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Science FINDINGS

INSIDE

"Science affects the way we think together."
Lewis Thomas

Where the Fish End: Predicting the Upper Reaches of Fish Habitat

A researcher pours stream water into an environmental DNA filtering system. With this system, researchers can simultaneously process four samples from one site. The replicate samples increase the ability to detect target species at a site. USDA Forest Service photo by Laura Hauck.

IN SUMMARY

Establishing riparian zones to protect fish has been a standard forest management practice in western Oregon and Washington for decades. But to effectively place these zones, one needs to know where fish are living.

Brooke Penaluna, a research fisheries biologist with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, has led the development of a new model that predicts the presence of fish more accurately than previous models or other methods, which relied heavily on electrofishing—a labor-intensive method of manually surveying streams.

Her new model, called UPRLIMET, uses light detection and ranging (LiDAR) mapping and computer algorithms to provide the most accurate picture to date of where fish are likely to live in a watershed. In western Oregon, the model predicted coastal cutthroat trout were farther upstream than had been previously estimated.

While she was working on UPRLIMET, Penaluna built on her previous research of environmental DNA (eDNA)—traces of genetic material left by hundreds of different species in rivers and streams—that confirmed UPRLIMET's prediction of extended occurrence.

Together, UPRLIMET and eDNA analyses are highly accurate and noninvasive methods for showing where fish live. They can be used as conservation tools by both public and private forest managers.

"A drop of water,
if it could write out its own history,
would explain the universe to us."

—Lucy Larcom, American poet

Managers of federal forests have worked for decades to balance timber production with fish and wildlife protection. Legislation such as the Northwest Forest Plan and Endangered Species Act require fish and wildlife habitat to be considered at almost every level of forest management.

When it comes to salmon and trout, that means establishing buffer zones along the banks of fish-bearing streams. Among other protections, these riparian buffers maintain shade on the water so that temperatures stay within habitable conditions for the fish. The vegetation and any downed wood in the buffer help prevent erosion, filter pollutants before they have a chance to enter the stream, and reduce stormwater runoff.

But putting protections in the right place is critical to success.

Surveys using traditional methods, such as electrofishing, yield valuable information about the fish species that inhabit various streams, but these methods are imperfect. They provide a snapshot of a particular location in a stream system, but those systems are wildly complex and can extend many miles upstream from where the field crew collected their samples.

How far upstream do fish actually live?

That's an important question to answer because riparian buffers and other protections are put in place based on where fish are known to live. Streams assumed to be "fishless" receive far fewer protections.

Brooke Penaluna, a research fisheries biologist with the USDA Forest Service's Pacific Northwest Research Station, led an effort to develop a new prediction model that combines high-tech mapping using LiDAR technology and computer algorithms to provide the most accurate picture to date of the upper limit of fish presence.

The model is appropriately named UPRLIMET: Upstream Regional LiDAR Model for Extent of Trout.

While she was working on UPRLIMET, Penaluna expanded previous research on environmental DNA (eDNA)—trace amounts of DNA found in streams and other areas of the environment that point to the presence of fish in areas where they were not previously detected. Not only is eDNA analysis an accurate method for detecting the presence of fish and other species, it has the potential for replacing or complementing labor-intensive traditional survey methods such as electrofishing. All that is needed is a water sample and the technology to analyze it.

