

Science

FINDINGS

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issue one hundred seventy seven / september 2015

"Science affects the way we think together."

Lewis Thomas

Should I Stay or Should I Go? Understanding the Shapeshifting Rainbow Trout/Steelhead



Dave Herasimtschuk / Freshwaters Illustrated

The metabolic rate of an individual fish appears to influence whether an *Oncorhynchus mykiss* becomes a sea-going steelhead or a freshwater rainbow trout. Above, steelhead in the north fork of the Alsea River, Oregon.

"To me heaven would be a ... trout stream outside that no one else was allowed to fish in."

—Ernest Hemingway

Steelhead, among the most iconic fish in the Pacific Northwest, are anadromous—migrating from streams to the ocean, where their Odyssean wanderings often take them to Asia and up into the North Pacific off the coasts of Alaska and Russia. Upon returning to its natal stream to spawn, this slivery blue fish weighs up to 40 pounds with enough fight to snap a \$1,000 fly rod when hooked.

Rainbow trout live their entire lives in freshwater streams and lakes. The adults, with the

telltale blue-green-red coloring that gives the fish its name, usually grow to a modest one to five pounds. The homebody rainbow is sometimes described as the perfect fish for new anglers because it's easy to handle.

Given these differences in the life histories of the two fish, it can be surprising to learn they are actually the same species: *Oncorhynchus mykiss*. Thus, steelhead can produce rainbows, while rainbows can produce steelhead.

Gordie Reeves, a research fish biologist with the U.S. Forest Service Pacific Northwest Research Station, and colleagues are working to understand what governs the shapeshifting ways of *O. mykiss*. This information may help ongoing efforts to manage and restore *O. mykiss* populations and their freshwater habitats.

IN SUMMARY

Steelhead are the sea-going form of *Oncorhynchus mykiss*. Rainbow trout, also *O. mykiss*, remain in freshwater. Each form, or life-history, can produce offspring of the other, but the mechanism for this and potential effects that climate change may have on the species are poorly understood.

Forest Service scientist Gordie Reeves, along with colleagues from other federal agencies and Oregon State University, conducted a series of studies to better document the biological processes that affect the life-history expression of *O. mykiss*. They found that standard metabolic rate and lipid levels play important roles: those fish with higher metabolisms and lower lipid levels tended to be steelhead, while those with lower metabolisms and higher lipid levels tended to be resident rainbows. Reeves' findings challenge the existing theory that faster growing individuals of the species tend to be seagoing steelhead.

The research examined the effects of water temperature on life-history expression within the species. These findings offer clues about how climate change may affect the rainbow/steelhead ratio in the years ahead. This research informs habitat improvement efforts and protection for steelhead populations, which are listed under the Endangered Species Act. It provides context, revealing how their life-history is interconnected with that of rainbow trout, which are not listed.

MOMENTOUS METABOLISMS

Reeves and collaborators from the U.S. Geological Survey, the National Marine Fisheries Service, and Oregon State University conducted a series of studies that examined how various biological processes and environmental factors might determine whether an individual *O. mykiss* becomes a steelhead or rainbow. The researchers examined fish metabolism, lipid accumulation, and the effects of water temperature on the life-history expression of the species.

Understanding how these things affect the life-history of this species has added relevance because the migratory steelhead form of *O. mykiss* is listed under the Endangered Species Act (ESA), whereas the resident rainbow form is not.

"I think the key takeaway from our work is the recognition that the recovery of the listed steelhead populations could be highly dependent on contributions from the resident rainbow populations," says Reeves. "Management measures that recognize that connection could adopt appropriate measures to fully take advantage of what the resident rainbow populations can do to help the species as a whole."

The best way to think about the *O. mykiss* steelhead-rainbow option is in terms of tradeoffs. As is true of all life, the overall evolutionary objective of the species is to survive and produce offspring. To achieve this, *O. mykiss* can employ two very different life histories.

