 1). They are well-known for their dramatic population oscillations [1]. An **oscillation** is a rhythmic pattern of low-to-high population numbers and back again, continuing endlessly

**OSCILLATION**

An endless, rhythmic pattern ranging from low to high.

Figure 1

**Figure 1**

Male (bull) caribou in Kobuk Valley National Park, Alaska, during their fall migration (Photo credit: Kyle Joly, NPS).

**POPULATION CRASH**

A rapid decline in the number of animals.

**BOTTOM-UP FACTOR**

An influence coming from food items, like plants at the bottom of the food chain, that influence animal populations. They are often dependent on the number (density) of animals.

**TOP-DOWN FACTOR**

An influence coming from predators, animals at the top of the food chain.

(Figure 2). Within just a few years, Arctic caribou herds can number in the hundreds of thousands of animals, but then decline by half or even much more. This is often referred to as a **population crash**. Upon reaching a population low, caribou herds can sharply rebound and grow quickly.

The math behind oscillations is quite simple: if there are more births than deaths, then the population goes up. If there are more deaths than births, then the population goes down. But the factors that drive population increases or decreases can be quite complicated.

## WHAT DRIVES CARIBOU POPULATION OSCILLATIONS?

If the number of births and deaths in a herd determines population oscillations, what determines the number of births and deaths? The number of births depends on the number of adult females in the herd and their physical condition. The bigger the herd, the more females there are and the greater potential for more births. For females to get pregnant, they must be in good enough condition. Body condition is determined by the quality and quantity of food. When the herd is very large, the potential number of births is high, but, at the same time, there is more competition for food. When there is more competition for food, the body condition of females can decline and not as many will give birth. This is what is called a **bottom-up factor**. It is called bottom-up because it is dependent on the *bottom* of the food chain: plants, which are food for caribou. Deaths can come from a wide range of causes. Caribou are eaten by predators, like gray wolves and brown bears, or hunted by humans for food. Predation is a **top-down factor** because the impact is coming from a higher level in the food chain. Caribou can also contract diseases, suffer malnutrition, and die in accidents, like avalanches or drownings. Accidents are random factors that are not driven by the food chain and can affect any individual. All these factors can make caribou population numbers decline. Bottom-up factors tend to be more important during population highs

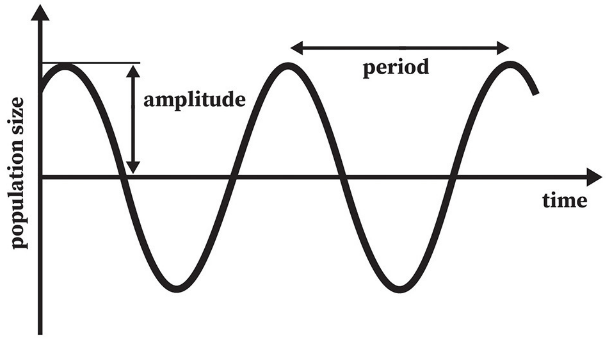

Figure 2

**Figure 2**

An illustration of oscillations. The y- (vertical) axis shows the size (for example, the number of animals in a population) and the x- (horizontal) axis represents time. The amount of time between peaks is known as the *period* of the oscillation. The height of the increase is known as the *amplitude* of the oscillation.

and top-down factors more important during population lows. When the population is low, there is less competition for food and animals can improve their body condition. Then pregnancy rates increase, and the oscillation cycle starts all over.

## OSCILLATIONS IN CLIMATE

Wildlife populations are not the only things that oscillate. There are large-scale weather patterns that oscillate, too. The most famous of these oscillations is El Niño/La Niña, known to scientists as El Niño–Southern Oscillation. Changes in water temperatures on the ocean surface affect air pressure, which affects the weather over large areas of the planet. El Niño is the warm phase, and La Niña is the cold phase [2]. This oscillation is centered in the southern Pacific Ocean. In the northern Pacific, there is a similar phenomenon called the **Pacific Decadal Oscillation**, or PDO. The PDO can strongly influence the **climate** of Alaska. As its name suggests, the PDO has a long lifespan, with oscillations lasting decades [3, 4]. The PDO has a positive (or warm) phase and a negative (or cold) phase, which bring with them changes in both temperature and the amount of precipitation.

**PACIFIC DECADAL OSCILLATION**

A persistent, large-scale weather pattern centered in the northern Pacific Ocean.

**CLIMATE**

Weather patterns over a long period of time.

## LINKING CARIBOU POPULATION AND CLIMATE OSCILLATIONS

Changes in weather, such as temperature and precipitation, impact plant growth. More plant growth equals more caribou food. But the amount and type of precipitation (rain or snow) determines how difficult it is for caribou to get to their food. Deep snow or ice layers can make it hard for caribou to dig down to ground-growing food like **lichens**. Lichens make up more than 70% of the diet of caribou in late fall and winter [5]. Thus, it makes sense that there could be a connection between climate oscillations (like the PDO) and caribou population oscillations. The largest caribou herd in Alaska is the Western Arctic Herd, which ranges over five national parks. This herd can have as many as 500,000 animals during its population

**LICHENS**

An organism made up of fungi combined with algae and/or bacteria. Lichens often grow on rocks, tree bark, or the ground.

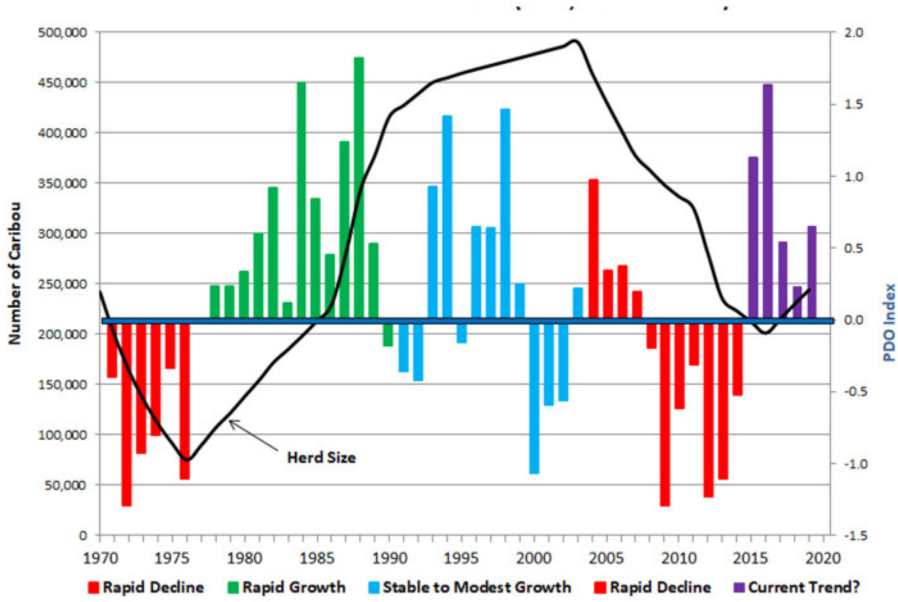


Figure 3

**Figure 3**

Relationship between the Western Arctic herd population oscillations (black line) and the large-scale climate oscillation known as the Pacific decadal oscillation (PDO; colored bars). The herd tends to increase when PDO values are positive (when it is warmer and wetter) and decline when they are negative (when it is colder and drier). These data tell us that when the PDO is positive, the herd tends to grow (green bars) and declines when the PDO is negative (red bars).

highs. An analysis looking at the swings in the PDO and the Western Arctic Herd showed that these two oscillations appear to be linked (Figure 3) [1].

## CONCLUSION

The relationships between animals and the environments in which they live can be quite complicated. Changes in ocean temperatures can affect the weather over long periods of time and huge areas. Weather impacts the bottom of the food chain (plants), which are food for caribou. More and higher-quality food can allow caribou to survive longer and produce more offspring, increasing the population. Less or poorer-quality food can reduce caribou body condition, decreasing population by lowering survival and birth rates. Food availability is also related to the number of caribou. When populations are high, there is more competition for food. Although there are many factors that impact population size, weather and climate are important to Arctic caribou. Understanding the relationship between weather and wildlife populations is important to help conserve them in a time when the climate is changing rapidly.

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## REFERENCES

1. Joly, K., Klein, D. R., Verbyla, D. L., Rupp, T. S., and Chapin, F. S. 2011. Linkages between large-scale climate patterns and the dynamics of Alaska caribou populations. *Ecography*. 34:345–52. doi: 10.1111/j.1600-0587.2010.06377.x
2. Grimm, A. M., Barros, V. R., and Doyle, M. E. 2000. Climate variability in southern South America associated with El Niño and La Niña events. *J Clim.* 13:35–58. doi: 10.1175/1520-0442(2000)013<0035:CVISSA>2.0.CO;2
3. Hartmann, B., and Wendler, G. 2005. The significance of the 1976 Pacific climate shift in the climatology of Alaska. *J Clim.* 18:4824–39. doi: 10.1175/JCLI3532.1
4. Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., and Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull Am Meteorol Soc.* 78:1069–79.
5. Joly, K., and Cameron, M. D. 2018. Early fall and late winter diets of migratory caribou in northwest Alaska. *Rangifer*. 38:27–38. doi: 10.7557/2.38.1.4107

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## YOUNG REVIEWERS

**ALESSANDRO, AGE: 14**

Hi, my name is Alessandro in Belgrade where I live and work on our family ranch with my brother. I play hockey and love the outdoors. Some activities I enjoy are hiking, fishing and sledding. My favorite subject in school is engineering and my least favorite is math. I love constructing Lego trains and tracks. My favorite season is summer. In addition to our cattle, we have 17 horses, 2 cats, a fish, and a dog.

**LUCY, AGE: 14**

I am 14 years old; I live in Montana and am in 8th grade. I enjoy playing soccer and basketball, ski, and mountain bike. I also love being outside and playing with our dog! I got involved because I love helping my dad with his work and hope to be a biologist one day.

## AUTHOR

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Kyle Joly is a National Park Service wildlife biologist. He works in all the northern Alaska national parks, researching and monitoring caribou, wolves, grizzly bears, moose, Dall's sheep, and other interesting Alaskan critters. In this photo, he is capturing a caribou calf that was swimming across the Kobuk River in Kobuk Valley National Park, Alaska, during its fall migration. Learn more at https://www.nps.gov/articles/kyle-joly-wildlife-biologist.htm. *kyle_joly@nps.gov

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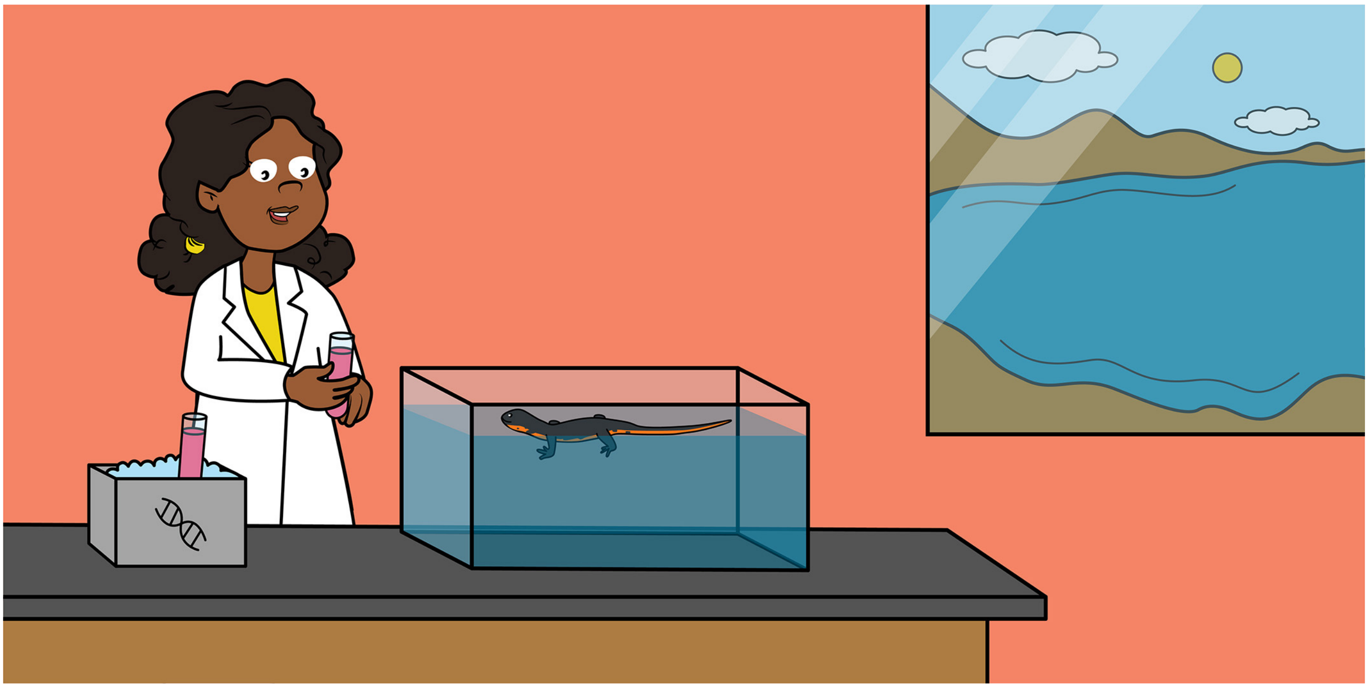

# CRACKING THE MYSTERY OF CRATER LAKE'S UNIQUE NEWTS

***Andrew M. Ray*[1*], *Stephen F. Spear*[2], *Scott F. Girdner*[3] and *David K. Hering*[3]**

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[2] *The Wilds, Cumberland, OH, United States*
[3] *Crater Lake National Park, Crater Lake, OR, United States*

YOUNG REVIEWERS:

ADELAIDE
AGE: 7

LUKE
AGE: 10

SILAS
AGE: 12

Why does Earth have such an incredible variety of plants and animals? One little newt helps tell the story. In Crater Lake, the world's clearest lake, a uniquely colored newt was discovered. Early explorers named it the Mazama newt. For more than 100 years, the newt has been considered a subspecies of the more common rough-skinned newt. A "subspecies" refers to a collection of animals or plants that can interbreed but can often be separated from other individuals of the same species by appearance. Nobody knew exactly how unique the Mazama newt was until scientists took another look. Using a mix of clues, like DNA, skin color, and even poison levels, scientists are cracking the mystery of how the Mazama newt differs from its neighbors. Learning about the newt's unique characteristics and about other members of the Crater Lake ecosystem is important for protecting biodiversity and lake health.

## SO MANY SPECIES ... SO MANY ENVIRONMENTS

For centuries, scientists have been cataloging Earth's species. Tens of thousands of new species are discovered each year. Some scientists believe the Earth contains 8–10 million species [1]. Plants and insects have the largest variety of species within the macroscopic (large enough to see with our eyes) groups of life. Tropical forests and coral reefs are the most species-rich places on Earth.

The vast number of species shows that Earth contains an unimaginably large number of habitats. These various habitats provide conditions that support the life of one or many species. Different conditions influence where a species can feed, live, grow, and reproduce and do so for generations. Throughout Earth's history, disturbances like earthquakes, fires, and floods have been destroying habitats and removing species. At the same time, disturbances create new habitats for species to colonize. Some disturbances create barriers that prevent groups of animals from the same species from interacting. Scientists call isolated groups of the same species **populations**.