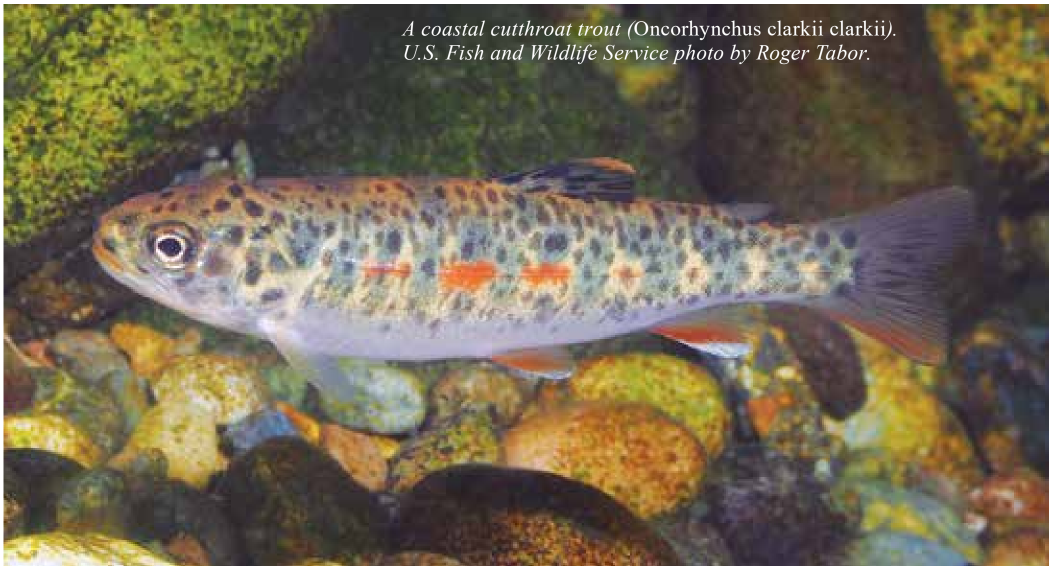
Together, the two technologies are pushing the boundaries of knowledge about fish occurrence and fish habitat, and show potential as valuable tools for forest management.

Where the fish end

Many factors can determine the uppermost reaches of fish habitat in a stream network. A 30-foot waterfall is an obvious barrier to upstream fish travel and can serve as a demarcation line predicting the upstream boundary. Fish are much more likely to live below the waterfall than above it.

Less obvious physical characteristics, such as the steepness of the land through which streams flow, can serve the same purpose. Terrain with a grade of 20 percent or more is assumed to be fishless and receives a lower level of protection (if any) than gentler slopes. Other factors include the absence of pools that fish can use for spawning and refuge; the presence of built structures, such as roads, dams, or culverts; and the precipitation patterns of a particular landscape. If water levels in parts of a stream system become too low to support fish during a typical dry summer, it's a safe bet that that portion of the stream network can be deemed "fishless" from a management perspective.

Mapping the upper distribution limit of fish is complicated because of differences in landownership, land use, and inconsistent mapping and surveying methods across ownership boundaries.



*A coastal cutthroat trout (*Oncorhynchus clarkii clarkii*). U.S. Fish and Wildlife Service photo by Roger Tabor.*

The upper extent of fish in Lookout Creek, H.J. Andrews Experimental Forest. USDA Forest Service photo.

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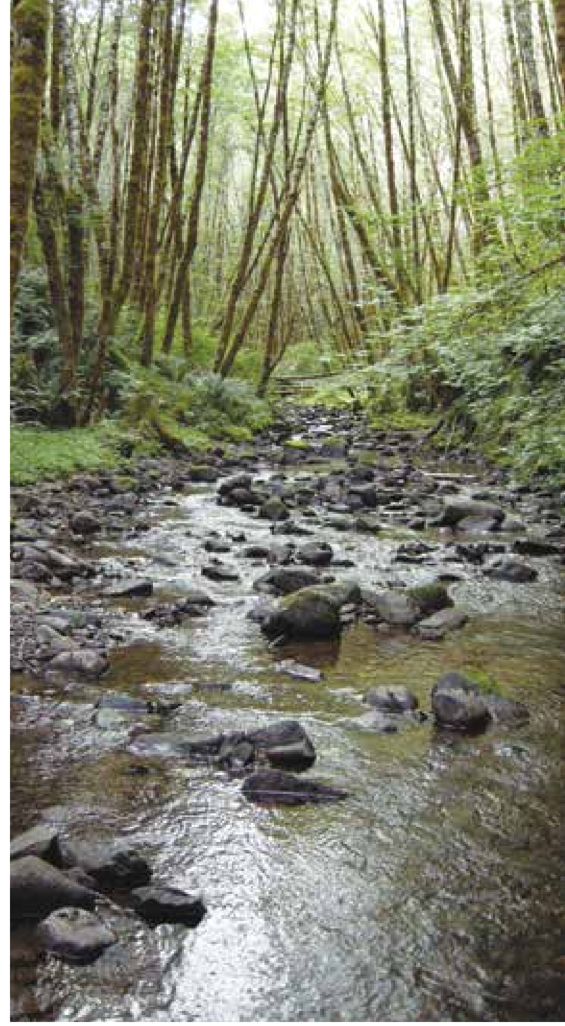
KEY FINDINGS

