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Science FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

The Idiosyncrasies of Streams: Local Variability Mitigates Vulnerability of Trout to Changing Conditions

Brooke Penaluna

Transects along a stream in the Trask Watershed Study in the Oregon Coast Range. Coastal cutthroat trout (inset) are the dominant fish in these streams.

"Fish say, they have their stream and pond; But is there anything beyond?"

—Rupert Brooke, poet (1887–1915)

Leaving riparian buffers along streams, minimizing soil disturbance during logging, and incorporating drainage and construction measures to reduce sediment runoff on forest roads—these are a few of the forest practices that protect streams during a timber harvest operation. Yet ask any long-time Oregon logger or forester, and they will say that these practices are relatively recent requirements. In the 1950s, trees were cut down to the streambank and the surrounding area was burned to remove the logging debris.

Timber harvests can impact streams by affecting physical factors, such as turbidity, streamflow, and water temperature, which in turn affect the number and survival of fish, amphibians, and other stream life. In recent years, there has been renewed discussion as

IN SUMMARY

Land use and climate change are two key factors with the potential to affect stream conditions and fish habitat. Since the 1950s, Washington and Oregon have required forest practices designed to mitigate the effects of timber harvest on streams and fish. Yet questions remain about the extent to which these practices are effective. Add in the effects of climate change—lower summer flow and warmer water temperatures in some streams—and more questions arise.

Scientists with the multipartner Trask Watershed Study set out to learn more about how the effects of climate change and timber harvests may interact and affect the long-term survival of cutthroat trout populations in the Oregon Coast Range. They collected data from four streams before and after an adjacent timber harvest and used that information to model stream and trout responses to these changing conditions. They also conducted experiments in semi-natural streams to evaluate the relationship of bird predation and instream cover to trout survival.

The scientists found that local variability in stream habitat, such as water depth and instream cover, play a greater role in reducing the effects of timber harvest and climate change on trout than previously realized. Instream cover and shade improve trout survival by providing a place to hide from predators.

to whether current forest practices designed to protect aquatic habitats are effective, especially related to coastal cutthroat trout (*Oncorhynchus clarkii clarkii*), which are generally the dominant salmonid fish in headwater streams in the Coast Range.

Brooke Penaluna, research fish biologist with the U.S. Forest Service Pacific Northwest Research Station, describes coastal cutthroat trout as ruling these headwaters: "They are the salmonid that is found the farthest up in the headwaters and are frequently affected by timber harvest. They tell a really interesting story about the ability to persist in such a dynamic environment. Of all the parts of the stream network, the headwaters are most sensitive to changes occurring on the land."

In 2005, the Oregon Department of Forestry, Weyerhaeuser Company, and the Bureau of Land Management (BLM) agreed to use some of their land to study the impact of current forest practices by forming the Trask Watershed Study. The study was conducted by scientists from multiple organizations, including the three project sponsors, Oregon State University, U.S. Geological Survey (USGS), and the U.S. Forest Service, and would run from 2007 to 2017.

"It was a terrific opportunity to work with the Department of Forestry and BLM to launch this large study," says Bob Bilby, chief environmental scientist for Weyerhaeuser and lead investigator for the Trask Watershed Study. "Weyerhaeuser had been interested in starting a large, integrated study to take a look at aquatic ecosystem response to forestry as it is currently being practiced in Oregon, and conducting this study with Oregon Department of Forestry and BLM enabled us to expand the range of questions we could address."

The Trask Watershed Study encompasses the headwaters of the Trask River watershed in Oregon's northern Coast Range and includes four streams: Gus Creek, Pothole Creek, Rock Creek, and Upper Mainstream Trask. The study area includes state, private, and federal ownerships, and coastal cutthroat trout are found in all four streams.

Penaluna worked with Jason Dunham, supervisory research aquatic ecologist for the USGS and fish lead for the Trask Watershed Study, to develop a study that wasn't just a before-and-after comparison of fish populations following a timber harvest, as has been the traditional approach. Instead, Penaluna chose to focus on finding a detailed, mechanistic explanation for trout survival. Dunham explains, "We wanted to look under the hood of a stream to see how things actually work because we manage processes, not responses."

To find that mechanistic explanation, Penaluna's study integrated hydrology, stream

KEY FINDINGS

- Local variability in stream habitat—such as water depth, number of deep pools, or instream cover (such as boulders or wood)—buffer the effects of forest management and climate change on coastal cutthroat trout (*Oncorhynchus clarkii clarkii*).
- In some streams, modeling simulations revealed climate change can increase water temperature, consistently triggering an early emergence of trout fry.
- Timber harvests had fewer and less consistent effects on trout than climate change in the modeling simulations. In some streams, harvests reduced the effects of climate change by increasing summer flows, which is when trout may be most vulnerable to avian predation.
- Instream cover and shade were found to reduce avian predation. This suggests that shade is important in streams when instream cover is limited, especially during low summer flows.