**POPULATION**

A group of individuals of the same species that can interbreed and exchange genetic information. Populations are often isolated from each other.

If two groups of a single species are separated long enough, new species can evolve. This process takes many thousands of years. It occurs when separation prevents individuals from the same species from breeding and exchanging **genes**. Genes are unique regions of DNA that code for the **traits** (physical characteristics) of organisms. Genes can be used to understand how individuals or populations are related. When populations are separated for many generations, genes, traits, and behaviors become different between the two groups. As disturbances on earth occur, so too will the separation of populations and the evolution of new species.

**GENE**

A specific sequence of DNA that is transferred from a parent to offspring and contributes to characteristics of the offspring.

**TRAIT**

A characteristic, like color, passed on from parents to offspring.

## VOLCANOES, EARTHQUAKES, AND FLOODS ... OH MY!

Volcanoes, earthquakes, floods, melting glaciers, and fires are disturbances that dramatically change habitats. Volcanoes, like Mt. St. Helens, explode, rearrange mountain tops, and deposit ash over large areas. Melting glaciers uncover ground that has not been exposed for thousands of years. Humans also play a role in the creation of habitats. Dams are built, holding back rivers to create lakes in previously dry areas. Disturbances can create new habitats that species can move into.

In Crater Lake National Park, a massive volcanic eruption removed the top of a mountain to create present-day Crater Lake. This started 30,000 years ago, when Mt. Mazama began erupting and changing the landscape where the park now sits. After the last major eruption 8,000 years ago, and with its magma chamber nearly empty, Mt. Mazama collapsed. It left a crater, called a **caldera**, 8–10 km wide and over 1 km deep. Over the next 1,000 years, snowmelt accumulated and formed

**CALDERA**

A crater formed by a major volcanic eruption that causes the collapse of the mouth of the volcano.

a lake within the caldera—Crater Lake (Figure 1). This lake was isolated from surrounding lakes and nestled within the tall, steep walls of the former volcano's crater. Animals and plants colonized this new habitat, and this is how the story of the Mazama newt began.

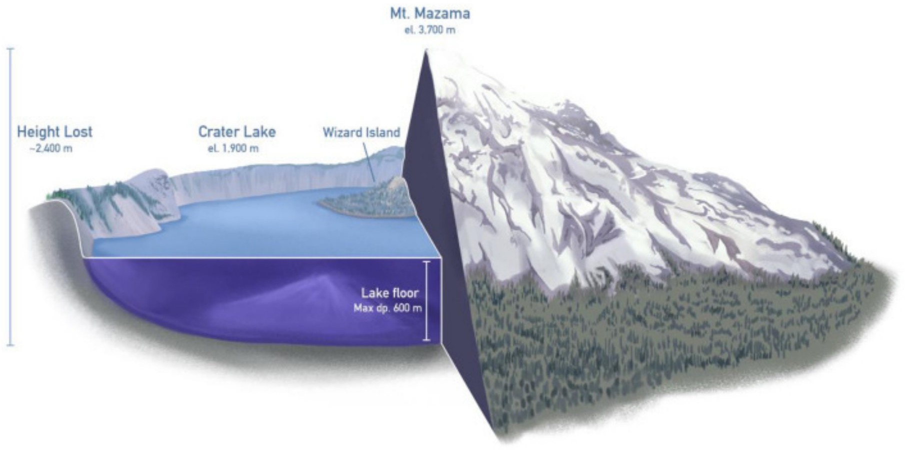


Figure 1

**Figure 1**

On the right is an artist's imagined view of Mt. Mazama, a mountain that stood approximately 3,700 m tall in southwest Oregon, USA, before it erupted and collapsed nearly 8,000 years ago. The Crater Lake caldera was formed from this collapse. On the left is a cross-sectional view of Crater Lake today. After the Crater Lake caldera formed, additional eruptions formed Wizard Island. Wizard Island and other volcanoes continue to grow to this day—one of which is shown underwater in this image (Image credit: Elena Hartley at www.elebarts.com).

**SUBSPECIES**

In taxonomy, subspecies is a classification that falls within species. Subspecies can interbreed but can often be separated from other individuals of the same species by appearance or genetic information.

## THE MAZAMA NEWT

Early park naturalists focused on one particular Crater Lake colonizer. They noted the unique appearance of Mazama newts and thought that they were a **subspecies** of rough-skinned newts [2]. Subspecies are related species that can interbreed but can typically be distinguished by differences in appearance and DNA sequence. Rough-skinned newts are a common species across the U.S. Pacific Northwest and Canada, from central California to southeast Alaska. Rough-skinned newts are brown on top with a bright, orange-colored underbelly (Figure 2). The orange belly warns others that the newt is poisonous. That is right, the skin of rough-skinned newts contains a deadly poison (called tetrodotoxin) that protects them from predators, including garter snakes. Outside the caldera, rough-skinned newts spend summers in small ponds eating insects. They spend winters in the forest, inside rodent burrows. In high-elevation lakes like Crater Lake, rough-skinned newts have adapted to overwinter within the lake itself!

The current hypothesis for how the Mazama newt evolved is that nearby rough-skinned newts entered the newly formed lake after the dust from the Mt. Mazama explosion had settled. Because of the steep walls of the crater, newts that entered likely did not migrate back out. This means that two groups of rough-skinned newts were separated. The group within the crater began accumulating differences in genes, traits, and behaviors that allowed those newts to survive in Crater Lake, a very different habitat from the one in which their ancestors lived.

Figure 2

Figure 2
Examples of the coloration patterns on the belly of a Mazama newt from Crater Lake (left) and a rough-skinned newt from nearby Spruce Lake, Oregon (right).

We used a series of clues to test the hypothesis that Crater Lake's newts are different from newts in ponds and lakes outside of the caldera. Specifically, we compared the orange belly color [3], which advertises the newts' toxicity, as well as the newts' weight-to-length ratio, which is an indicator of their health. We also compared the poison levels between groups of newts [4]. Additionally, we explored information locked inside newt DNA. While biologists have used clues like color and size for centuries to separate species or populations, genetic tools provide even more powerful clues. Exploring the DNA code can uncover similarities and differences among populations based on their shared history. Think of a family tree that goes back thousands of years!

## CRATER LAKE'S NEWTS ARE … DIFFERENT

Crater Lake's newts have darker bellies, often with black leopard-like splotches or tar-like smears (Figure 2). Newts in Crater Lake are also skinnier compared to newts in habitats outside of the caldera. Interestingly, tetrodotoxin levels in Crater Lake newts are among the lowest levels measured.

Traits such as weight, color, and poison levels are signs that Crater Lake newts might indeed be an unusual group. Such differences can also be due to different environments even within the same population. The evidence that most clearly tells us that Crater Lake newts are different from all other rough-skinned newt populations can be seen by looking at their genes. Every gene has multiple forms that are slightly different in their genetic code. These differing forms of the same gene are called **alleles**. Groups of newts that are closely related will have similar combinations of alleles. A population of newts that is isolated will have a different set of alleles common to that population. The most common alleles in newts in Crater Lake are different from those of newts anywhere else in Oregon (Figure 3)! In fact, we can tell if a newt came from Crater Lake just by looking at these genetic clues. This is even more striking because all other rough-skinned newts sampled in Oregon tend to be similar genetically, even from ponds hundreds of kilometers apart.

**ALLELE**

Alternative forms of a gene resulting from small changes found at the same place on the chromosome of different individuals.

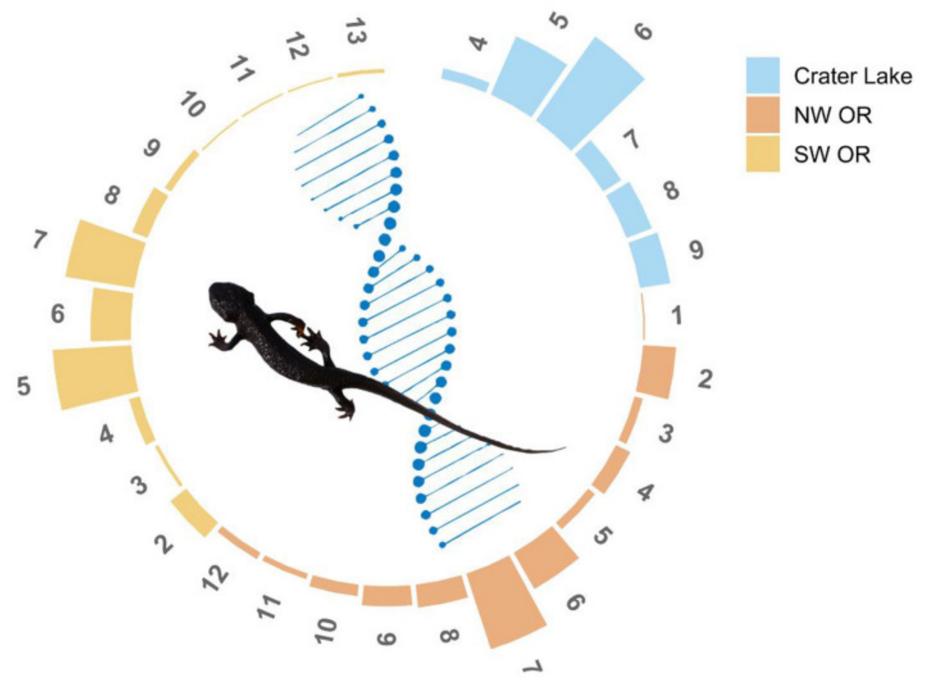


Figure 3

**Figure 3**

Separation between newt populations created differences in the number and relative proportion of individual alleles within each population. The circular bar graph shows alleles at a single gene for three newt populations: Crater Lake, southwest Oregon (SW OR), and northwest Oregon (NW OR). Individual alleles are represented by a numbered bar. Taller bars indicate a greater proportion of that allele relative to other alleles. Crater Lake newts have fewer alleles (fewer bars) and there is a greater proportion of allele 6 compared to other areas. Although this example shows one gene, scientists typically use many genes to describe genetic isolation.

## DIFFERENT, BUT HOW DIFFERENT?

Differences in traits like color, weight, and poison levels show that newts in Crater Lake have adapted to conditions in Crater Lake. In nature, small variations in traits and genetic codes are expected among individuals or populations. However, the stark differences reported here are evidence that individuals from different populations of the same newt species are not regularly interbreeding and exchanging genes.

When breeding is prevented by a barrier, like a mountain top or a highway, differences in characteristics, behaviors, or allele numbers and proportions can change over time. In the case of the Mazama newt, the steep, rocky caldera walls may have served as a natural barrier. We hypothesize that the near-vertical walls blocked all but an occasional newt from trekking down into the lake. Our DNA data suggest that this trek *into* the lake *does* rarely happen, but the reverse scenario, in which newts from Crater Lake move up the caldera walls to breed in outside ponds, does *not* happen.

So, if Mazama newts are measurably different than rough-skinned newts but they are *not* a different species, then what are they? We believe that the differences described here are representative of an isolated population adapted to local conditions—conditions present only within Crater Lake. Adaptations to unique conditions are called **adaptive variation**. Isolation of newts within Crater Lake means that the alleles of the Crater Lake newt population are accumulating measurable differences, generation after generation. Since this population is still part of the wide-ranging rough-skinned newt species, it also means that Crater Lake's newts are expanding the overall **genetic diversity** for this species. This increased genetic diversity may be slight, but genetic diversity is a component of the overall biodiversity of national parks. Biodiversity, the total number of genes, species, and habitats of an area, is important because it provides a measure of ecosystem health and protecting genetic diversity helps species to better survive changing environments especially with ongoing climate change. In Crater Lake, dark-colored newts have confused scientists for more than a century, but now we better understand how a volcanic disturbance added to the genetic diversity of rough-skinned newts.

**ADAPTIVE VARIATION**

Genetically linked variation in color patterns and other traits that contributes to differences in survival and reproduction among individuals in the wild.

**GENETIC DIVERSITY**

The diversity of alleles at genes present within a species.

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## REFERENCES

1. Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G. B., and Worm, B. 2011. How many species are there on earth and in the ocean? *PLoS Biol.* 9:e1001127. doi: 10.1371/journal.pbio.1001127
2. Farner, D. S., and Kezer, J. 1953. Notes on the amphibians and reptiles of Crater Lake National Park. *Am. Midl. Nat.* 50:448–62.
3. Buktenica, M., Girdner, S., Ray, A., Hering, D., and Umek, J. 2015. The impact of non-native crayfish on a unique population of salamanders in Crater Lake, Oregon. *Park Sci.* 32:5–12. Available online at: `https://www.nps.gov/ParkScience/articles/parkscience32_1_5-12_buktenica_et_al_3815.htm`
4. Stokes, A. N., Ray, A. M., Buktenica, M., Gall, B. G., Paulson, E., Paulson, D., et al. 2015. Otter predation on *Taricha granulosa* and variation in tetrodotoxin levels with elevation. *Northwest. Nat.* 96:13–21. doi: 10.1898/NWN13-19.1

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## YOUNG REVIEWERS

**ADELAIDE, AGE: 7**
My name is Adelaide and I love to ski, camp, hike, and bike. I also love arts and crafts and my favorite color is blue. I love stuffed bears, cats, and dogs. I love to paint, and I want a dog. I love to be outside.

**LUKE, AGE: 10**
I like skiing, mountain biking, and fishing. I like legos and getting dirty. My favorite subject in school is math and I want to be a scientist when I grow up.

**SILAS, AGE: 12**
I really like to ski and snowboard. I also really like hanging out with friends and playing video games. I love music, so I play piano and drumset. My favorite subject in school is language arts.

## AUTHORS

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Andrew M. Ray is an ecologist with the National Park Service's Greater Yellowstone Network in Bozeman, Montana. Andrew received his B.S. from Purdue University, an M.S. from Northern Michigan University, and a Ph.D. from Idaho State University.

He previously worked as the science coordinator with the Crater Lake Science and Learning Center, where he helped document the distinguishing characters of a population of rough-skinned newts in Crater Lake. He now coordinates long-term monitoring of wetlands and amphibians in Yellowstone and Grand Teton National Parks. *andrew_ray@nps.gov

**STEPHEN F. SPEAR**

Stephen F. Spear is a research biologist with the USGS Upper Midwest Environmental Sciences Center in La Crosse, Wisconsin. Before that, Stephen worked as director of wildlife ecology at The Wilds in eastern Ohio, and as a conservation scientist with the Orianne Society in Georgia. He also serves as the co-chair of the IUCN Viper Specialist Group. He earned his Ph.D. from Washington State University in 2009 and a M.S. from Idaho State University in 2004; both his dissertation and thesis focused on using genetic diversity to understand how amphibians are affected by natural and human-caused disturbance.

**SCOTT F. GIRDNER**

Scott F. Girdner is an aquatic biologist at Crater Lake National Park, Oregon, where he manages a long-term lake-monitoring program of the deepest lake in the United States and one of the clearest lakes in the world. He began his studies of inland waters at the Institute of Limnology in Uppsala, Sweden while getting a B.S. in biology from Chico State University. Scott received his M.S. from Oregon State University, studying high mountain lakes in Mount Rainier National Park, Washington. His work revolves around mountain lakes and using long-term monitoring of protected areas for answering scientific questions.