Purpose of PNW Science Findings

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

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscriptions and change of address information to:

pnw_pnwpubs@fs.fed.us

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Science Findings is online at: <http://www.fs.fed.us/pnw/publications/scifi.shtml>

To receive this publication electronically, change your delivery preference here:

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KEY FINDINGS



- The standard metabolic rate of an individual fish strongly influenced life-history expression in *O. mykiss*.
- Steelhead tend to have higher metabolisms, lower lipid (fat) levels, and to be more territorial than rainbows.
- Rainbow trout tend to have lower metabolisms, higher lipid levels, and to be less aggressive than steelhead.
- Steelhead populations are predominantly female. Researchers found that 65 to 70 percent of steelhead smolts sampled in streams from northern California to southeast Alaska to central Idaho were female.
- Lipid levels decreased at higher temperatures and more individuals were steelhead in such temperature regimes.

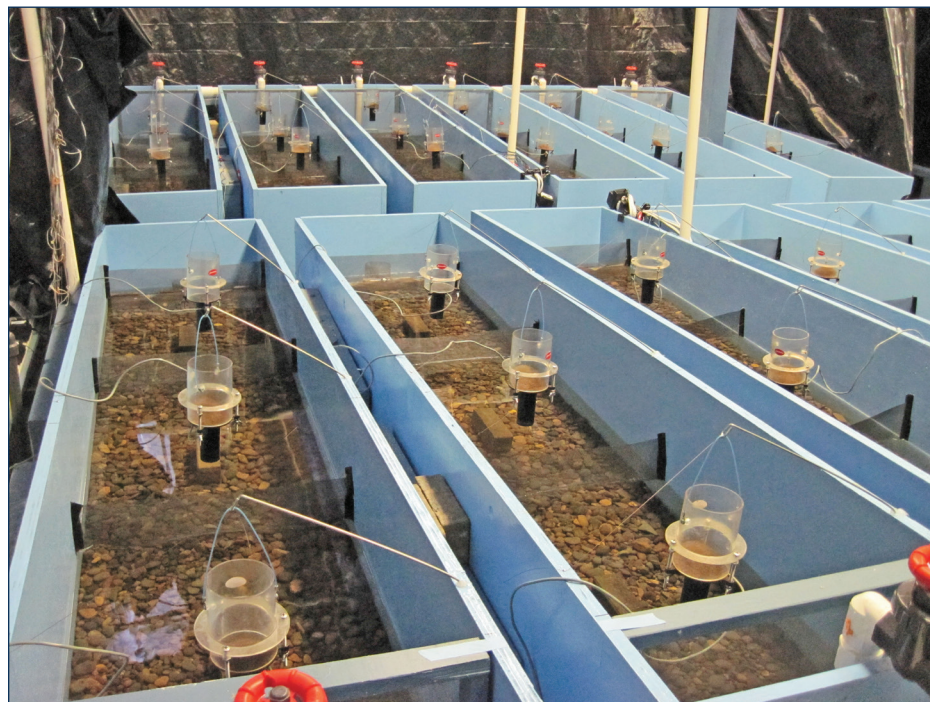
One collection of tradeoffs has to do with metabolism and lipid accumulation. To study these factors, Reeves and Matthew Sloat, a graduate student at Oregon State University, spawned a pair of wild steelhead from the Clackamas River. The researchers took the fertilized eggs to their lab and tended to them. Just before the fry emerged, Reeves and Sloat put the eggs in a basket and submerged them in an artificial stream in the lab.

"We let them emerge into the artificial stream and saw two very different behaviors among

the fish," Reeves says. "One group formed territories and defended them within just a few hours of emergence. The other basically swam around in a loose aggregation."

Reeves and Sloat let this go on for about a month or so, and then separated the 700 siblings by behavior into different tanks. Each fish was marked with a unique color combination and then tracked for a year.

Periodically, Reeves and Sloat would put the fish back in the artificial stream to confirm



Matt Sloat

Scientist collected fertilized eggs from a wild steelhead and had the fry emerge in an artificial stream (above). Within a few hours, some of the young fish were notably territorial (a behavior characteristic of steelhead) while the others swam in a loosely formed group, a rainbow characteristic.

