Artificial streams reveal how drought shapes California's alpine ecosystems

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University of California, Berkeley, researchers used a network of artificial stream channels to mimic the behavior of headwater streams under present day conditions and future climate change scenarios. The zig-zagging channels, each 50 meters long and 1 meter wide, resemble a mountain headwater stream. The channels divert fresh water from nearby Convict Creek and are equipped with gates to control how much water flows through each channel. Credit: The Ruhi Lab, UC Berkeley

A network of artificial streams is teaching scientists how California's mountain waterways—and the ecosystems that depend on them—may be impacted by a warmer, drier climate.

Over the next century, climate change is projected to bring less snowfall to the Sierra Nevada. Smaller snowpacks, paired with warmer conditions, will shift the annual snowmelt earlier into the year, leaving less water to feed streams and rivers during the hot summer months. By 2100, mountain streams are predicted to reach their annual base, or "low-flow," conditions an average of six weeks earlier in the season than now.

In a new study, University of California, Berkeley, researchers used a series of nine artificial stream channels off Convict Creek in Mammoth Lakes, California, to mimic the behavior of headwater streams under present-day conditions and future climate change scenarios. The study appears in the journal *Proceedings of the National Academy of Sciences*.

Over the course of a summer, the researchers monitored the populations of algae, aquatic insects and other organisms growing in and around the stream channels. They found that shifting the timing of the low-flow conditions also shifted the life cycles of many of these organisms and the relative abundance of different species. It also caused pulses of midges, the dominant insect group, to nearly double in magnitude.

However, because species adjusted to the shifts in a variety of ways, the stream ecosystems were generally resilient to the changing conditions.

"We were surprised to see such a clear example of how biodiversity can stabilize ecosystems," said study first author Kyle Leathers, a graduate student in the Ruhi Lab at UC Berkeley.

"It's similar to having a balanced financial portfolio—because different species respond in different ways to warming, the more species a river has, the more likely it is that warming will not drastically impact an ecosystem process that is key for the broader food web."

University of California, Berkeley, researchers used a network of artificial stream channels to mimic the behavior of headwater streams under present day conditions and future climate change scenarios. The outdoor stream channels allow for natural colonization of insects, algae and other nutrients. They are also equipped with sensors to monitor natural fluctuations in the temperature and dissolved oxygen levels of the water. The wooden-framed screen in the foreground prevents fish from entering the channel. Credit: The Ruhi Lab, UC Berkeley

Changing the rhythm of the seasons

Ecosystem processes follow natural seasonal rhythms, and animals, plants and other organisms are adapted to these seasonal changes. For example, aquatic insects disperse, reproduce and grow along fixed developmental timelines—and their success depends on factors such as water temperature and nutrient availability. Their predators, likewise, are cued to expect abundant populations of insects at specific times of year.

Leathers and senior study author Albert Ruhi, an associate professor of environmental science, policy and management at UC Berkeley, wanted to understand how earlier low-flow stream conditions might impact these natural rhythms.

"When you only study annual averages, you may not get the full story because important changes are happening on a much finer scale," Ruhi said.

The system of artificial stream channels, maintained by the UC Sierra Nevada Aquatic Research Laboratory, offered an ideal location for studying these fine-scale changes. Originally built by researchers at the U.S. Fish and Wildlife Service, the channels divert fresh-flowing water from nearby Convict Creek. Each of the nine channels is 50 meters long and 1 meter wide—approximately the size of a small mountain stream—and equipped with a gate to control how much water flows through the channel.

The outdoor stream channels allow for natural colonization of insects, algae and other nutrients. They also reflect natural fluctuations in temperature, dissolved oxygen and other variables—all of which can be monitored via modern sensors.

"At this scale, this is the only system that uses natural water, not recirculated water, and the water comes from the actual snowmelt in the watershed," Ruhi said. "We could potentially run a similar study by comparing dry and wet years in natural waterways, but it's almost impossible in nature to have nine nearby, identical streams where some are under low flow and others are not."

University of California, Berkeley, researchers used a network of artificial stream channels to mimic the behavior of headwater streams under present day conditions and future climate change scenarios. In this image, lead researcher Kyle Leathers uses a home-built device to capture insects as they emerge from their nymphal stage, which they spend in the water, into their adult stage, which they spend on land or flying in the air. The team built the device using PVC pipes and mesh, and added pool noodles to help it float. Credit: The Ruhi Lab, UC Berkeley

During the summer of 2019, the researchers set three of the nine channels to mimic low-flow conditions starting in early August, which is when streams usually reach low-flow in this region. They set an additional three channels to low-flow three weeks earlier, in early July, and set a final three to low-flow six weeks earlier, in mid-June.

As the summer progressed, Leathers and other members of the research team took periodic measurements of various stream conditions, from water temperature and dissolved oxygen levels to the number of insects in the stream channels. They found that the channels responded almost immediately to low-flow conditions with rising water temperatures, changes in algae metabolism and earlier emergence of insects.

These shifts could have significant consequences not only for the fish, but also for terrestrial predators like birds, bats and lizards that rely on pulses of aquatic insects for food. The boom in midges, for example, attracted nearby Brewer's blackbirds, which collected the nutritious insects to feed their young.

"It is remarkable that despite the stability at the broad ecosystem level, even slight changes can be consequential," Ruhi said. "We did not expect that early snowmelt would control the abundance of stream insects metamorphosing, leading to earlier, more abundant pulses of flying bugs that in turn attracted riparian birds. This type of cross-ecosystem linkage is something we just had not envisioned, and we would have never captured in a laboratory setting. It underlines that timing is everything."

The Ruhi Lab is now expanding on this work to understand how climate change may lead to mismatches—or new matches—in aquatic food webs.

"Ecologists often think of climate change leading to predator-prey mismatches, because predators and their prey shift their life cycles at different rates, or even in different directions, resulting in starved predators," Leathers said. "The notion of novel matches may be underappreciated, but important."

More information: Leathers, Kyle, Climate change is poised to alter mountain stream ecosystem processes via organismal phenological shifts, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2310513121. doi.org/10.1073/pnas.2310513121

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