**DAVID K. HERING**

David K. Hering is an aquatic ecologist at Crater Lake National Park. His interests include life history diversity and behavior of freshwater fish, the effects of invasive species, and conservation of native fish and amphibians. For 14 years, Dave has worked to protect imperiled populations of trout in Oregon's Upper Klamath Basin. His work emphasizes collaborative partnerships to accomplish ecological restoration. Dave recently assisted a project to restore an alpine lake ecosystem in Slovenia. He holds a M.S. in fisheries science from Oregon State University. Dave lives in Ashland, Oregon with his wife and two daughters, who also enjoy science.

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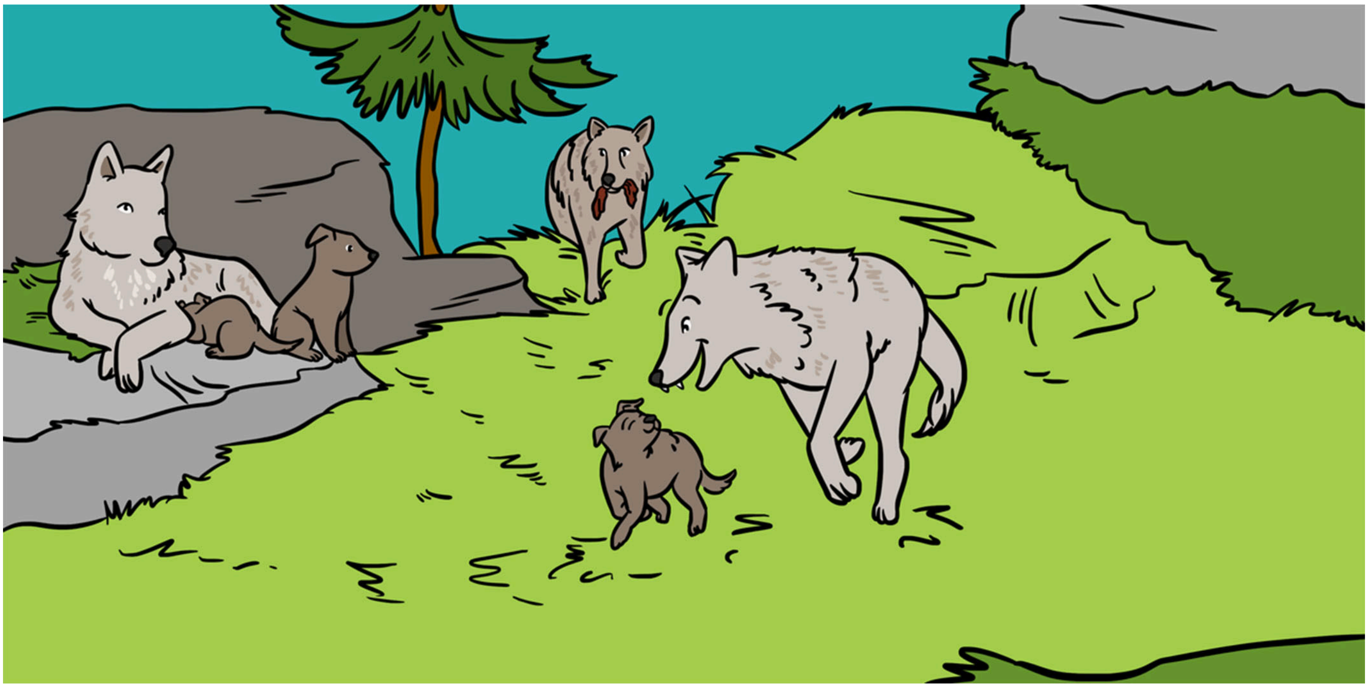

# IT TAKES A PACK TO RAISE A PUP

***Mathew Sorum*[1*], *Jordan Pruszenski*[1] *and Bridget L. Borg*[2]**

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YOUNG REVIEWERS:

7TH GRADE CLASS OF HEADWATERS ACADEMY

AGES: 12–13

PARKER

AGE: 11

Wolves are important to keep ecosystems healthy. For wolf populations to thrive, pups need to survive into adulthood. Wolf pups can be harmed, even killed, by wolves from outside their pack. To protect the pups, some wolves in the pack must stay at the den and guard the pups. But some of the adults must leave the den sometimes, to hunt for food and to keep other wolves out of the pack's territory. By monitoring and studying wolves for many years across North America and in Alaska's national parks, we are learning how wolves divide these tasks. We know that the mother wolves care for their pups for the first several weeks while nursing, but once the pups no longer need milk, all pack members share in taking care of the pups. We have come to understand that all wolves are important to the success of the pack.

## LIVING IN A PACK IS HOW WOLVES SURVIVE

Wolves are considered **keystone species** because they have a large effect on many other species—both plants and animals—within the

**KEYSTONE SPECIES**

A species on which other species in an ecosystem largely depend, such that if it were removed the ecosystem would change drastically.

**ECOSYSTEM**

A biological community of interacting organisms and their physical environment.

**ecosystem**. Wolves help regulate the numbers of their prey, such as deer, caribou, and moose, which helps prevent these prey animals from overgrazing the plants they need to survive.

Wolves are very social animals. They live and hunt together in groups called packs. A pack is usually made up of an adult male and female wolf, their offspring of various ages, and sometimes unrelated wolves, too. Pack sizes often range from 3 to 20 wolves. There are two pack leaders, one female and one male, and they are generally the only wolves in the pack that breed and produce pups. Litter sizes are often between two and six wolves. The breeding pair are not the only ones that care for the pups. In fact, all the wolves in the pack help [1]. This is important because it takes a lot of energy to feed and care for pups.

**WEANED**

The period when wolf pups are transitioned from mothers' milk to semi-solid foods.

As wolf pups grow, they eat different kinds of foods. Pups are born in the spring (April to May) and during the first 7 weeks of their lives, pups nurse from the mother (Figure 1). During that time, the mother wolf spends a lot of time feeding and caring for the pups [1]. The pups are **weaned** around 7 weeks of age, which means the mother wolf no longer provides milk. Instead, the pups are fed meat, which is brought to them by pack members because the pups are too small to hunt for themselves.

Figure 1

**Figure 1**

Mother wolf nursing pups in Denali National Park and Preserve, in Alaska USA/NPS photograph.

**DEN**

The location, often a hole in the ground that wolves dig, where wolf pups are birthed and raised for the first couple months of their lives.

Pack members spend a lot of time protecting and caring for the pups, too. Wolf pups can be harmed and even killed by wolves from other packs. So, it is important that a pack member stays near the **den** with the pups. This also gives the pack members an opportunity to interact and play with the pups, which is important for the pups' development (Figure 2). By spending time with pack members, the pups learn how to socialize with other wolves and, as they get older, they learn other important lessons, like how to hunt.

Figure 2

**Figure 2**

Pack members guarding and playing with pups in Denali National Park and Preserve/NPS photograph.

## LEARNING ABOUT WOLVES

Wolves have been studied across North America since 1950's, including in national parks across the United States, such as Yukon-Charley Rivers National Preserve and Denali National Park and Preserve in Alaska, in Yellowstone National Park in Wyoming, and in Isle Royale National Park in Michigan. In Alaska's national parks, wolves are monitored to assess the health of the park's ecosystem. These studies count how many wolves there are and where they go. With this information, biologists can identify important areas used by wolves, like dens, and understand what kinds of food wolves need to be healthy. The studies also reveal how much time various pack members spend guarding the pups. Biologists can do this by following the movements of wolves with **GPS collars**. The collars record the location of each wolf over time. From this information, biologists can see how long each wolf is at the den with the pups and how long it is away.

**GPS COLLARS**

Collars placed on animals that have GPS tracking so biologist know where animals are.

## MOM DOES A LOT, BUT EVERYONE HELPS

To grow up and become healthy and strong pack members, pups need food, and they need to be cared for. Pack members must leave the den to hunt food for the pups and themselves. Often, they are gone for a few days. Wolves take turns hunting and guarding the pups. While some wolves are hunting, other pack members stay at the den and take care of the pups. That way, all the wolves get enough food, and the pups are kept safe.

From monitoring wolves in Yukon-Charley Rivers National Preserve, biologists learned that the mother wolf stayed in the den with the pups for the first 8 days of their lives, on average. She only left the den to drink water and defecate (poop). Over the first 2 weeks, the mother wolf stayed very close to the den and almost never traveled farther than 1 km (about 0.6 mi) away [2]. After that, the mother wolf traveled farther from the den to hunt for food for herself and the pups.

From several other study areas, including Yellowstone National Park, biologists learned that the mother wolf spends the most time guarding and caring for the pups during the first several weeks [3, 4]. On average, the mother wolf spends two-thirds of her time with the pups—about 16 h a day (Figure 3) [3, 4]. Once the pups no longer need milk, all pack members share more equally in the duties of guarding the pups. Most pack members spend about one quarter of their time with the pups, or on average about 6 h per day (Figure 3) [3, 4]. They spend the remaining time either hunting or patrolling the pack territory.

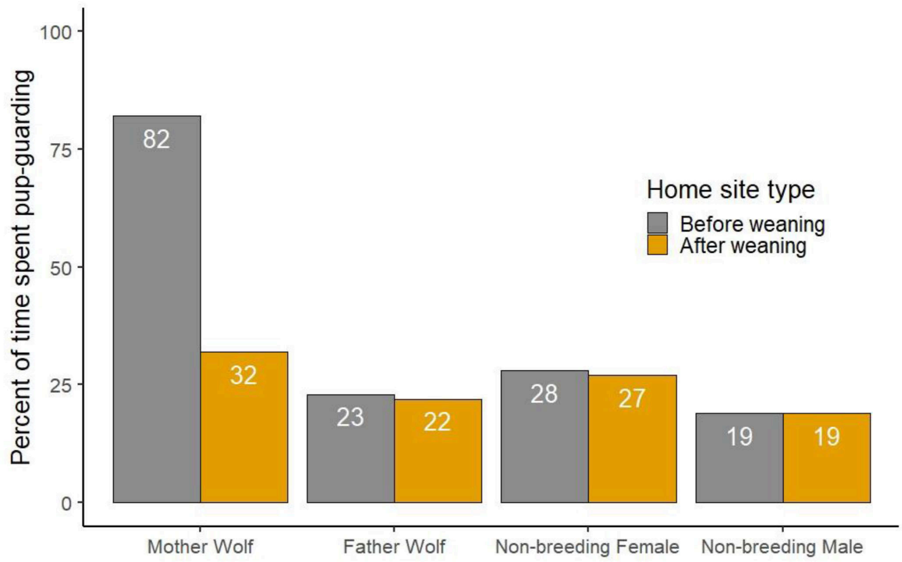


**Figure 3**

Average percent of time each wolf pack member spends (mother, father, non-breeding female, non-breeding male) caring for the pups before the pups are weaned from the mother's milk and after weaning, when the pups are able to eat other food. The mother spends most of her time with the pups until they are weaned, but after that, other pack members share the pup-raising duties. These data are based on studies of wolves in North America.

## WHY IS SPENDING TIME WITH PUPS IMPORTANT?

The health and survival of wolf pups depends on pack members working together to help feed, protect, and care for pups. It takes a lot of energy to raise pups and one wolf could not do it all. When the responsibility of gathering food and patrolling the territory is shared among pack members, this allows adult wolves to spend more time bonding with the young pups and teaching them how to socialize and become helpful pack members. Strong packs help maintain a healthy wolf population which, in turn, helps maintain healthy populations of other species across the ecosystem. Ultimately, when all pack members help to raise the pups, they are also helping to protect the ecosystem and parks where the wolves live.

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## REFERENCES

1. Mech, L. D., and Boitani, L. (Eds.). 2007. *Wolves: Behavior, Ecology, and Conservation*. Chicago: University of Chicago Press.
2. Joly, K., Sorum, M. S., and Cameron, M. D. 2018. Denning ecology of wolves in east-central Alaska, 1993-2017. *Arctic* 71:444–55. doi: 10.14430/arctic4749
3. Ruprecht, J. S., Ausband, D. E, Mitchell, M. S., Garton, E. O, and Zager, P. 2012. Homesite attendance based on sex, breeding status, and number helpers in gray wolf packs. *J. Mamm*. 93:1001–5. doi: 10.1644/11-MAMM-A-330.1
4. Ausband, D. E, Mitchell, M. S., Bassing, S. B., Morehouse, A., Smith, D. W., Stahler, D., et al. 2016. Individual, group, and environmental influences on helping behavior in a social carnivore. *Ethology* 122:963–72. doi: 10.1111/eth.12566

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## YOUNG REVIEWERS

**7TH GRADE CLASS OF HEADWATERS ACADEMY, AGE: 12–13**

The 7th grade class of headwaters academy, with all of its eccentricities, is a humorous and adventuresome community. Located in Bozeman, Montana, our class is made up of great backgrounds of both sport and mind. Our community, built to create leaders and learners for a changing future, has allowed us to thrive and develop in our beautiful ecosystem, though it allows us to look upon the world in a different way: to know what should be and how to improve upon what is.

**PARKER, AGE: 11**
I love hiking and hunting with family, I also like climbing and bouldering.

## AUTHORS

**MATHEW SORUM**
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**JORDAN PRUSZENSKI**
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**BRIDGET L. BORG**
Bridget L. Borg is a US National Park Service wildlife biologist. She studies wolves, caribou, and Dall's sheep in Denali National Park and Preserve. Learn more at `https://www.nps.gov/articles/000/bridget-borg.htm`.

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# MONITORING THE MIGRATORS: TRACKING THE ANIMALS PASSING THROUGH OUR PARKS

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YOUNG REVIEWERS:

EDNA
AGE: 8

YANA
AGE: 15

Migrating animals are good at making long trips between seasons. These trips can be dangerous, and scientists monitor migrators in United States National Parks to help detect dangers and find solutions. However, migrators are challenging to monitor. Sometimes they only stay in a park for a few days. This might require a scramble to find them during the proper season, using specialized techniques. It is worth the effort! Birds are some of the best-known migrators, and birdwatchers come to parks every spring to help count them. Migrating butterflies and bats are less well-known and require more effort to monitor. Monarch butterflies are tagged with special numbered stickers, and bat calls are recorded at night with special computers. These monitoring activities reveal where, when, and how many migrators occur in parks. If we discover through monitoring that they are in decline, we can sound the alarm and get help for these special animals.

## PARKS ARE IMPORTANT HOMES FOR MIGRATORS!

Migration is a remarkable behavior performed by many kinds of animals. Just like people who head to warmer climates before the cold winter months, many animals use long-distance migration to escape harsh weather. Sometimes migrators are escaping difficult seasons when food is scarce. Did you know that some birds, such as the common nighthawk and arctic tern, travel thousands of miles every spring and fall, between North and South America? Hummingbirds, no heavier than a handful of paper clips, fly across the Gulf of Mexico in a single trip. Other famous long-distance travelers include the hoary bat and the monarch butterfly.