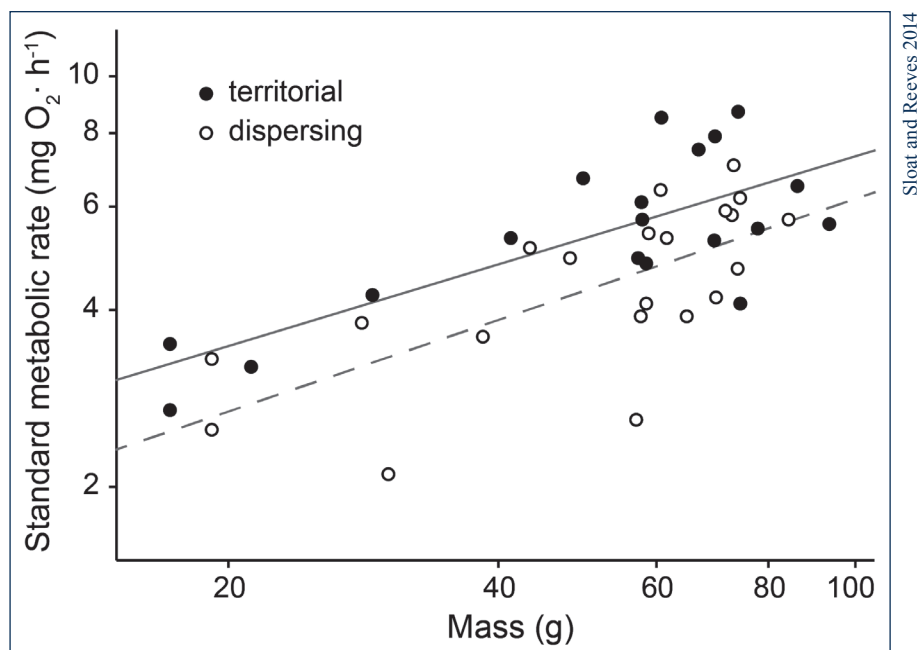
that their behavioral patterns stayed the same, which generally they did. One year later, many of the territorial fish in the study began to show signs of smolting, the transformation that steelhead undergo before migrating to the sea. Meanwhile, many of the nonterritorial fish showed signs of reaching sexual maturity and becoming rainbows, which skip smolting altogether.

What led some fish, from such an early age, to be territorial—a hallmark of the steelhead? Looking for an answer, Reeves and Sloat decided to examine the effects of metabolism, which had not been studied in steelhead. The faster a fish's metabolism, the less likely it is to accumulate fat, which translates to energy needed to succeed as an adult through reproduction.

To measure metabolism, the rate at which physical and chemical processes occur in the fish, the two researchers placed each fish in a water-filled respirometer tube with sensors for measuring the oxygen consumed by the fish. In general, fish with higher metabolisms, which also had lower lipid levels, were in the territorial/steelhead group. Fish with lower metabolisms, with higher lipid levels, were more likely to be in the nonterritorial/rainbow group.

This distinction makes sense considering the very different food environments in freshwater and the ocean. Rainbow trout generally subsist on small insects in stream beds, such as mayflies and stoneflies, a food source that provides low nutrient quality and meager energy levels compared to the shellfish, squid, and other fish that steelhead eat in the ocean.

"If you're a fish and have a fast metabolism and a ton of food in the ocean front of you, you just can gulp down what's available, digest the easily digestible pieces and then



The young *O. mykiss* with territorial behavior of steelhead, tended to have faster metabolisms, compared to the fish that dispersed and showed signs of developing as rainbow trout.

basically get rid of the rest," says Sloat. "As you crank through that process, you're going to grow much faster than if you are taking a long time to digest your low-energy, scarce freshwater food."

For *O. mykiss* with fast metabolisms, the benefit of the migratory steelhead life-history is access to a food environment in which they are most suited to thrive. Steelhead make their long trek because they stand to reap a far greater benefit from the ocean's smorgasbord than would slow-metabolism rainbows, which thrive on the freshwater diet. The cost of the migratory life-history, however, is the lower survival rate stemming from the dangers of the journey and ocean predators.

These findings are poking holes in existing theories about metabolism and *O. mykiss*. Conventional wisdom held that fish with fast metabolisms, which also are generally fast-growing, were more likely to be the first to capitalize on all the suitable freshwater habitats and become resident rainbows, crowding other *O. mykiss* out of their natal environments and forcing them to take their chances as steelhead in the ocean.

"Our work showed that's not true," says Reeves. "The fast-growing, fast-metabolism fish simply can't continue to meet their metabolic demand in freshwater. This finding challenged one of the scientific dogmas in the field."