Jason Dunham

The Trask Watershed fish team collected data on stream conditions and cutthroat trout populations at study sites along four streams before and after a timber harvest.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

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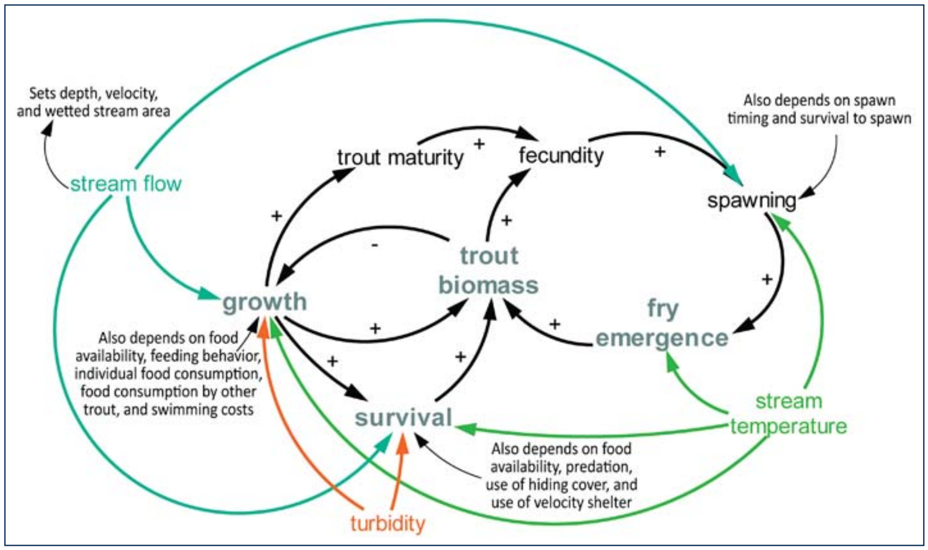
ecology, fish ecology, forest management, and climate change. "Fish experience change locally," says Penaluna. "Understanding how timber harvest, climate change, and predation affect change at a local scale is important." She continues, "Climate change is occurring across the landscape right now and without considering climate change, understanding the effects of timber harvests can be misleading because you're not accounting for a major pressure across the landscape that affects the ability of trout to respond to change."

CUTTING-EDGE SIMULATIONS

From 2007 to 2011, Penaluna and other crew members hiked throughout the Trask Watershed collecting preharvest fish and stream data, such as trout biomass estimates and measurements of stream characteristics that included depth, turbidity, streamflow, and temperature. These baseline data were fed into inSTREAM, an individual-based trout model developed by researchers with the U.S. Forest Service Pacific Southwest Research Station and Railsback, Lang, and Associates. "There isn't another model that can do better what inSTREAM does," she explains. "In this model, individual trout interact with one another and the environment, just as they would in the real world, and their interactions emerge to produce population-level dynamics."



Penaluna et al. 2015

A representation of key processes used in the trout model, inSTREAM, highlighting how stream temperature, flow, and turbidity drive individual growth and survival, and hence population dynamics, including responses of fry emergence and biomass.

Kelly James

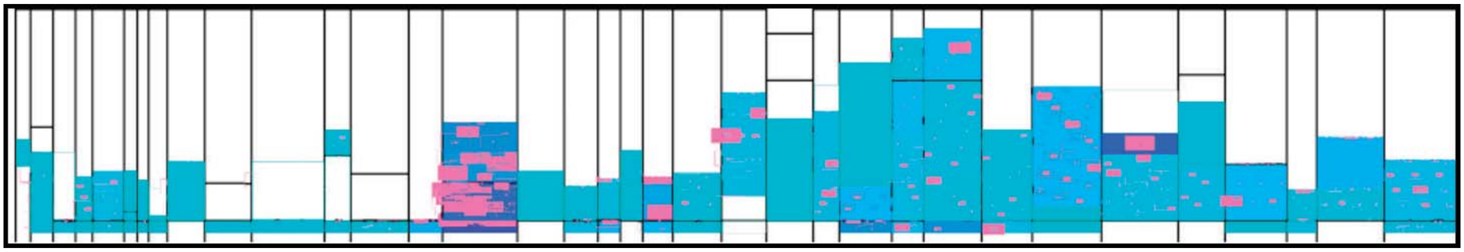
The 2011–2012 harvest in the Trask Watershed. Scientists are now evaluating the field data collected before and after the harvest and will compare those results with outcomes from the model simulations to identify information gaps in our understanding of the effects of forest harvest and climate change on trout.