In North America, migrators rely heavily on **United States National Parks** and other protected habitats that offer abundant food and shelter. In fact, depending on the location, migrators use parks for every stage of migration: wintering grounds, spring and fall migration stopovers, and summer breeding grounds. Migrators are important members of animal communities inside these national parks.

**UNITED STATES NATIONAL PARKS**

The National Park Service in the United States consists of over 300 parks, monuments and historic sites such as war memorials and battlefields. The National Park Service began with the creation of Yellowstone National Park and was formally established by the US Congress in 1916 with the passage of the 1916 Organic Act.

## MIGRATORS LIVE TOUGH LIVES BUT WE CAN HELP!

Migration takes an extraordinary amount of energy, and traveling such long distances is dangerous. Many migrators do not survive the trip! This is one reason that migrating species are often considered rare and at risk of decline. Many need our attention. Furthermore, sometimes our visiting migrators spend time during the off-season in habitats unseen by us that are no longer healthy for them. These degraded habitats may contribute to population declines that we can observe as migrators move through United States National Parks—we need to count the migrators passing through parks each year to be sure that the same number are returning. This helps us detect worrisome declines and sound the alarm.

For example, in the early 1990s, concern grew among the scientists and community members that count migrating hawks in the spring and fall each year, in places like Golden Gate National Recreation Area in California, Grand Canyon National Park in Arizona, and Acadia National Park in Maine. They noticed that one species, the Swainson's hawk, was in big trouble. Swainson's hawks travel thousands of miles each year between their wintering grounds in Argentina, South America, and their summer nesting areas in the grasslands of western North America! It turned out that thousands of Swainson's hawks were dying during winter in Argentina from eating grasshoppers full of toxic farm chemicals called pesticides [1]. This discovery allowed for safer pesticides to be used to grow food in Argentina and around the world.

## WE COUNT MIGRATING BIRDS IN NATIONAL PARKS!

Birds are one beloved group of animals that we count in national parks. Every year, bird watchers assist professional **ornithologists**, the scientists that study birds, to track birds in these parks (Figure 1). In spring, we count the brightly colored warblers, tanagers, hummingbirds, and orioles that winter in Central and South America and pass through parks on their way to raise babies during the summer in North America. We call these birds **neotropical migrants**. Because so many neotropical migrants eat insects or flowering plant parts (like nectar, fruit, and seeds), they are forced to follow their food supply south when winter arrives. Flying up to a mile above the ground, often at night, some neotropical migrants end up traveling several thousand miles to their destinations. To power their long journeys, they fatten up just before traveling.

**ORNITHOLOGIST**

A scientist that specializes in the study of birds.

**NEOTROPICAL MIGRANTS**

Species of birds, butterflies, bats and other migratory organisms that spend part of their year in tropical America (e.g., countries in Central America such as Panama).

Figure 1

**Figure 1**

Young minds at work! Youth assistants participate in a hawk watch event during migration season in Golden Gate National Recreation Area (California, United States; photo credit: Alison Taggart-Barone, Parks Conservancy).

We also count the birds that spend their winters in national parks. Every December, parks across the United States host the annual Christmas Bird Count. For example, in California's Yosemite National Park, this annual count started in 1932! We use the many years of data to understand how bird populations have changed over time. Sometimes we find surprises—hummingbirds or other neotropical migrants that never left for winter, or arctic birds like the snowy owl that are pushed southward into parks outside the Arctic during strong storms.

## WE TAG BUTTERFLIES IN NATIONAL PARKS!

Monarch butterflies migrate from parks such as Great Smoky Mountains National Park to the mountains of Central Mexico and back again. This is a very unusual way for a butterfly to survive harsh winters. In fact, the monarch is the only butterfly species known for round-trip migration. Other species of butterflies survive the winter in cold places just by staying put, as eggs, or as babies in a protective shell, called **pupae**. Monarchs depend on one type of plant, the milkweed, to feed their young (which are caterpillars). Conserving milkweed along

**PUPAE**

Pupae is a significant life cycle stage of insects.

roadsides and farmlands is one of the most important ways to help monarch butterflies.

**ENTOMOLOGIST**

A scientist that specializes in learning about insects, therefore also butterflies.

Every year, professional **entomologists** (scientists that study butterflies and other insects), assisted by community volunteers, work together to gently catch, tag, and release thousands of monarch butterflies. Can you believe that such delicate little animals can actually be tagged? While GPS tracking devices can be fitted on some larger animals, the monarch tag is a lightweight, numbered sticker placed on the butterfly's delicate wing (Figure 2). It does not transmit information like a GPS tracker. Instead, any entomologist lucky enough to catch the monarch again during a survey can learn where it came from by reading the tag. This is how we learn the monarch butterfly migration routes [2]. Armed with this information about migration routes, we can then protect milkweed plants along the route.

Figure 2

**Figure 2**

A monarch butterfly with a wing tag, Great Smoky Mountains National Park (North Carolina and Tennessee, United States; photo credit: Great Smoky Mountains Institute at Tremont).

## WE EVEN RECORD THE CALLS OF BATS IN PARKS!

**HIBERNATE**

Some mammals, including bats, hibernate to survive during winter by lowering body temperature, reducing bodily functions, and using stored fat reserves.

Over 50 species of bats occur in U.S. national parks! During the winter, some bats **hibernate** in caves, but other bats migrate south to avoid the cold winters. Some of our most widespread migrating bat species include the hoary bat, the red bat, and the silver-haired bat. These three insect-eating species raise their babies, called pups, during summer in parks all across the northern U.S. and southern parts of Canada. They then head south into the southern U.S. and Mexico during winter, to have a steady supply of mosquitoes, flies, and moths to eat.

**ECHOLOCATION**

The process used by bats and other mammals, including dolphins, to make noises using their voice boxes and then listen to their own echoes to navigate and chase down prey.

How do scientists monitor bats? The answer begins by understanding bat **echolocation**. Did you know that most bats find their way in the dark and chase down insect prey by shouting? It is true! Well, most do not shout—they whisper—but they are all making noises with their voice box, just like humans and other mammals do. We do not hear bats making these calls because they call at such high pitches, or frequencies. We describe bat calls as echolocation because they make high-frequency calls and listen for the echoes of their own calls. They use those echoes to avoid objects in their path, such as rocks, trees, and even other bats. They also use echoes to chase down and catch flying insects, like mosquitoes and moths. With special weatherproof computers and microphones tuned to high-frequency bat calls, we can hear and record those calls (Figure 3).

Figure 3

**Figure 3**

Scientists set up a bat "detector" to record echolocation calls in Smith Rocks State Park (Oregon, United States) as part of the North American Bat Monitoring Program. Note the microphone at the top of the tall pole (photo credit: Oregon State University-Cascades).

Scientists have joined together all across North America to form a team called the North American Bat Monitoring Program. This team records bats both inside and outside of parks during summer [3]. Recorded bat calls can tell us where and when bats occur. Over time, we can discover if a species like the hoary bat is occurring in fewer places because of habitat loss and disease or occurring in new places because of a changing climate [4]. Bats are very sensitive to changes in their environments. Climate changes that result in more long dry spells, shortened winters, and earlier springs can force bats to shift their ranges northward. These kinds of changes can also prevent bats from finding enough food to store as fat reserves to survive hibernation and raise pups.

## CONCLUSION

United States National Parks are home to a dizzying array of animal life. We monitor the populations of as many animals as we can, including the migrators that do not stay very long. Some of these migrators turn out to be very sensitive to changes in the environment, including increases in chemicals like pesticides, loss of important food plants like milkweed, and changing climates. Monitoring migrators not only helps us to understand and protect them but also to detect big changes in the environment.

Monitoring birds, butterflies, and bats is fun and not just for professional scientists. People of all ages and backgrounds can join birdwatching and butterfly-tagging outings. With a bit of extra effort, you can even learn how to operate a bat echolocation recording computer and assist the North American Bat Monitoring Program. In some parts of the country, we have bats that make low-pitch calls that can easily be heard without a special computer. We monitor these deeper-voiced bats just by listening for them [5]. Find your nearest park and come give us a hand!

## REFERENCES


1. Goldstein, M. I., Lacher, T. E., Zaccagnini, M. E., Parker, M. L., and Hooper, M. J. 1999. Monitoring and assessment of Swainson's hawks in Argentina following restrictions on Monocrotophos use, 1996-97. *Ecotoxicology* 8:215–24. doi: 10.1023/A:1026448415467
2. Inamine, H., Ellner, S. P., Springer, J. P., and Agrawal, A. A. 2016. Linking the continental migratory cycle of the monarch butterfly to understand its population decline. *Oikos* 125:1081–91. doi: 10.1111/oik.03196
3. Reichert, B. E., Bayless, M., Cheng, T. L., Coleman, J. T. H., Francis, C. M., Rodhouse, T. J., et al. 2021. NABat: a top-down, bottom-up solution to collaborative continental-scale monitoring. *Ambio* 50:901–13. doi: 10.1007/s13280-020-01411-y
4. Rodhouse, T. J. Rodriguez, R. M., Banner, K. M., Ormsbee, P. C., Barnett, J., and Irvine, K. M. 2019. Evidence of region-wide bat population decline from long-term monitoring and Bayesian occupancy models with empirically informed priors. *Ecol. Evol.* 9:11078–88. doi: 10.1002/ece3.5612
5. Rodhouse, T. J., Rose, S., Hawkins, T., and Rodriguez, R. M. 2021. Audible bats present opportunities for citizen scientists. *Conserv. Sci. Practice* 2021:e435. doi: 10.1111/csp2.435



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## YOUNG REVIEWERS

### EDNA, AGE: 8

Edna is a curious 8 year old girl who is interested to know more about nature. She is also keen to learn how to be a good baker. She loves to help people and is very sociable: she brings joy to whomever meets with her. She plays piano and enjoys to dance.

### YANA, AGE: 15

Hi, I am Yana and I am a normal teenage girl who seeks adventures and is really passionate about the climate change. I like reading fantasy books and enjoy long walks in the forest. I am trying to live as sustainable and green as possible. My mission is to help the planet or at least not to harm it so much.

## AUTHORS

### THOMAS J. RODHOUSE

Tom Rodhouse is an ecologist with the National Park Service in Bend, Oregon. He specializes in monitoring plants and animals and helped build the North American Bat Monitoring Program. When not doing science work, Tom can be found with his daughters exploring the rivers and mountains of the Pacific Northwest. *tom_rodhouse@nps.gov

### SONYA DAW

Sonya Daw is a science communication specialist with the National Park Service in Ashland, Oregon. She helps scientists share what they are learning about nature in parks. She does a lot of editing, but the best part of her job is weaving together words and images about park science that make learning enjoyable. You could call her a translator. In her spare time, she loves to backpack in the high mountains of the Sierra Nevada, play guitar, cook, read, and find elusive birds.

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# MILLIONS OF MONARCH BUTTERFLIES AND THE QUEST TO COUNT THEM

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YOUNG REVIEWERS:


HARJAS
AGE: 14

ISLA,
PIPER,
OWEN,
THEO
AGES: 9–11

Monarchs are capable of amazing feats! They transition from caterpillars to beautiful butterflies. During migration, they fly for thousands of miles—from the northern part of the United States and southern Canada to Mexico. But monarch butterflies are in trouble. In the past 25 years, citizens and scientists have reported fewer and fewer of them. There were less than half as many monarchs in 2020 as in 2019. Parks across the United States, like Rocky Mountain and Indiana Dunes National Parks, host the monarchs along their migration paths. The park rangers are helping scientists track monarchs through "capture, tag, and release." With this method, anyone who sees a tagged butterfly can report when and where they saw it. By tracking monarchs along their migration paths, we expect to learn where they run into problems. Scientists are also using new technology to count monarchs in their winter habitats.

## WHY MONARCHS?

Have you seen orange wings fluttering by? Or maybe you have seen a green caterpillar eating a milkweed plant? Certain caterpillars transition into the popular orange-and-black monarch butterflies (Figures 1A,B). Monarchs do important work in the ecosystem. While these insects feed on nectar, they also move pollen between plants. **Pollination** helps plants reproduce (Figure 1C). When pollination is successful, there is more food available for all types of animals, including people! While monarchs help create food for us, they are also a good source of food for birds, other insects, and small animals (though they have ways of defending themselves according to https://monarchwatch.org/biology/pred1.htm).

**POLLINATION**

Transfer of dust-like pollen particles from the flower of one plant to another (or to a reproductive part of the same plant). Pollination is essential for plant reproduction.


Figure 1

**Figure 1**

**(A)** Monarch butterfly. **(B)** Monarchs clustering on cold winter day to keep warm. **(C)** Monarchs pollinating a milkweed flower.

There are two different populations of monarch butterflies. One population spends winters in California (United States) and travels through state and national parks west of the Rocky Mountains; the other population, called the Eastern population, stays east of the Rocky Mountains. We will focus on the much larger Eastern population. These butterflies travel thousands of miles every year, from southern Canada all the way to Mexico. This event is called **migration** [1]. Imagine traveling thousands of miles (up to 4,000 km, which is 2,500 miles) under your own power! That is almost like traveling from New York to Los Angeles! Butterflies make the trip only once in their lifetimes. This makes monarchs very interesting to scientists—how do monarchs know where to go if they have never been there?

**MIGRATION**

Movement of wildlife or people to find a location that is optimal for finding food and safety for the next generation. For birds and insects, migration is often seasonal.

Since these creatures are helpful to ecosystems across North America, it is very important to keep track of their population sizes. The best way to count Eastern monarchs is in Mexico in the winter, when all Eastern monarchs snuggle together in the trees of protected **cloud forests**. The rest of the year, monarchs are spread out across the United States and Canada and are too difficult to count. Mexican cloud forests have the perfect temperature and humidity for monarchs. Areas further north are too cold; monarchs can freeze to death. Areas further south are too warm for the plants monarchs depend on for food. Monarchs crowd into these few places in Mexico during the winter because conditions are just right.

**CLOUD FOREST**

Cloud forests are like rain forests: they exist in tropical areas. Cloud forests are all at high elevations where low clouds filter through the trees and produce precipitation.

## TRAVELING TO MEXICO

As they migrate to Mexico, monarchs must rest along the way. Some of their rest stops are in Indiana Dunes and Rocky Mountain National Parks in the United States, where staff and visitors have been monitoring monarchs for 15 years. Monarch monitors catch monarchs with butterfly nets, gently put little tags on them, and release them. This method is called "capture, tag, and release." The tags look like little stickers with numbers on them (Figure 2). Anyone who sees a monarch with a tag can write down the number and report it online to an organization called Monarch Watch. The stickers work like car license plates—you can tell which state a car came from no matter where it is seen. This way, researchers can piece together the path of that specific monarch. If the butterfly does not make it to Mexico, researchers can figure out where it was last seen and maybe even why it ran into trouble. Anyone, including you, can help researchers collect this information! Whenever you see a monarch with a tag, write down the number and report it to MonarchWatch.org! On this website you can see how the number of butterflies goes up and down. The numbers go up as more monarchs are sighted, and they go down if the monarchs get caught in storms or fires.