WHY IT PAYS TO BE A STEELHEAD IF YOU'RE FEMALE

Haley Ohms, another OSU graduate student working with Reeves, helped to test another idea about *O. mykiss*: that the mix between male and female fish varied depending on how far spawning beds were from the ocean. Ohms looked at sex ratios of *O. mykiss* in nine streams in the West, from northern California to Alaska and as far east as Idaho. She examined fin tissues samples collected by a nonlethal method and performed a genetic analysis, novel at the time, to determine if the sample came from a male or female fish.

The results were somewhat surprising. Ohms found that, regardless of the location of the stream, about 65 percent of the migrating

steelhead—averaged across all samples—were female. Although the female bias in steelhead had been previously studied, it was not known if the percentage of females might vary significantly depending on migration distance. In Ohms' study, the female bias was about the same among fish sampled from Idaho streams hundreds of miles from the ocean as those from coastal streams in California, Oregon, and Alaska.

As with the data on metabolism, the key to understanding these results is to again consider the tradeoffs.

"If you're a female, you want to be big, period," says Reeves.

First, bigger bodies usually produce a greater number of eggs. Second, heft helps steelhead when it comes to carving out their redds, or nests, in the streambeds when the fish return to freshwater to spawn. These redds are 1 to 2 feet across and several inches to a foot deep.

In terms of reproductive fitness, for males the life-history question is more of a toss-up, even though at first blush it seems that a 6-inch resident rainbow might be at a severe disadvantage when facing off against a 26-inch steelhead for access to females and their nests. However, that steelhead had to spend several years in the ocean bulking up, and while he was away the smaller rainbow had multiple opportunities to reproduce every season.

This explains why, in both Sloat's and Ohm's research projects, no similar skewing toward males was seen among either steelhead or rainbows.

Reeves cautions that it's a mistake to look at life-history strategies as a black-or-white, either/or proposition. "Within the *O. mykiss* population, there are actually multiple strategies to achieving reproductive success," he says. "Think of the population as essentially trying to diversify its portfolio of strategies to ensure that the species as a whole is maintained."