For the climate change and postharvest stream data that would be fed into inSTREAM, Penaluna culled the current literature for the observed effects of climate change and timber harvest practices on streams. "For the climate change data, I used two studies that are based on 65 years' worth of data on the timing and magnitude of temperature and flow collected in the Coast Range," she explains. "For the forest harvest scenario, the data I used is very reflective of what's going on in the field under general contemporary forest harvests."

Penaluna ran multiple simulations in inSTREAM with two objectives—one examined trout biomass (a combination of weight and population) in response to a stream's physical characteristics and streamflow; the other examined trout biomass, growth, survival, and fry emergence in response to timber harvest and climate change.

After creating a baseline simulation of existing stream conditions and populations based on the field data, Penaluna swapped measured temperature, streamflow, and turbidity from one stream with those of another. This enabled her to determine whether the physical characteristics of a stream affected trout biomass. For the second objective, she manipulated temperature and flow in each stream to mirror timber harvest and climate change. Looking back on the novel work involved to create complex simulations of future trout populations.

The InSTREAM simulations showed that climate change has a greater effect on trout than timber harvests because increasing temperatures will result in an earlier fry emergence and, consequently, a shift in the population to a younger demographic. In contrast, timber harvests didn't appear to have a consistent effect on trout. The simulations' results also confirmed that late summer low flow leads to increased trout mortality because low water levels decrease available habitat, including pools, and reduce cover availability both of which result in higher risk of predation and limited feeding opportunities. However, timber harvests were found to increase summer flow in the short term in some streams, which had a positive effect on trout growth and survival.



Snapshot of one day in the modeled stream of Gus Creek in trout model, inSTREAM. Boxes represent habitat cells. Blue color shows water depth with darker shades representing deeper water. Pink represents fish.

"Brooke was able to use the model to run simulations that are impossible to do in nature," Dunham explains. "She was able to take the temperature, flow, and turbidity from one stream and substitute it in another stream channel. It's the perfect virtual experiment, but the difference is that it's built on real data, and it's built on processes we've been studying for decades."

A SERENDIPITOUS SNACK

To study the relationship of stream cover, shade, and bird predation on trout survival, Penaluna and her team conducted an experiment at the Oregon Hatchery Research Center in Alsea. They designed eight semi-natural stream sections 65 feet long and 6.5 feet wide. Large cement pavers were randomly placed in the streams to create four with high amounts of instream cover and four with little instream cover. The pavers mimicked large cobble and boulders, a preferred cover type for cutthroat trout. Twenty tagged trout were placed in each stream.

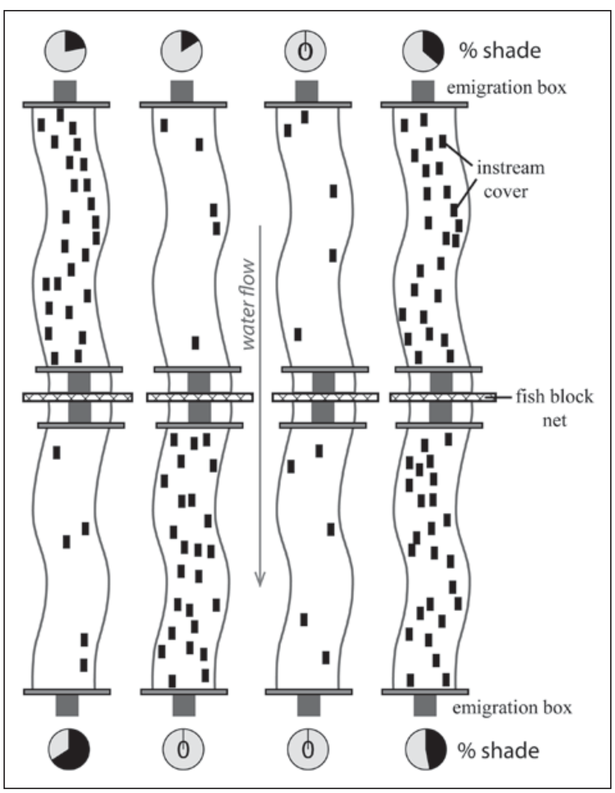
Despite the barriers in place to prevent the fish from escaping, they did. And they escaped in a way that Penaluna hadn't anticipated. "Even though I was going out on Monday to start collecting data, I was excited for my experiment to start so I went out on Saturday to look at my fish in their stream channel—and there were three belted kingfishers (*Megaceryle alcyon*) in there eating them!" The kingfishers' visit proved serendipitous because Penaluna originally had wanted to study the relationship of avian predation and instream cover but couldn't acquire the permits, so she had shifted her focus to study how trout use instream cover to hide from predators and for foraging.