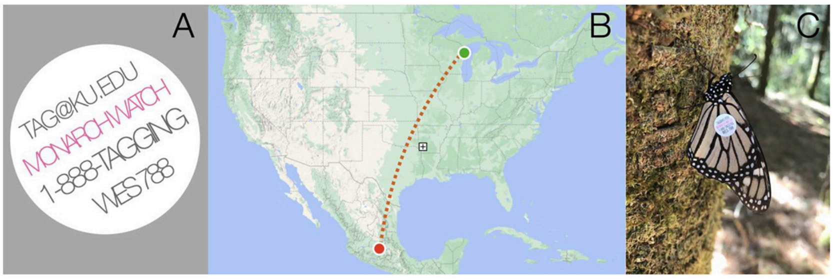


Figure 2

**Figure 2**

**(A)** To track its migration route, a monarch butterfly was tagged by Monarch Watch on September 20, 2016 and released from Egg Harbor, Wisconsin, USA. **(B)** The monarch traveled 2,300 miles in 5 months. **(C)** This picture of the tagged monarch was taken on February 20, 2017, in Zitácuaro, Mexico (for more on tagging, see https://monarchwatch.org/tag-event).

## COUNTING MILLIONS OF BUTTERFLIES

Monarchs cluster together on fir trees high in the cloud forests of Michoacán, Mexico [2]. Scientists have been wondering how to accurately count so many monarchs. The problem is that monarchs come in extremely large numbers, and they hang on to the trees in very dense groups. If you did not know you were among butterflies, you might think you were walking through trees with blankets tossed over them! This has made it very difficult for scientists to be sure they are getting correct numbers. Picture it this way: you are asked to estimate the number of M&Ms in a giant jar in front of you. When they are all clumped together in the jar, it is difficult! If you could line them up, it would be much easier.

What if you had super eyesight and could count the shapes of the hidden butterflies to get your answer? Scientists have that technology today! It is a laser-beam technology called **LiDAR**, for **li**ght **d**etection **a**nd **r**anging. LiDAR technology uses a laser scanner, which is like a camera. But instead of making a two-dimensional image (like a drawing of a square on a piece of paper), it makes a digital, three-dimensional model (like a Rubik's cube). To generate the model, the LiDAR scanner sends out millions of laser beams to record the positions and distances of objects in the environment. Two scientists, Louise Allen and Nickolay Hristov, decided to use LiDAR to estimate large populations of animals that cluster together. To find out how many monarch butterflies were in the forest, the scientists scanned the forest two times: first when there were no butterflies, and then when the butterflies were covering the trees. Since the laser scans show detail in three dimensions, they can be used to figure out how much space something in the image takes up (its volume). They subtracted the volume of the bare trees from the volume of the covered trees, to get the volume of just the butterflies (laser **SVE**) (Figure 3, Video 1). Since scientists can estimate the typical volume of one monarch, they can divide the total volume by the volume of one butterfly, to estimate the total number of monarchs in the forest [3].

**LIDAR**

Light detection and ranging. A technique in which a camera-like device directs a beam of light into a space and measures the distance to the first solid object it hits.

**SVE**

Subtractive Volume Estimation. A method for estimating the number of animals in dense groups by analyzing the shape and volumes of these groups when scanned with LiDAR.

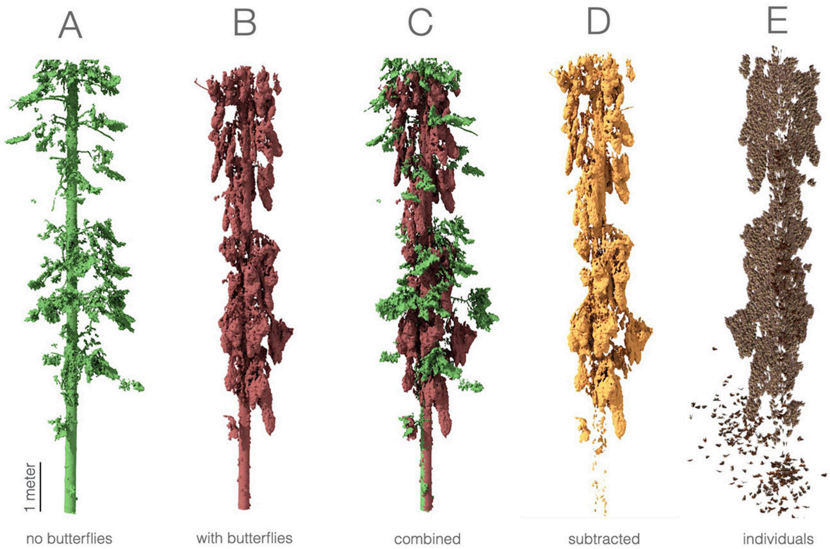


Figure 3

**Figure 3**

Three-dimensional models of Oyamel fir trees in central Mexico, based on LiDAR. **(A)** A tree without butterflies. **(B)** The same tree with butterfly clusters. **(C)** The combination of **(A,B)**, to show the shapes of the tree with and without butterflies present. **(D)** Only the roosting butterflies, created by subtracting **(A)** from **(B)**. Notice that the trunk and branches of the tree are missing. **(E)** Conversion of the volume of butterflies from **(D)** into estimated individual monarchs.

**VIDEO 1**

Visual description of the SVE method showing how the LiDAR scan of a tree with and without butterflies is converted to 3-D models for analysis and estimating the count of individual butterflies.

Before this new method, SVE scientists estimated that, between 2000 and 2020, the monarch population was between 1.6 and 1.5 billion butterflies [4, 5]. That is like saying you either have $70 or $70,000, you are not sure which, but at any time the amount is somewhere in that range. That is a big range. Of course, the number of butterflies changes every year. If the techniques for estimating the numbers of monarchs are not accurate, it is difficult to tell if efforts like milkweed plantings are making a difference. We need the most accurate numbers to understand whether there is a big problem with monarch populations. In the past 2 years alone, the estimated number of monarchs dropped by half according to the area estimations.

With LiDAR, more accurate counts of monarchs in Mexico are possible. Using LiDAR technology, scientists can compare a baseline count taken today to future scans. If future scans show an increase in monarchs, it will tell us that whatever help we are providing for monarchs is successful.

## THE CHALLENGES

We know monarch butterflies face many challenges. Besides the storms and fires that kill them, monarchs only eat and lay their eggs on the leaves of the milkweed plant. Milkweeds are getting harder to find because people often kill these plants with herbicides or other chemicals. As we build more houses, stores, and parking lots, we lose space for plants and trees, including milkweeds. The same is true at the end of the monarch migration route in Mexico. More houses, stores, farms, and factories mean fewer trees where monarchs can spend the winter. Mexicans who grew up seeing thousands of monarchs are working hard to preserve the cloud forest habitats, so the monarchs have a place to go. Monarchs have also suffered the effects of changing weather patterns, like more frequent storms, sudden drops in temperature, and excessive rain.

## WHY WE CARE

We all benefit from monarchs. They help us by pollinating the plants we eat. We can use new technologies to track and count monarchs, which will help us learn how best to protect them. National parks, both in the United States and Mexico, have a big role to play in protecting monarchs. We can all help decrease the dangers monarchs face by helping to preserve forest areas, limiting the use of chemicals, and leaving milkweed plants in place for monarch habitats. Let us continue the hard work so that we can see larger numbers of monarchs across North America. Help save monarchs! Visit www.monarchwatch.org or www.xerces.org/monarchs to learn more.

## AUTHOR DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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## ORIGINAL SOURCE ARTICLE

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## REFERENCES

1. Brower, L. P. 1977. Monarch migration. *Nat. Hist.* 86: 40–53.
2. Anderson, J. B., and Brower, L. P. 1996. Freeze-protection of overwintering monarch butterflies in Mexico: critical role of the forest as a blanket and an umbrella. *Ecol. Entomol.* 21:107–16.
3. Hristov, N. I., Nikolaidis, D., Hubel, T. Y., and Allen, L. C. 2019. Estimating overwintering monarch butterfly populations using terrestrial LiDAR scanning. *Front. Ecol. Evol.* 7:266. doi: 10.3389/fevo.2019.00266
4. Calvert WH. 2004. "Two methods estimating overwintering monarch population size in Mexico," in *The Monarch Butterfly: Biology and Conservation*, eds K. S. Oberhauser, and M. J. Solensky (Ithaca, NY: Cornell University Press). p. 121–7.
5. Thogmartin, W. E., Diffendorfer, J. E., López-Hoffman, L., Oberhauser, K., Pleasants, J., Semmens, B. X., et al. 2017. Density estimates of monarch butterflies overwintering in central Mexico. *PeerJ*. *5*, e3221. doi: 10.7717/peerj.3221

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## YOUNG REVIEWERS


### HARJAS, AGE: 14

Hey! My name is Harjas and I am 14 years old. My favorite subjects in school are Math and Science. I have been learning Indian classical singing since I was 6 years old. I also love to play cricket in my backyard with my brothers. In my free time I enjoy reading and going on bike rides.

### ISLA, PIPER, OWEN, THEO, AGES: 9–11

We are elementary school students. We like to explore outside, be creative, mess around, and think about science.

## AUTHORS

### SOPHIE PHILLIPS

Sophie Phillips is a graduate student studying energy and environmental policy at the University of Delaware, U.S. She is also a research assistant for the Water Resource Center within the Biden School of Public Policy and Administration. She studied environmental and marine science during her time as an undergraduate, and she worked as a laboratory technician in the Robotics Discovery Lab on University of Delaware's Hugh R. Sharp Campus in Lewes, Delaware. Her research interests include human noise impacts on wildlife, wildlife conservation, environmental justice, and the connection between environmental history and race within the United States. *sophiekp@gmail.com

### MARTHA MERSON

Martha Merson has co-led the project Interpreters and Scientists Working on Our Parks, along with Hristov and Allen. Merson was never an outstanding science student, but she was curious about scientists' work. She has worked closely with scientists and park rangers to bring science stories to public audiences.

**LOUISE C. ALLEN**

Louise C. Allen is a biologist and higher-ed administrator with expertise in undergraduate mentoring. Her research has focused on human impacts on behavior and stress in wildlife, including bats. She also has expertise in science learning inside and outside of the classroom.

**NICKOLAY I. HRISTOV**

Nickolay I. Hristov is a scientist with interests in information and learning design and population dynamics. His research (done in tandem with Louise Allen) using LiDAR technology has provided more accurate counts of clustering species like monarchs in Mexico and cave-dwelling bats in the south-central United States.

EARTH AND ITS RESOURCES
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# SCIENTISTS SPY ON TREEFROGS USING PLASTIC PIPES IN TREES

***Carolyn A. Carlson and Jane E. Carlson*** *

*Gulf Coast Inventory and Monitoring (I&M) Network, National Park Service, Lafayette, LA, United States*

YOUNG REVIEWERS:

FLYNN
AGE: 9

RENEE
AGE: 8

Have you ever spied on a treefrog? These nocturnal creatures can be hard to observe, cloaking their lives in mystery. They hatch as legless swimmers but quickly transform into adults with camouflaged skin for daytime hiding and sticky toepads for hunting in tree branches by night. Yet even the most secretive, high-climbing treefrog cannot escape from pollution, new enemies, and habitat loss. Scientists want to know how treefrogs are coping with these threats, so we spy on them in a clever way: we hang small plastic pipes from trees, which mimic the dark cavities where treefrogs love to rest. Since 2011, we have counted treefrogs inside thousands of pipes, yet with so many mysteries, our work will continue for years. One pipe at a time, treefrogs are sharing their secrets about which threats harm them most, helping us better protect and manage the beautiful trees and waters they call home.

## WHAT ARE TREEFROGS?

Treefrogs are small, shy amphibians that dwell in our forests and nearby wetland areas. While often difficult to see, their cheerful trills, chatters, and croaks remind us of their presence, sometimes even within our own neighborhoods. A curious and patient observer may find one of these small frogs clinging tightly to a tree branch, its color matching the bark so closely that, when motionless, it almost disappears. In fact, most treefrog species can change their body colors to match their surroundings. With the ability to flatten themselves closely to woody surfaces and hold tight with sticky toepads, treefrog are not only well-hidden from predators, but are skillful and successful hunters of gnats, mites, beetles, and other invertebrates. Within the forested ecosystems that they call home, including within the region's national parks and preserves, these small, tree-climbing amphibians benefit greatly when ecosystems are kept in balance. Understanding the threats and dangers faced by treefrogs helps the National Park Service manage their lands in ways that protect not only treefrogs, but the places where they thrive. How do scientists set up monitoring projects to do this difficult job?

## TREEFROG MONITORING PROJECTS

Determining how animal population numbers change over time helps researchers evaluate the health of habitats and their inhabitants. This knowledge is extremely valuable for making good management decisions about the lands that the National Park Service manages and protects. Setting up a project to collect population information takes careful planning, and treefrogs, with their sensitive skin and water-dependency, are good subjects for population studies. In this project, the bottomland hardwood forests of the Barataria Preserve (part of the Jean Lafitte National Historical Park and Preserve south of New Orleans, Louisiana) served as the focus for the amphibian monitoring program [1]. Data collection in the preserve began in 2011 and is still ongoing.

Scientists must sometimes get very creative to "catch" the animals they want to study, and the simplest setups can often be the most effective. To observe treefrogs, the researchers came up with a very clever plan. They used small plastic pipes, which they hung in trees at roughly chest-level. Such pipes were ideal because they resemble other natural cavities, such as holes or crevices in trees. Treefrogs seeking shelter could enter and leave the pipes without harm (Figures 1A,B) and, as the pipes were very durable, they could be used year after year [2, 3].

The research team started by hanging 52 pipes within one small area, which they checked every month to count the treefrogs inside (Figure 1C). Researchers also identified each species and recorded the air


Figure 1

**Figure 1**

Plastic pipes were hung from trees at the Barataria Preserve, and scientists checked them for the presence of treefrogs. **(A)** A green treefrog peeking out of a short plastic pipe 5 cm in diameter. **(B)** A small squirrel treefrog within the same-sized plastic pipe. This frog has plenty of room to enter and leave the pipe. **(C)** A scientist checking a plastic pipe for treefrogs.

temperature and air moisture level, so a picture could be painted of the site's environmental conditions. This information could then be combined with data on recent weather events, like rainfall amounts, heat waves, cold snaps and windstorms, to help scientists better understand changes in treefrog populations over time.

## TREEFROGS AND THEIR HABITS

Four different treefrogs are commonly found in the plastic pipes in the Barataria Preserve (Figures 2A–D): Cope's gray treefrog, bird-voiced treefrog, squirrel treefrog, and green treefrog. As well as sharing the woodland habitats, these treefrogs have many traits in common [4, 5]. Being nocturnal, they are all active at night, hunting for their insect prey sometimes high in trees, sometimes closer to the ground. During the spring and summer, the treefrogs move to nearby wetlands, bayous, and ponds to find mates and lay eggs, attaching the eggs to underwater vegetation. The eggs hatch into tadpoles that feed on algae and other similar aquatic plant matter until, after a number of weeks, these swimmers morph into small frogs that continue their life cycles on land like their parents.