- The UPRLIMET model accurately predicts the upper limit of fish occurrence in streams. In western Oregon, it estimated more fish in waterways running through private lands than on lands managed by the state, Forest Service, or Bureau of Land Management.
- The analysis of eDNA—residual DNA found in the environment—provides insights into the presence, diversity, and management effects on fish and freshwater biodiversity above and below the upper extent of fish. This boundary marks a shift in species assemblages, elevating the importance of eDNA as an analytic tool.
- eDNA analysis indicates that fish are present farther up in stream networks than previously known.



Rock Creek in the Trask River watershed, Oregon; a waterway where researchers conducted environmental DNA research. USDA Forest Service photo.

"The existence of multiple distribution maps, multiple sources of information for fish observations, and multiple stream network databases presents a potentially confusing array of decision-support options for a land manager to work with. This may lead to different conclusions for management and conservation actions," Penaluna says.

She wanted to develop a consistent and reliable model—one that included state-of-the-art mapping that spanned ownerships and combined an array of hydrological and other environmental data.

Mapping from above

For mapping, LiDAR proved to be the perfect solution. LiDAR (light detection and ranging) is a remote-sensing technology that uses pulsed laser light to measure distances on the Earth's surface, creating precise 3D information about terrain and objects. By combining LiDAR with geospatial and other data, scientists can create detailed 3D models and maps accurate down to half a meter.

LiDAR images are gathered from aircraft and are publicly available to researchers such as Penaluna.

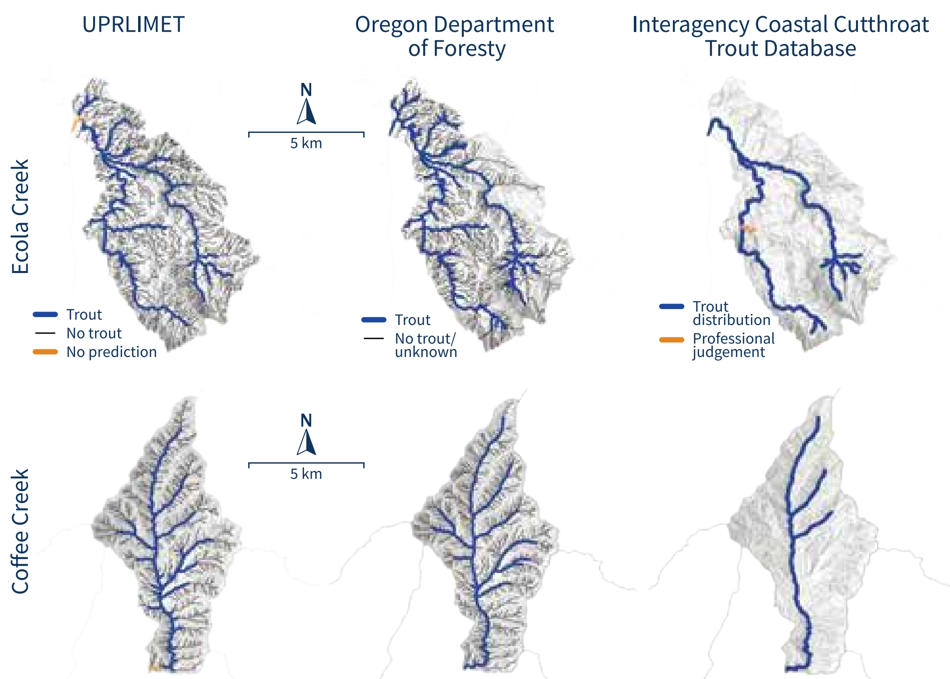
"It's laser light from the sky, and it tells you where things are on the landscape. It gives a really clear picture that we really didn't have before," Penaluna says.