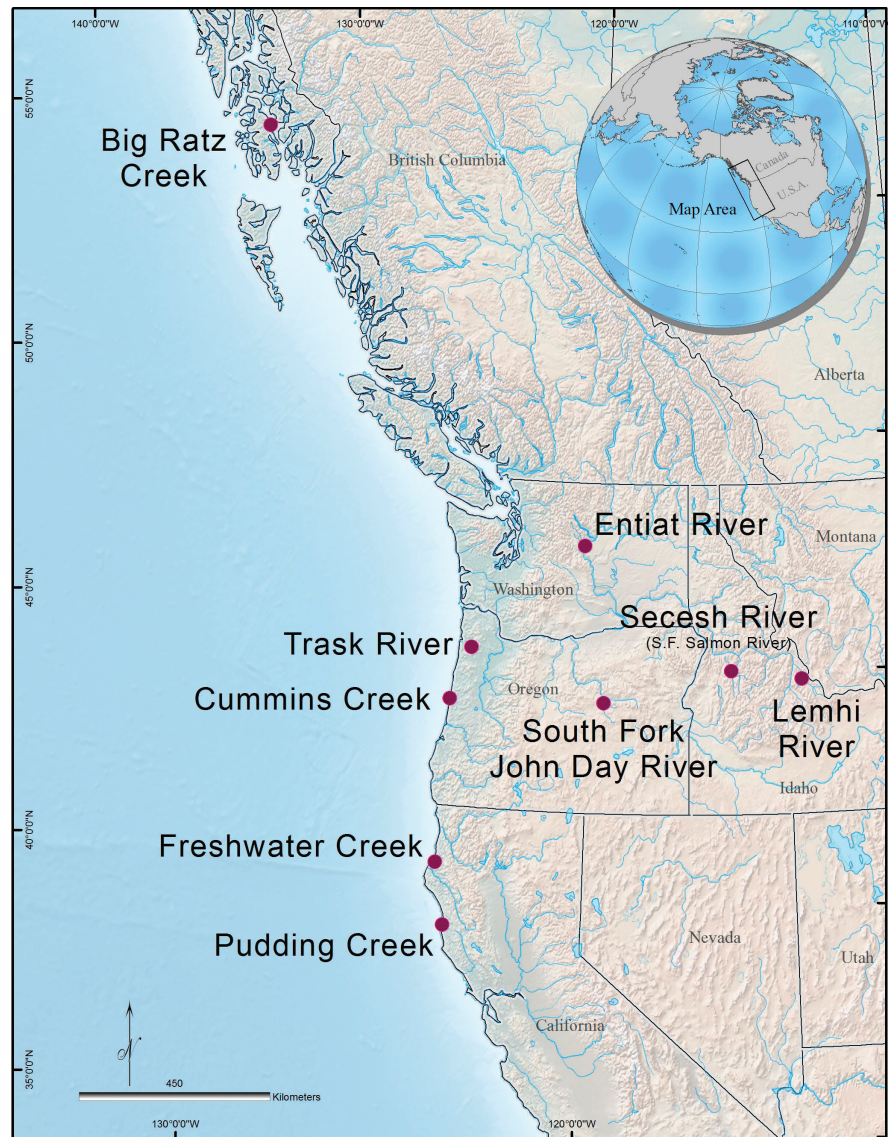
CLIMATE CHANGE, STREAM TEMPERATURE, LIFE EXPRESSION

In a study with Jeffrey Falke, a postdoctoral researcher at OSU, Reeves and several other collaborators helped build a mathematical model to explain the distribution and abundance of steelhead spawning across more than 9,000 miles of stream in Oregon's John Day Wilderness. The model attempts to explain the relative importance of variables like temperature, access to spawning sites, quality of spawning habitat, and rates of juvenile survival. The researchers found that given the importance of both temperature and stream flow for steelhead spawning, *O. mykiss* may be highly sensitive to impacts of land and water uses and projected climate impacts in the region.

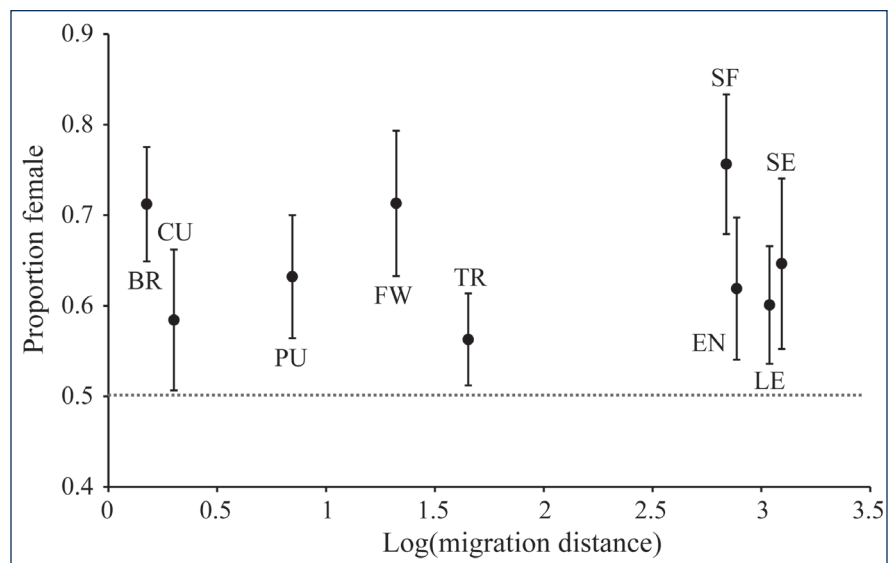
How might *O. mykiss* life-history expression be influenced by climate change? Reeves found that, on one hand, warmer waters may initially boost the *O. mykiss* metabolism, making it more efficient in its ability to store fat. This would likely increase the expression of rainbows, particularly among males. However, as warming trends continue, fish metabolism may be revved up so much that a tipping point is passed. In such a scenario, fish would be unable to eat enough in freshwater habitats to pay their new, higher metabolic bill, and so selection pressure might favor steelhead expression.

"Climate change is just one more modification to these systems, where temperature regimes have already been altered quite substantially," said Reeves. "Are we now pushing the systems to limits that may exceed their ability to adapt?"