## WHAT THE SCIENTISTS DISCOVERED

There were two main objectives that the scientists wanted to explore. The first was to determine roughly how many treefrogs of each species


Figure 2

**Figure 2**

Treefrog species at the Barataria Preserve. **(A)** Cope's gray treefrog; **(B)** bird-voiced treefrog; **(C)** squirrel treefrog; and **(D)** green treefrog.

lived or visited the bottomland hardwood forests, using the numbers of treefrogs they counted in the pipes as a representation of the frogs' abundance at the site. The second objective was to see how treefrog detections changed across the seasons and from 1 year to the next. Combining these numbers with the environmental data allowed the researchers to paint a picture of the cycles of treefrog presence over several years.

The earliest phase of the study emphasized treefrog identification and how much they used the pipes across seasons. The original 52 pipes were checked monthly between 2011 and 2017, to produce an average number of treefrogs per check for each species recorded (Figure 3A). Two interesting findings emerged. First, some species were found more often than others: squirrel treefrogs were the most often encountered species in those early years, and Cope's gray treefrogs were so scarce that they were not seen even once. Second, treefrogs used pipes less often during the summer than the winter. During one summer season, there were 2 months when not even one frog was counted! This contrasts with the single winter visit, with 80 treefrogs seen in less than 4 h, including 3 pipes with 5 treefrogs each!

In early 2018, the scientists examined their methods for opportunities to improve and decided on three main changes. First, they doubled the number of pipes by adding a second, similar site nearby. Second, they reduced how often they checked to just once every other month, checking both sites in the morning over 2 days. Third, they focused their search primarily on the winter season (November, January, and March), when treefrogs were seen most often. Figure 3B shows the data so far, in terms of total treefrog counts from both sites over the past three winters. The results show that, so far, some years have more treefrogs than other years, and the dominant species changes as well. For example, during the first two winters, squirrel treefrogs

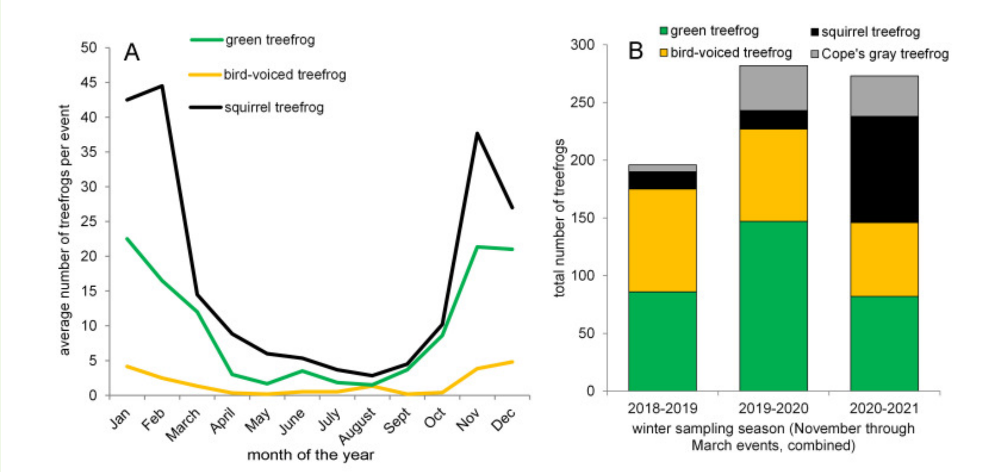


Figure 3

**Figure 3**

**(A)** The average number of treefrogs found during a single morning per month at one site with 52 pipes at Barataria Preserve, from 2011 to 2017. Averages were taken for each species, and one of the target species, Cope's gray treefrog, was not recorded before 2018. **(B)** The total number of treefrogs recorded over three winter events for 3 years in a row, beginning in November 2018. The three events were in November, January, and March, and consisted of checking 116–128 pipes, divided between the study's original site and a new, similar site nearby.

were relatively scarce, but during the third winter, they were the most common species.

## LEARNING FROM TREEFROG STUDIES

Checking pipes thousands of times provided invaluable information for documenting changes in treefrog populations within and across years. Once the researchers realized that treefrogs did not use pipes evenly throughout the year, they focused their efforts on the winter, allowing them to use their scientific resources more efficiently. Not only were the scientists happy to find ways to improve, but they also considered the seasonal differences an interesting discovery. They think the most likely explanation is that treefrogs, like other amphibians, rely on external temperatures to maintain their own ideal internal temperatures, and to do so, their surrounding environment should remain relatively warm. Thus, as temperatures cool, they take shelter in natural or artificial cavities, which retain accumulated heat. In warmer weather, they more often rest on exposed branches or leaves where the cooler air aids temperature regulation, and it is reasonably safe for them to do so, thanks to their camouflage.

In addition to the discovery of seasonality in cavity use, many other unexpected insights emerged as researchers examined their findings. The scientists became aware of many things that surprised them and raised new questions. For example, precisely how cold did it need to get for treefrogs to seek out cavities for protection, and how likely was each species to share space? Also, what were the consequences of unseasonably cold, hot, or dry spells? To better understand these situations, the researchers now record the temperature inside each pipe as well as the outside air temperature, and they have installed sensors that continuously record the water depth in a nearby waterbody. This extra information is helping to clarify how treefrog pipe use is related to temperature and moisture cues from the environment. Scientists are also discussing how to increase the frequency of winter sampling.

New and bigger treefrog-related questions are being considered by the National Park Service ecologists. What happens when hurricanes or other storms sweep over the preserve, knocking down trees and causing salt water to seep in? What new enemies may threaten the treefrogs? The biggest threat may be us: land use by humans is increasing. However, humans can also help, by studying treefrogs and adding to the bank of knowledge being collected by scientists all over the world. Collectively, this information can lead to better decisions about how we can all survive together, treefrogs and humans alike. Even treefrogs of different species will share a plastic tube cavity for rest, safety, and shelter. Can we also learn to share the Earth with the treefrogs?

## REFERENCES


1. Carlson, J. E., Woodman, R. L., Finney, W., Granger, W., Bracewell, J., Buhlmann, K. A., et al. 2018. *Monitoring amphibians in Gulf Coast Network Parks: Protocol narrative—Version 2.0. Natural Resource Report. NPS/GULN/NRR—2018/1742*. Fort Collins, CO: National Park Service. Available online at: https://irma.nps.gov/DataStore/Reference/Profile/2256511
2. Graeter, G., Buhlmann, K. A., Wilkinson, L. R., and Gibbons, J. W. (eds). 2013. *Inventory and Monitoring: Recommended Techniques for Reptiles and Amphibians: With Application to the United States and Canada.* Birmingham, AL: Partners in Amphibian and Reptile Conservation (PARC) Technical Publication IM-1.
3. Dodd, C. K. Jr (ed). 2010. *Amphibian Ecology and Conservation, a Handbook of Techniques*. Oxford: Oxford University Press.
4. Dodd, C. K. Jr. 2013. *Frogs of the United States and Canada, Volume 1*. Baltimore, MD: Johns Hopkins University Press.
5. Powell, R., Conant, R., and Collins, J. T. 2016. *Peterson Field Guide to Reptiles and Amphibians of Eastern and Central North America, 4th Edn*. New York, NY: Houghton, Mifflin, Harcourt.


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## YOUNG REVIEWERS

**FLYNN, AGE: 9**

Hi, I am Flynn! I love football and the Kansas City Chiefs, and Patrick Mahomes is my favorite quarterback! I also love video games. In the summer I like fishing and camping. In the winter, I like to ski with my dad and brother.

**RENEE, AGE: 8**

I like insects and I am very interested in plants. I have a lot of cactuses and like to catch crickets in the springtime. I also like to cuddle with my kitty, Lisa.

## AUTHORS

**CAROLYN A. CARLSON**

Carolyn Carlson is a retired 4th grade teacher living in rural upstate New York, where she tends gardens, bees, and plants trees. Before retirement, she specialized in environmental and science education and was also a Star Lab Planetarium presenter and a volunteer naturalist. Carolyn likes to work with her husband Doug on their 20 acres of wildflowers, wetlands and fields or head out to hike the nearby trails of the Tug Hill, eastern Adirondacks, and Lake Ontario region.

**JANE E. CARLSON**

Jane Carlson is an ecologist for the National Park Service, working in 8 national parks from Texas to Florida. As part of the Gulf Coast Inventory and Monitoring Network, she carries out long-term studies in parks so that managers can learn when their plants or animals need special help. In past jobs, Jane studied plants and animals in far-away places, such as the Costa Rican rainforest and the Cape Region of South Africa. In her spare time, she loves to travel, hike, take photos, draw, and spend time outdoors with her favorite people, like her daughter who is in this picture with her. *jane_carlson@nps.gov

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# THE MYSTERIOUS CASE OF THE MISSING RAZOR CLAMS

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*[7] Alaska SeaLife Center and University of Alaska Fairbanks, College of Fisheries and Ocean Sciences, Seward, AK, United States*

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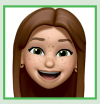
YOUNG REVIEWERS:

COLUMBIA CREST A-STEM ACADEMY

AGES: 11–14



SKYE

AGE: 13

Oceans are changing and these changes are affecting the animals that live there. Animals respond differently to changes in water temperature, food availability, and contaminants. Those responses can be seen in their genes. A technique called transcriptomics allows scientists to see the response of an animal's genes to its environment. We used transcriptomics to compare two populations of Pacific razor clams in Alaska (United States): one that has lots of clams and one that used to have lots but does not anymore. We were surprised when we did not find any differences in their gene responses! So, we had to think about what else might be influencing the number of

clams in these two populations. As we "dug" for answers, we found out that there are differences between the populations that do not influence their genes but may impact their numbers, such as being eaten by predators.

## GENES HELP US STUDY ANIMALS

**Ecosystems** around the world, including ocean ecosystems, are changing rapidly. How do we know if these changes are healthy or not? We cannot bring the ecosystems to a doctor for a checkup, but we can send scientists out to the ecosystems to measure the health of animal populations and individuals. By measuring repeatedly, scientists can tell how the ecosystems are doing. Comparing changes over time tells us what is changing and by how much. One way for scientists to measure ecosystems' health is to measure the activity of the genes in the animals they study. **Gene transcription** is a cellular process that shows scientists how animals react to their environments, and studying gene transcription is one way to understand the health of the ecosystem.

**ECOSYSTEM**

A community of organisms (animals, plants, and microbes) interacting with non-living things, like rocks and sand. Ecosystems can be as small as a puddle or as large as the ocean.

**GENE TRANSCRIPTION**

The process by which an RNA molecule copies a gene from the DNA so it can be used to build proteins.

## USING GENES TO INVESTIGATE A RAZOR CLAM POPULATION CRASH

How do scientists use gene transcription to assess ecosystem health? Let us look at a real-world issue that has us scratching our heads: clams living on ocean shorelines. The clams we are studying are Pacific razor clams, a prized food for people who come to dig them and important prey for other animals that live along the coast, like sea otters. Historically, there have been two razor clam **fisheries** in Cook Inlet, Alaska (United States): one on the east side and one on the west side, about 63 km (or 40 miles) apart. About 10 years ago, the population of razor clams on the east side of Cook Inlet started to crash. The numbers became so low that scientists worried the population was in trouble. But the population of razor clams on the west side of Cook Inlet was doing fine. How could that be? These two populations of razor clams lived along the same body of water, in the same climate, in the same type of habitat, and close to each other (Figure 1). Scientists began to think about what could be different between the two populations.

**FISHERY**

The harvest by humans of a marine species that is managed by a state or federal entity.

Scientists wondered if there were differences between the two clam populations, like food availability, pollution, or increased **ocean acidification**. Some of these differences can be "seen" using a technology called **transcriptomics**. Transcriptomics measures how much a gene is turned on or turned off [1]. Genes have various functions in the bodies of every living thing, and genes can be turned on or off depending on whether or not they are needed at that time.

**OCEAN ACIDIFICATION**

Carbon dioxide ($CO_2$) released in the atmosphere can be absorbed by the ocean. As the ocean absorbs $CO_2$, the ocean waters are becoming more acidic (lower on the pH scale).

**TRANSCRIPTOMICS**

The scientific technique used for measuring gene transcription.

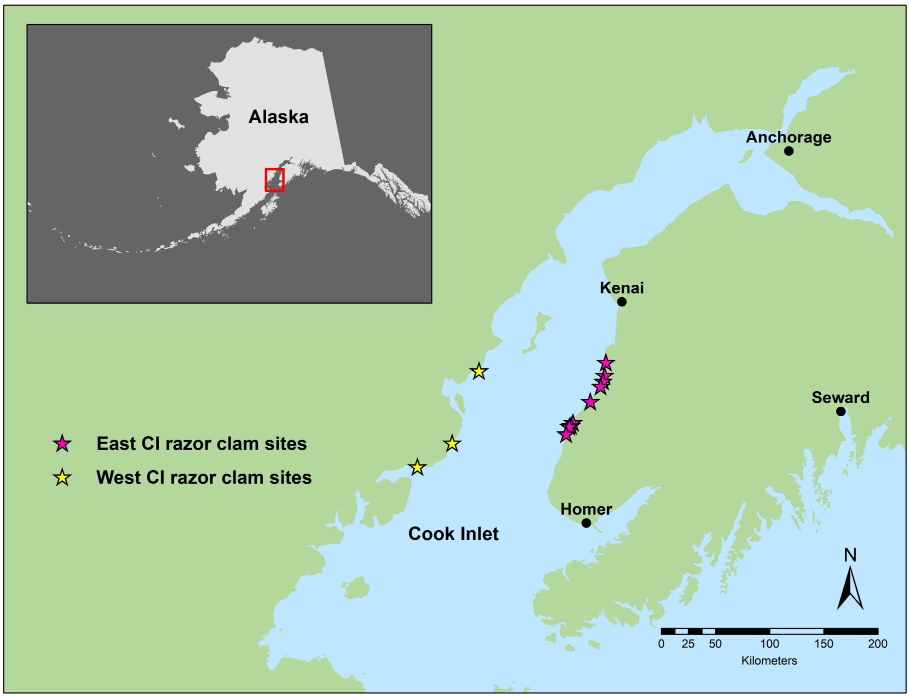



Figure 1

**Figure 1**

Map of Alaska and Cook Inlet (CI), where our study sites were located. The razor clam sites on the east side of Cook Inlet are shown with pink stars, while yellow stars show the west Cook Inlet razor clam sites.

Genes can be activated for many reasons, including certain types of stress. When genes are activated, DNA gets transcribed into a molecule called messenger RNA (mRNA). It is called *messenger* RNA because it carries DNA's message. The mRNA gets turned into proteins that do important jobs within the organism. The amount of mRNA clams make depends on what is happening in their world. Let us say the razor clam encounters a contaminant, like fuel oil. The gene that makes contaminant-fighting proteins turns on, making more mRNA, which makes more proteins. Or, if a razor clam meets up with some bad bacteria, it will need to turn on its immune function genes for protection. By measuring the amount of mRNA that an organism makes from a specific gene, we can learn about problems razor clams may be facing (Figure 2).