"Even now in 2025, the maps that are commonly used in management don't show the upper limits of some streams. LiDAR changes all of that," she continues. "And it comes with other cool data. Information can be derived from it showing how much of an area is conifer versus deciduous and what's being done on the landscape. It just gives us more information about watershed characteristics than we've ever had before."

In 2006, Brian Fransen, a (now retired) scientist with Weyerhaeuser Company, developed the fish distribution model currently in place for managing private forest lands in Oregon. It combines field data—such as from electrofishing surveys—with geographical information to form a visual representation of the areas being considered. The geographical information can include gradient, upstream basin area, elevation, and annual precipitation. Fransen and his colleagues gathered data on 517 streams on private lands in western Washington and found that the model accurately predicted the upper extent of fish occurrence.

In developing UPRLIMET, Penaluna wanted to improve on the Fransen model. In the 18 years since it was developed, computing power and the availability of data has exploded, giving scientists a huge amount of information at their fingertips.

Penaluna used LiDAR data to observe about 100 sites across federal, state, and private lands throughout western Oregon, and combined the information with 67 environmental predictor



Examples of fish distributions in two hydrologic unit code 12 subwatersheds, including Ecola Creek (Oregon Coast Range) and Coffee Creek (drains into Rogue River). The left panel shows predictions of presence and absence of trout using UPRLIMET. The middle panel shows trout occurrence and habitat distributions from Oregon Department of Forestry. The right panel shows trout occurrence distributions from the Interagency Coastal Cutthroat Trout Database. Adapted from Penaluna et al. (2022a).

LAND MANAGEMENT IMPLICATIONS

- Computer modeling and eDNA analysis are noninvasive tools to help determine the upper extent of fish in streams.
- The ability to accurately determine the upper extent of fish is critical when designing targeted forest management prescriptions that protect freshwater species of concern.
- Data-driven information about the variability of diversity within ecosystems and populations above and below the upper extent of fish is essential when managing for freshwater biodiversity.

variables, including upstream channel length, drainage area, channel slope, and elevation. The model, focusing on coastal cutthroat trout (*Oncorhynchus clarkii clarkii*), predicted the presence of fish farther upstream than previous models and survey methods.

The survey area included Ecola Creek, Coffee Creek, the west fork of the Smith River, and Panther Creek. In all cases, UPRLIMET predicted the upstream fish occurrence with less error than databases, including what Interagency Coastal Cutthroat Trout Database maps showed, and in most cases more upstream habitat than noted on the Oregon Department of Foresty's maps.

Moreover, it predicted a greater abundance of fish on private lands than on land managed by the State of Oregon, the Forest Service, or the Bureau of Land Management. Penaluna says this points to a need for using something like UPRLIMET to develop management plans across ownership boundaries.

That was the goal of the Private Forest Accord, an agreement signed in 2022 between private forest products companies, conservation groups, and State of Oregon agencies to set standards for private timber harvests that maximize protection of fish. It recommends changes to Oregon's Forest Practices Act, impacting more than 10 million acres of private and nonfederal forests.

Jason Walter, an aquatic resources manager for Weyerhaeuser's Western Timberlands and a collaborator on Fransen's research, said he sees potential for UPRLIMET and is working with Penaluna to improve it.

"The use of LiDAR data with UPRLIMET provides the opportunity for it to potentially perform better than the Fransen model," he says. "It's something we didn't have readily available when we developed the model in 2006."

He is partnering with Penaluna on what he calls UPRLIMET II, which will use Weyerhaeuser's vast store of fish distribution and habitat survey data in conjunction with other survey information to develop "the most accurate and useful product possible," he says.

"Typically, when you have more data going in, you have better results coming out," he says. "And one thing about Weyerhaeuser is we have the internal subject matter expertise and the scale to be able to help with research like this."

The promise of eDNA

To use eDNA to inventory stream life, all that's needed is a single water sample. After it's analyzed in a lab, the results provide a rich portrait of what's living in those waters—not just close where the sample was collected but far upstream.

Penaluna had previous experience with this method. She and her research team collected stream samples in Oregon and Washington in 2017 and 2018 and found that the upper limit of where coastal cutthroat trout lived was anywhere between 50 and 250 meters (55 and 273 yards) farther upstream than previous sampling.