"We've understood for a long time that predation was probably a pretty important factor in terms of cutthroat population in these headwater streams," explains Bilby, "but what we've only come to appreciate more recently is that predation is of greatest consequence during specific times of year, such as the late summer low-flow period."

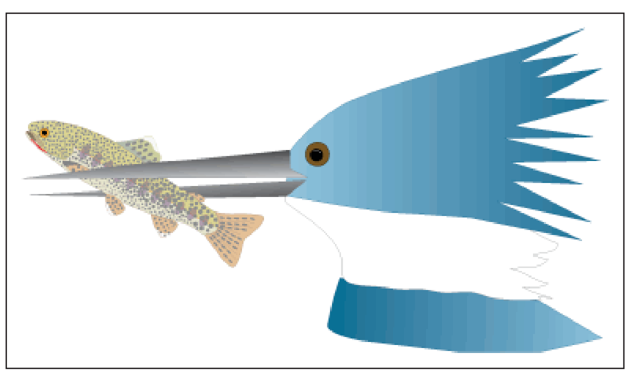
After observing the birds snacking on her fish, Penaluna returned the experiment to its original focus. The kingfishers ultimately ate 66 trout, but that loss resulted in a successful experiment because it's difficult to capture predation in a controlled study, she explains. "Even though we think we understand so much about predation, it's a really difficult process in nature to capture and to isolate."

Her results showed that the availability of instream cover was linked to trout survivorship—higher amounts led to higher survival rates. The availability of shade also proved important in trout survivorship—stream sections with more shade resulted in higher survivorship.

> "Predation is of greatest consequence during specific times of year, such as the late summer."
>
> —Brooke Penaluna, fish biologist PNW Research Station



Kathryn Ronnenberg



Kathryn Ronnenberg

The experimental design of the streams and placement of instream cover that allowed scientists to study the relationship between availability of cover and predation of trout by birds such as the belted kingfisher (illustration).

SEEING THE STREAM

These studies left the team with a new appreciation for how a stream's physical characteristics—instream cover, channel shape, and number of deep pools—can buffer the effects of avian predation, timber harvest, and climate change on trout. Although there had been speculation that these characteristics were important to trout survival, she says that these studies revealed which specific characteristics have a very clear role and are highly important because they influence trout survival.

"Previous studies have suggested that the reason we get different responses to timber harvest in our streams is because the timber harvest must have been implemented differently or because they left those trees in one spot but not here," says Penaluna. "Researchers attributed the differences to what we do as humans, rather than due to differences among the streams themselves."

Penaluna says, "It's much more complex than any of us thought it was going to be, and we have to take the time to isolate the separate and cumulative effects of each pressure on trout and their aquatic habitats to understand the complexities, uncertainties, and the natural variability surrounding them. We have to understand the basic building blocks and the interplay between climate change and timber harvests."

For Bilby, these results suggest a possible shift in land management practices because of the high degree of variability within each stream.

LAND MANAGEMENT IMPLICATIONS

- Local variability in a stream's habitat is key to protecting trout because habitat diversity minimizes the effect of land use and climate change. Management plans that encourage a mixture of conditions that change over time may diversify the responses of trout populations.
- Trout mortality is most likely in late summer when streamflows are lowest. Increasing the number of pools in streams will increase trout biomass by increasing trout survival and body size, which may play a key role in safeguarding trout populations, particularly in streams projected to dry out along portions of their channel with a warming climate.
- Climate change is a key factor to include when designing conservation plans for trout and aquatic ecosystems. It is not possible to isolate the effects of climate and timber harvests on cutthroat trout.

"It raises the possibility of tailoring protective measures for the individual stream reaches."

—Bob Bilby, environmental scientist, Weyerhauser Company

"Because of this high degree of spatial variability, it raises the possibility of tailoring protective measures for the characteristics of individual stream reaches. For example, buffers could be designed to specifically address the sensitivities at a site. This management approach may enable us to both enhance protection of aquatic ecosystems while enabling the landowner to extract the most value from a timber harvest. We can become much more strategic about how we design management protection."

"If our overall goal is to conserve fish into the future," Penaluna says, "understanding more about local habitat structure offers the potential to safeguard them by identifying specific characteristics that will buffer the effects from multiple stressors, including water depth, number of deep pools, and instream cover. And because managers generally manage at a local level, they can actually make changes that matter for the trout."

"Discovery is discernment, selection."

—Jules Henri Poincaré, mathematician (1854–1912)

FOR FURTHER READING

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