To the extent that this remains an open question, Reeves' work suggests that perhaps the best bet for now is to think about lending more of a hand to that entire diverse portfolio of life-history strategies displayed by *O. mykiss*—and to many other migratory fish



The map above shows study sites from northern California to south-central Alaska where researchers studied sex ratios in wild *O. mykiss* populations between 2011 and 2012.



Steelhead populations tend to be predominately female, regardless of the distance they must travel to reach the ocean. BR, Big Ratz Creek, AK; CU, Cummins Creek, OR; PU, Pudding Creek, CA; FW, Freshwater Creek, CA; TR, Trask River, OR; SF, South Fork John Day River, OR; EN, Entiat River, WA; LE, Lemhi River, ID; and SE, Secesh River, ID.

that are a part of the heritage of the Pacific Northwest and so unique among the world's fish species. Indeed, the many mentions of never-to-return historical salmon and steelhead runs obscure the fact that just 1 percent of the world's fish species are anadromous.

EVOLVING THOUGHTS ABOUT *O. MYKISS*

Early suppositions about *O. mykiss* have given way as research has provided enhanced understanding of the species. When Reeves first encountered rainbow trout/steelhead in a biology class, the fish were classified as part of the genus *Salmo*, which includes Atlantic salmon. In the late 1980s, after closer genetic analysis, the species was moved to the genus *Oncorhynchus*, which includes various species of Pacific salmon and trout.

Most Pacific salmon and trout populations, including *O. mykiss*, are vastly diminished compared to historical levels. Logging, interbreeding with hatchery fish, agriculture and development, fishing, and dams and other impediments are the main culprits, according to a September 2008 “species of concern” bulletin published by the National Marine Fisheries Service.

In 2006, ten distinct population segments of steelhead along the West Coast and Idaho were listed under the federal Endangered Species Act. Generally ESA protection is given to a species in a given geographical area. In Oregon, several species of salmon in the genus *Oncorhynchus* are listed as endangered or threatened—Chinook in the lower Columbia River, coho on the Oregon Coast, and sockeye in the Snake River. In the case of *O. mykiss*, however, protection extends only to the steelhead form, which is relatively rare compared to the much more numerous rainbows.



USFWS Togiak National Wildlife Refuge

As an evolutionary tactic, the freshwater or sea-going life-history options available to *O. mykiss* provide the species with two pathways for survival. Above, a rainbow trout is released.



LAND MANAGEMENT IMPLICATIONS



- Rainbow trout populations may be important for recovering listed steelhead populations, a critical consideration for resource managers when setting objectives for habitat improvement and protection efforts, as well as sport fish harvest levels.
- Climate change impacts are likely to be mixed. Increases in water temperature may lead to increases in the expression of the steelhead life-history in some situations, particularly where water temperatures are currently cold. However, elevated water temperatures may also result in increased mortality, particularly in streams that are already warm. Reducing temperatures moderately in such situations may improve the expression of the steelhead life-history.
- Accounting for broader landscape processes, such as stream flows and water temperature regimes, may increase the potential for success in habitat restoration.

This decision to list steelhead while not considering the relative abundance of rainbow trout has been challenged in court. However, in August 2010, the U.S. 9th Circuit Court of Appeals upheld a lower court decision affirming steelhead's status as an endangered species. Six irrigation districts in California's Central Valley argued unsuccessfully that steelhead must be considered with rainbow trout, and given the combined numbers, that ESA protection was not warranted.

“Resident rainbow populations just don't get as much attention as the anadromous steelhead life-history of *O. mykiss*, which really is among the charismatic megafauna of this region,” says Reeves. “We're talking about the same species here, and if you think it's worthwhile to maintain steelhead populations, I think the science suggests it may be also important to maintain resident rainbow populations. Doing so may be key to recovering the steelhead life-history.”

“Fifty years ago, every live brook, runnel, and stream that made a pretense of carrying some head of water through the summer drought had its quota of steelhead moving upstream.”

—Clark Van Fleet, *Steelhead to a Fly*, 1954

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FOR FURTHER READING

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those fish, the impacts of climate change on aquatic ecosystems and associated biota, and aquatic aspects of landscape ecology. He has studied the ecology of anadromous salmon and trout in the Pacific Northwest, northern California, Idaho, and Alaska and fish ecology in New Zealand and New York. Reeves has a Ph.D. in fisheries science from Oregon State University.

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