## HOW WE DESIGNED OUR STUDY

Our goal was to monitor ecosystem health in Cook Inlet, where we were trying to figure out why there were different numbers of razor clams in two adjacent populations. We came up with a study plan to assess the health of the Cook Inlet ecosystem. We decided to collect 10 razor clams along nine sites on the east side and three sites along the west side of Cook Inlet, for a total of 120 clams per year. We wanted to look at their genes. We expected to find differences in the genes that were turned on and off between razor clams in east and west Cook Inlet. Those differences would tell us about the unique environmental pressures affecting each population.

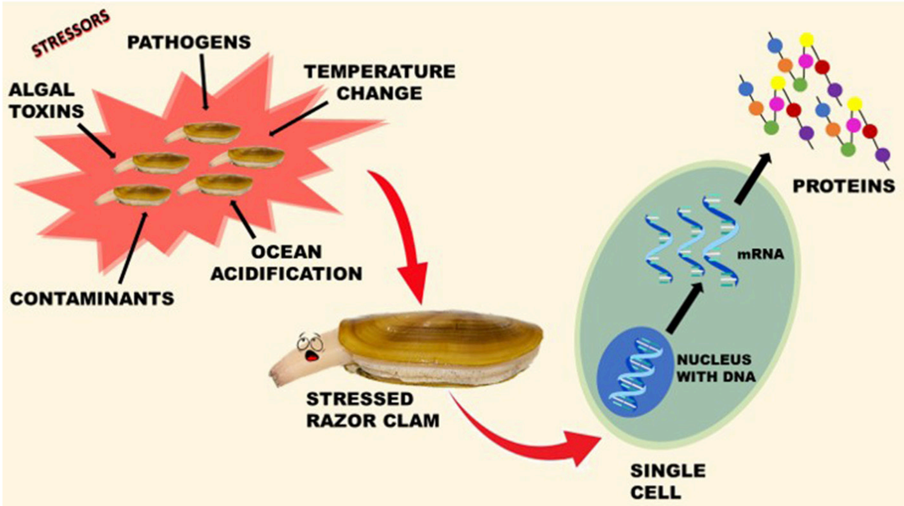



Figure 2

**Figure 2**

A razor clam can be stressed by many things. Stress activates genes, and DNA gets transcribed into mRNA. The mRNA gets turned into proteins that do important jobs within the organism. The amount of mRNA made depends on what is stressing (or not) the clam. Transcriptomics is the process of measuring the mRNA (figure credit: Min She Wenig).

First, we had to catch the clams. Using shovels, we dug holes on sandy beaches, hoping to find razor clams. We put the clams we found in a bucket and carried them back to the boat. Then we **dissected** them to get tissue samples for the gene analyses, which we did later, in the laboratory.

**DISSECT**

To break something apart, or cut it up, to examine its parts and understand it better.

## NO DIFFERENCES IN GENE TRANSCRIPTION

We analyzed five genes that respond to stressors like pollution, ocean acidification, nutrition, and temperature. Somewhat surprisingly, we found no differences between the two sampling areas! The genes from razor clams living on beaches on both the west and east sides of Cook Inlet showed similar transcription patterns. So, what does that tell us?

There are two possible conclusions. First, maybe we did not test the right genes. There could be other genes that are affected by stressors that impact the health of the clams. So, we need to test more genes. In this study, we have only identified five razor clam genes, and this is a small number. In comparison, thousands of genes have been identified in humans! But human genes have been studied a great deal, and Pacific razor clam genes were not studied at all until we started our work. Second, maybe there are other differences between the two populations of clams that can affect their numbers, but do not make a difference to their genes.

It seems that something is affecting the east side razor clams, but not causing their genes to turn on or off. What could it be? Two ideas came to mind: habitat differences and predation. We needed to learn what researchers have discovered about habitat differences and predation between the two areas.

## COULD IT BE A CHANGE IN HABITAT?

**ALGAL BLOOM**

A rapid growth of microscopic algae in water. Algae are food for many marine animals such as clams.

We found that temperature and saltiness of the water are two things that might be different between the east and west sites. **Algal blooms**, which provide a burst of food for clams, are also probably different in timing and amounts of algae. However, if there were differences in food, temperature, or salinity that were big enough to affect the clams, we would expect to see gene transcription differences. Several of the genes we measured should turn on or off if the clams are stressed. Other habitat factors could involve big storms or changes to the sand in which the clams live. Storms and ice churn up beaches, remove sand, and can keep clams from reproducing or can even kill them. However, we would not see gene transcription changes in response to those kinds of events. In addition we did not find much information about storms and habitat loss over time in these two areas. More research is needed to answer this question.

## COULD IT BE PREDATION?

**KEYSTONE SPECIES**

A species with a big impact on its ecosystem and that plays an important role in maintaining the ecosystem. Without it, an ecosystem might look very different.

We also wanted to look at predation—whether other organisms were eating the clams. Predation would not result in gene transcription changes. So, who could be eating the clams? We found that sea otters, a marine mammal that loves to eat clams and other marine invertebrates, live in Cook Inlet. Sea otters are a **keystone** predator [2], which means they have a large impact on their ecosystem through predation [3]. Sea otters have a very high metabolism, so they have to eat almost a third of their body weight every day. A 27 kg (60-pound) otter needs to eat almost 9 kg (20 pounds) of clams a day. That would be about the same as a 27-kg (60-pound) kid eating more than 20 pizzas every day! If sea otters were around, a lot of razor clams could be eaten, especially if there were not many other items on the otter menu in that area.

Scientists count sea otters in Alaska using airplanes. The data from Cook Inlet sea otter surveys were really surprising! We discovered that, in the last few years, the number of sea otters increased from <1,000 to over 3,000 on the east side. But on the west side, where the clams continue to thrive, there are still not very many sea otters.

While we did not start our study thinking about sea otters, we realized that the number of sea otters is very different between the east and west sides of Cook Inlet. Predation could be a big reason why there are far fewer razor clams on the east side of the inlet. We expect that sea otters and clam populations will eventually find a balance. To learn more about this balance, called carrying capacity, see this Frontiers for Young Minds article [4]. In the meantime, one of the next steps in our studies of razor clams will be to watch sea otters when they are eating. We want to understand how many sea otters there are and how many clams they are eating each year (Figure 3).

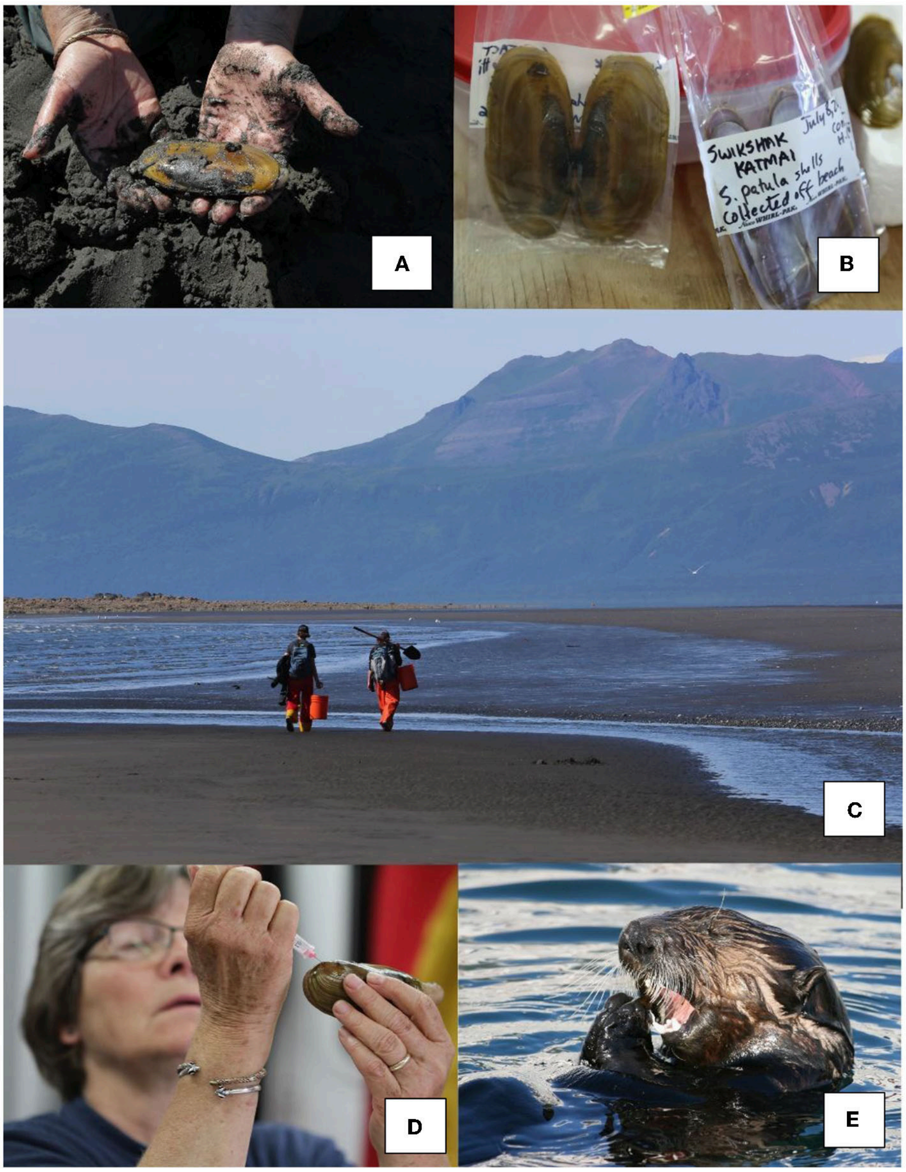



Figure 3

**Figure 3**

**(A)** Pacific razor clam after recently being dug. **(B)** Pacific razor clam samples bagged for analysis. **(C)** Scientists on a razor clam beach in Katmai. **(D)** Scientist sampling a razor clam: and **(E)** Sea otter eating a clam (photo credits: NPS Photo/J. Pfeiffenberger).

## CONCLUSION

Our gene transcription results showed us that neither pathogens, contaminants, nutrients, or physiological stress seem to be causing the abundance differences between the east and west Cook Inlet razor clam populations. However, we now know that there are differences in the sea otter population sizes between the two areas and will conduct more studies to see what impact sea otters may be having on the clams. Our next steps for studying the clams will be to collect clams from the beaches, take them to a lab (alive) and conduct experiments to see if we can measure a response in certain genes by changing their food or the temperature of their water. Combined, these studies will allow us to have a better understanding of the impacts of environmental stressors, including predation, on the clam populations in Cook Inlet [5].

## FUNDING

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## REFERENCES

1. Bourlat, S. J., Borja, A., Gilbert, J., Taylor, M. I., Davies, N., Weisberg, S. B., et al. 2013. Genomics in marine monitoring: new opportunities for assessing marine health status. *Mar. Pollut. Bull*. 74:19–31. doi: 10.1016/j.marpolbul.2013.05.042
2. Estes, J. A., and Palmisano, J. F. 1974. Sea otters: their role in structuring nearshore communities. *Science* 185:1058–60. doi: 10.1126/science.185.4156.1058
3. Paine, R. T. 1969. A note on trophic complexity and community stability. *Am. Nat.* 103:91–3. doi: 10.1086/282586
4. Coletti, H., Hilderbrand, G., Bodkin, J., Ballachey, B., Erlenbach, J., Esslinger, G., et al. 2022. Where land and sea meet: brown bears and sea otters. *Front. Young Minds* 10:715993. doi: 10.3389/frym.2022.715993
5. Coletti, H. A., Bowen, L., Ballachey, B. E., Wilson, T. L., Waters, S., Booz, M., et al. 2021. Gene expression profiles in two razor clam populations: discerning drivers of population status. *Life* 11, 1288. doi: 10.3390/life11121288

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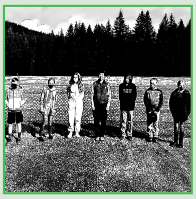
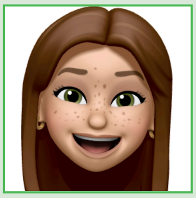
## YOUNG REVIEWERS



### COLUMBIA CREST A-STEM ACADEMY, AGES: 11–14

We are students in a program designed to create opportunities for extra academic challenge, exploration, and enrichment. We support each other on as we work to solve problems, develop original ideas, and explore new possibilities. We provided this review as a part of a writer's workshop aimed at increasing our skills in writing and editing. We were very excited about the opportunity to learn new concepts and be part of the review process!



### SKYE, AGE: 13

I love to ski, go camping, paint, read, watch movies, and bike. Some of my favorite things are candles, rain, The Goonies, malachite rainbows, sagebrush, and dogs.

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Heather Coletti is a marine ecologist for the National Park Service. She has studied nearshore marine ecosystems, in particular sea otters and their prey, since 2001. Her favorite part of her job is to be in the field which includes living on a boat, conducting lots of different types of coastal surveys and watching sea otters. She also hopes her work contributes to marine conservation. For fun, Heather likes to spend time with her family cross-country skiing and mountain biking in Alaska. *heather_coletti@nps.gov

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Lizabeth Bowen is a research ecologist with the U.S. Geological Survey in Davis, California. Her research looks at how wildlife responds to environmental stressors and how this affects health. She uses molecular tools to measure these responses in wildlife. She loves her research focus and hopes to continue asking questions and solving problems for a long time. In her spare time, she loves to hang out with her family, hike, paddleboard, and walk on the beach.

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Brenda Ballachey is an Emeritus scientist with the U.S. Geological Survey in Anchorage, Alaska. Her research has included studies of physiology, toxicology and genetics in both wildlife and domestic livestock. She spent many years exploring the effects of the 1989 *Exxon Valdez* oil spill on sea otters and continues to study sea otters and the nearshore areas where they live. When not working, she loves to be outdoors, exploring nature, or to curl up with a good book.

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Tammy L. Wilson is a research ecologist with the U.S. Geological Survey in Amherst, MA. She researches how wildlife responds to natural and human-caused changes in their habitat. She uses aerial surveys, remote cameras, and genetic material from hair, feathers, and scat to gather data about animal abundance and resource use. In her spare time Dr. Wilson loves exploring the natural world.

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Tuula Hollmen is a marine ecologist at the University of Alaska Fairbanks and the Alaska SeaLife Center. She studies coastal marine ecosystems from tidewater glacier fjords in southcentral Alaska to the high latitudes along the Arctic Coastal Plain. In her spare time, she enjoys playing music with friends, practicing yoga, and exploring the Alaska outdoors by hiking and riding her bike.

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Benjamin Pister is the Director of Resource Management at Kenai Fjords National Park. His job is to preserve the natural and cultural resources of the park for the education, inspiration, and enjoyment of current and future generations. By training he is an intertidal ecologist with a Ph.D. in Biology and loves to study all things in the ocean—but especially invertebrates! When not working he enjoys fishing, hunting, gathering and spending time outdoors in Alaska with his kids.