She followed up that research with a paper published in 2023 that gave a more detailed picture of the same watershed. It uncovered a hidden biodiversity in the streams, detecting a sparsely distributed amphibian pathogen, the elusive mountain beaver (*Aplodontia rufa*), fish species that went undetected using traditional sampling methods, and newly discovered cryptic lineages of sculpins. It also

The water sample has been poured through the fine filter, which traps the particulates, including environmental DNA. The researcher then places the membrane in a sterile tube for later DNA analysis in a laboratory. USDA Forest Service photo.

Back in the lab, Laura Hauck, a Forest Service researcher, prepares water samples for environmental DNA analysis to identify species present in the waterway where the samples were collected. USDA Forest Service photo.

detected salmonids living farther upstream than expected.

The findings not only predicted the upper limit of fish, they indicated a distinct ecological change in freshwater biodiversity. So, not only was there a point beyond which no fish were detected, but there were fewer traces of other organisms as well. That downward shift in the presence of other species was further evidence of the upper limit of fish.

The findings were further confirmation of the validity and usefulness of eDNA. Based on her work, the State of Oregon has written into policy that fish detections can be made with eDNA for forest management purposes.

This marks a shift in the status quo. The traditional method used for decades by both government and private land managers is electrofishing. Used since the 1960s, electrofishing involves wading through streams and stunning fish with an electrical device. It's usually done in pairs: one person stuns the fish, the other captures it in a dip net. Together they identify, measure, and release the fish back into the stream. As a census-taking tool, it works, but it can be arduous and can potentially harm the fish: the electricity causes muscle spasms that, albeit very infrequently, can damage their vertebrae.

Fransen himself acknowledged problems with electrofishing in his 2006 research, including the fact that fish migrate to different parts of a stream system depending on the time of year, and that numerous factors—droughts, debris torrents, and other disturbances—can temporarily compress fish distribution over 1 or more years.

"The information generated from single-visit surveys of fish occurrence cannot account for intra-annual or interannual variation in the upstream extent of fish distribution," he wrote.

In her previous research, Penaluna and her fellow researchers performed both electrofishing and eDNA sampling at five sites in Fall Creek, a tributary of the Alsea River in western Oregon. Electrofishing identified 13 species, including fishes, crayfish, and amphibians. eDNA sampling identified all those species and many hundreds more.

With eDNA and UPRLIMET, managers now have two new noninvasive and highly accurate methods for predicting fish location.

Fall Creek, Alsea Basin, Oregon; researchers collected water samples here for environmental DNA research. USDA Forest Service photo.

This is something that interests policymakers as well.

Rod Krahmer, forest program coordinator with the Oregon Department of Fish and Wildlife, said the revised Oregon Forest Practices Act rules based on the Private Forest Accord, signed into law 3 years ago, currently uses the Fransen model, but that the long-term goal is to transition to UPRLIMET.

"It's a newer, better model," he says. "We'll get there, but it's probably several years down the road."

In the meantime, Penaluna is confident that UPRLIMET will be the wave of the future for conservation management on both public and private lands. Not only will it be used in the Private Forest Accord, but it could also assist in continued implementation of other plans and rules, including National Forest System lands managed under the Northwest Forest Plan, Bureau of Land Management lands guided by their resource management plans for western Oregon, and lands governed by Washington State forest practice rules.

"You can't possibly manually sample every stream across every ownership," she says. "UPRLIMET is a model that everyone can use."

"A drop of water is as powerful as a thunder-bolt."

—Thomas Huxley, English anthropologist

Writer's Profile

John Kirkland has been writing about science, higher education, and business for more than 20 years. He lives in Portland, Oregon.

For further reading

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Science

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Scientist's Profile

BROOKE PENALUNA is a research fisheries biologist whose work focuses on understanding the effects of climate change, forest harvest, and other disturbances on fish in both riparian and aquatic habitats. She is the lead scientist at the USDA Forest Service's H.J. Andrews Experimental Forest, a 16,000-acre site located in Oregon's western Cascades dedicated to the research of forests, streams, and watersheds. Penaluna holds a Ph.D. in fisheries science from Oregon State University.

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