BIODIVERSITY
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# THE RECOVERY OF THE AMERICAN PEREGRINE FALCON IN ALASKA

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YOUNG REVIEWERS:

RANJAI
AGE: 12

RANVIR
AGE: 11

SHAHAR
AGE: 12

American Peregrine Falcons nesting along Alaska's upper Yukon River have been studied for nearly 50 years. Peregrine populations decreased in the 1960's because widespread use of the insecticide DDT caused their eggshells to thin. Thin eggshells meant that eggs crushed easily in the nest, which reduced the number of baby birds produced. Eventually, Peregrine Falcons were listed as endangered under the Endangered Species Act in the United States (U.S.). After the U.S. banned the use of DDT, the U.S. Fish and Wildlife Service, National Park Service, and others helped Peregrine Falcons recover. Today, upper Yukon River Peregrine Falcons have rebounded and are thriving. The Peregrine Falcon's recovery in the U.S. is a shining success story of the Endangered Species Act, although climate change and other pollutants create continuing challenges for the species.


Figure 1

**Figure 1**

**(A)** An American Peregrine Falcon pair in Yukon-Charley Rivers National Preserve, Alaska (photo credit: Sean Tevebaugh, NPS). **(B)** A perched female American Peregrine Falcon. Note the bright yellow talons (photo credit: Melanie Flamme, NPS).

## THE AMERICAN PEREGRINE FALCON

The upper Yukon River in Alaska is home to one of the world's most well-studied populations of American Peregrine Falcons. Peregrine Falcons are large, stocky falcons with dark, slate-colored feathers on their backs, lighter feathers on their stomachs, and distinctive facial markings (Figure 1A). They have bright yellow, clawed feet called talons, used for perching and catching prey (Figure 1B). We monitor these birds along a 265-km (165-mi) section of the Yukon River in Yukon-Charley Rivers National Preserve (Figure 2A), in Alaska, U.S. A preserve is like a national park created to protect wildlife, habitat, and history. The high, steep, golden **bluffs** found here are an important Peregrine Falcon nesting habitat. They provide a safe place to raise young and good viewing to look for prey. Each summer, Peregrine Falcons return to the upper Yukon River from their winter ranges, as far away as Argentina, to mate and raise chicks.

**BLUFF**

A cliff rising steeply from the banks of a river, typically having a broad flat or rounded front.

Falcons are birds of prey, meaning they hunt other animals for food. Peregrine Falcons are among the fastest birds in the world. Diving from above, they can reach over 322 km/h (200 mi/hr). This helps them catch their favorite meal—other birds. Using their sharp vision, they target prey in mid-air, chase it, and strike with a sharp blow of their talons. Though they are powerful predators, the **species** has faced difficult challenges. As a top predator in the ecosystem, human activities such as pollution and climate change can threaten Peregrine Falcons.

**SPECIES**

A group of similar organisms that can breed together.

## DAMAGE FROM AN INSECTICIDE AND HELP FROM A LAW

**Dichloro-diphenyl-trichloroethane**, or DDT for short, is an insecticide introduced in the U.S. in 1947. It was used to kill insects that were pests on crops and that caused human diseases. But DDT had other, unintended effects on the environment. When birds ate insects contaminated with DDT, they themselves became contaminated. As Peregrine Falcons fed on contaminated birds, the contamination was passed on to them in ever-increasing amounts. In Peregrine Falcons and other birds, one effect of DDT was to interfere with egg formation,

**DICHLORO-DIPHENYL-TRICHLOROETHANE (DDT)**

A toxic chemical used to kill insects and crop pests. It caused eggshell thinning in many birds.

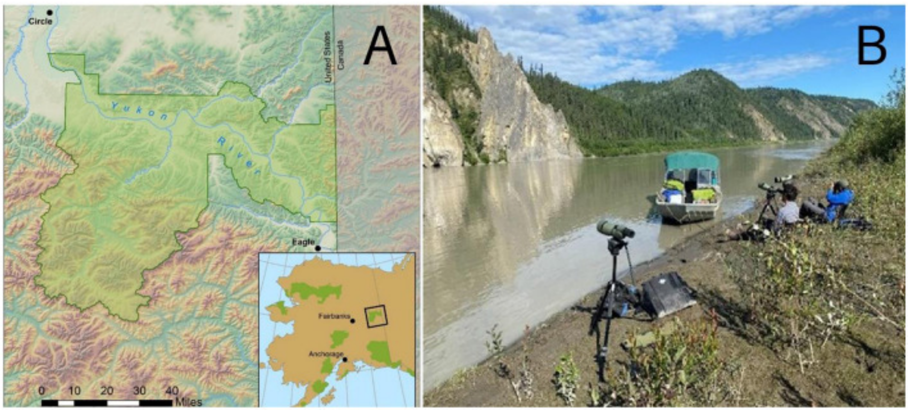


Figure 2

**Figure 2**

**(A)** The upper Yukon River flows 266 km (165 miles) between the Canadian border and Circle, Alaska. Yukon-Charley Rivers National Preserve, Alaska, is outlined in green and the straight green line at the right of the map shows the boundary with Canada. Inset shows the location of the preserve in Alaska with national park lands in green. **(B)** Biologists travel by motorboat and use binoculars and spotting scopes from riverbanks to look for Peregrine Falcons on bluffs (photo credit: Josh Spice, NPS).

resulting in eggs with thin shells. The fragile shells made the eggs susceptible to being crushed in the nest. As a result, nesting birds produced fewer chicks. By the 1960's, many species of birds, including Peregrine Falcons, declined across North America because of DDT. Peregrine Falcons disappeared completely from the eastern U.S. at this time.

The U.S. banned the use of DDT in 1972. In 1973, Peregrine Falcons were listed as endangered under the **Endangered Species Act** (ESA). The ESA is the primary U.S. law that protects imperiled species and their habitats. Efforts started soon after to help the species recover, led by the U.S. Fish and Wildlife Service. In Alaska, scientists tracked the number of breeding Peregrine Falcons nesting along the upper Yukon River. They measured the amount and types of toxins in the Peregrine Falcons' feathers and eggs. More needed to be done to protect Peregrine Falcons, however, because they migrate through other countries and needed protection there, too. Joint efforts by many countries and groups helped the species recover. Although DDT is still used in some areas outside of the U.S., its use worldwide has been much reduced. Further, breeding programs helped baby birds survive and Peregrine Falcons were reintroduced into areas where they had disappeared. The recovery of Peregrine Falcons in Alaska occurred naturally, without breeding programs or reintroductions, but such programs were essential to the overall recovery of the species in many areas outside of Alaska where the species had suffered severe declines.

**ENDANGERED SPECIES ACT (ESA)**

A U.S. law enacted in 1972, designed to protect and conserve threatened and endangered species and their habitats.

## OTHER THREATS TO PEREGRINE FALCONS

Impacts from DDT have been reduced and, while that is good news, other forms of pollution can still harm Peregrine Falcons and other birds. Alaska is remote and the environment there is in pretty good shape. But global pollution carried by air currents still finds the falcons. One pollutant, mercury, can be especially toxic to wildlife.

Mercury is an element that occurs in nature. It is released into the air during mining, manufacturing, and the burning of waste. Once released, mercury can be chemically changed into methylmercury by tiny microorganisms in lakes and ponds. When this happens, methylmercury gets into small organisms like insects living in the water. Those insects are then eaten by larger living things, such as fish and birds. Methylmercury is toxic to birds, affecting multiple organs and egg development. Because Peregrine Falcons are at the top of the food web, they are more likely to consume toxins from their prey. Over the birds' lifetimes, these toxins can build up inside their bodies. Unfortunately, the levels of mercury found in Peregrine Falcon eggs along the Yukon River are cause for concern and, if the mercury levels continue to rise, it could cause failure of eggs to hatch.

Climate change is another threat to Peregrine Falcons. Weather patterns and winds are changing, storms are getting stronger and more frequent, and summer air temperatures are warmer, which can stress the birds. Also, some of the Peregrine Falcon's favorite prey species are shifting their distributions or becoming less abundant, making them less available as a meal. All these things can threaten the health of Peregrine Falcons.

## HELPING PEREGRINE FALCONS THROUGH LONG-TERM MONITORING

One of the reasons the Yukon-Charley Rivers National Preserve was created was to protect Peregrine Falcons and their nesting habitat. We monitor Peregrine Falcons because they are at the top of the food web and can be indicators of ecosystem health. We track animals and their environments to assess ecosystem health over time.

In the preserve, we monitor Peregrine Falcons twice each year to determine their health and numbers [1]. In May, we make our first trip down the Yukon River to count the number of Peregrine Falcons and record which bluffs are being used for nesting. In July, we return to count the number of fuzzy, white chicks in each nest, which is typically between 0 and 4.

Traveling by motorboat, we search the bluffs along 266 km (165 mi) of the upper Yukon River, from Circle, Alaska to the border with Yukon, Canada and back downriver again (Figure 2A). We count the total number of Peregrine Falcons, both mating pairs and single birds, seen at over 175 bluffs. These high, steep bluffs provide Peregrine Falcons with protection from predators, especially for their nestlings. We find birds by using binoculars and spotting scopes, and we watch from the riverbanks or islands (Figure 2B). We have photographs of all nesting bluffs and mark them with all nests found. Nest sites are called **eyries**. Our photographs help us to quickly find eyries and check for birds

**EYRIE**

A nesting site of a bird of prey, often found high on bluffs or in trees.

Figure 3

**Figure 3**

Two American Peregrine Falcon nestlings in an eyrie along the upper Yukon River in Yukon-Charley Rivers National Preserve, Alaska (photo credit: Melanie Flamme, NPS).

in subsequent years because Peregrine Falcons tend to re-use the best sites.

Peregrine Falcons make nests in the eyries by scraping the ground with their bellies. They lay up to four rusty-brown eggs. The nestlings are fragile for their first 2 weeks of life (Figure 3). They can easily overheat or get too cold. Both parents work hard to continuously protect their chicks. They take turns hunting, feeding, shading, warming, and protecting them. After 30 days, the young falcons have grown from fluffy white cotton balls to hulking, black-and-white teenagers. By fall, they have learned to fly and they leave the nest to migrate south.

Nearly 50 years of monitoring shows that the number of Peregrine Falcons in the preserve has increased and is now leveling off. Our study tracked the natural recovery of an endangered species from a population crash to healthier levels. We looked at the Peregrine Falcon recovery from 1977 to 2015, to see how many falcons were occupying each bluff and how many nestlings were produced. We observed 1,602 occupied territories and 2,349 nestlings over those years. The fastest increase in Peregrine Falcon numbers was in the 1970's and 1980's. The increase slowed in the 1990's and 2000's. As the number of occupied bluffs grew, the distance between them got smaller and Peregrine Falcon territories got closer together. Bluffs got more crowded as birds competed for good nest sites. With closer neighbors, the numbers of nestlings dropped. This is probably because pairs were competing for food to feed their young and were spending more time defending their territories from other birds. In recent years, the Peregrine Falcon population has remained fairly steady, which suggests the habitat along the river may now be fully occupied [2].

It took nearly 50 years for Peregrine Falcons to recover from the damage caused by DDT. The Peregrine Falcon population along the upper Yukon River has grown from 12 breeding pairs in 1975 to over 60 pairs today. This is a shining example of the power of international teamwork, long-term monitoring, and effective environmental laws. We will continue to monitor and protect the Peregrine Falcons in the preserve as they face new threats from pollutants and climate change. We hope these continued efforts will help Peregrine Falcons endure future challenges[1].

[1] For more on these falcons, see the video: The American Peregrine Falcon of Yukon-Charley Rivers National Preserve: https://www.nps.gov/media/video/view.htm?id=58132444-1DD8-B71B-0BC14692FB439ECD

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## ORIGINAL SOURCE ARTICLE

Ambrose, S., Florian, C., Ritchie, R. J., Payer, D., and O'Brien, R. M. 2016, Recovery of American peregrine falcons along the upper Yukon River, Alaska. *J. Wildlife Manag.* 80:609–20. doi: 10.1002/jwmg.1058

## REFERENCES

1. Ambrose, S., Guldager, N., Daw, S., Beer, M., Flamme, M. J., MacCluskie, M., et al. 2018. *American Peregrine Falcon Monitoring Protocol for the Central Alaska Network: Protocol Narrative, Version 2.0. Natural Resource Report NPS/CAKN/NRR–2018/1747*. Fort Collins, CO: National Park Service. Available online at: `https://irma.nps.gov/DataStore/DownloadFile/608645` (accessed March 23, 2022).
2. Ambrose, S., Florian, C., Ritchie, R. J., Payer, D., and O'Brien, R. M. 2016, Recovery of American peregrine falcons along the upper Yukon River, Alaska. *J. Wildlife Manag.* 80:609–20. doi: 10.1002/jwmg.1058

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## YOUNG REVIEWERS

### RANJAI, AGE: 12

I like space, fungi, rocks, chemistry, architecture, biology, physics, fortnite, NASA, space telescopes, Rockets, pizza, pasta, chicken (fried, smoked, etc.), sea creatures, Dude perfect, Brave wilderness, history, geography, Rick Riordan books, weapons, archery, Cobra Kai, Beyblade burst, Jurassic park: Camp Cretaceous, Teen titans, Arrow, The Flash, DC, Marvel, Botany, MCU, Dinosaurs, Alan Walker songs, and debating.

### RANVIR, AGE: 11

My name is Ranvir and I am in class 7. As hobby I catch snakes to learn about herpetology. I started doing that when I was 8. I used to catch skinks, but I got bored doing that, so I learned a few things about herpetology and went out with some of my friends. After some time, we found our first Microhylid frog. And after half a year we also found our first snake, a *Lycodon capucinus*! Besides herpetology, I also like doing origami. I also like reading Greek mythology.

### SHAHAR, AGE: 12

Hi! I am Shahar, I am 12 years old and live in Israel. I love art, music, reading fantasy books like Harry Potter and Lord of the Rings. I love learning about all things related to science and technology, and especially about math and astrophysics. I enjoy very much reviewing articles at frontiers, as I get to deeply understand a topic and express my thoughts about it.

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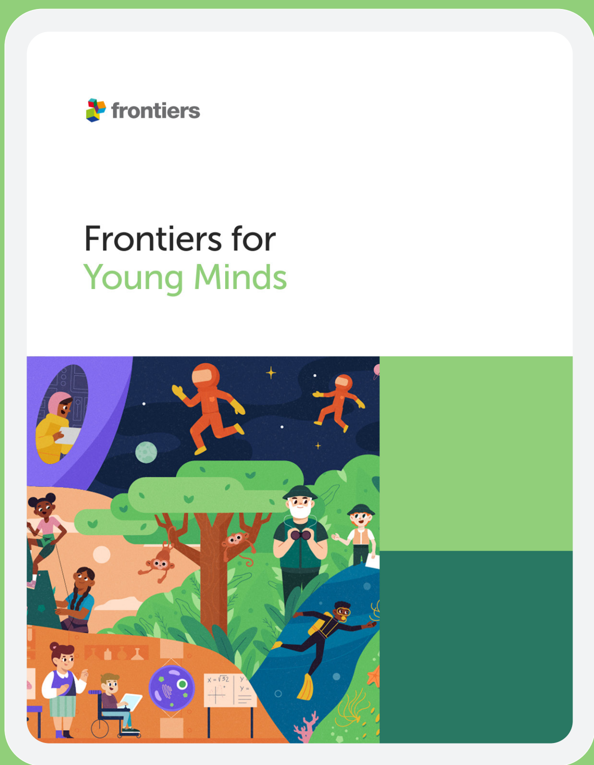


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