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Science FINDINGS

INSIDE

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

Let the Fish Do the Talking: How Fish Behavior Is Linked to Patterns of Temperature and Stream Discharge

Rick Swart, Oregon Department of Fish and Wildlife

Coho salmon migrate up a tributary of the Columbia River, fall 2009. Scientists are investigating the environmental conditions that trigger salmon migration. They developed a visual tool that provides dam managers and restoration planners with needed information for managing streamflows to benefit salmon migrations in the future.

IN SUMMARY

Adult salmon sense when the time is right to leave the ocean and head for fresh water to spawn. But how do they know this? And how will climate change affect this cycle? Rebecca Flitcroft, a research fish biologist with the USDA Forest Service, Pacific Northwest Research Station, and colleagues took a closer look at the connection between migration patterns and stream conditions.

They found that water temperature and the rate of streamflow appear to be two of the environmental conditions that precipitate the migration of salmon to their freshwater spawning grounds. This doesn't bode well for salmon, given that these stream conditions are being altered by climate change.

The researchers used hydrologic data collected at dams in Oregon and Washington and linked them with data showing the timing of migratory fish passing those dams. The findings are displayed visually in ichthyographs, a newly developed graphic tool that shows the precise conditions under which fish move upstream.

This research provides a current baseline for understanding the connection between hydrologic conditions and fish movement. It also highlights ways in which the effects of climate change potentially could be mitigated by managing streamflows at critical times of the year to benefit salmon migration.

*"Observe due measure,
for right timing is in all things
the most important factor."*
—Hesiod, Greek poet

It's been known for centuries that salmon spawn in fresh water, travel to the ocean to live out most of their adult lives, and then return upstream to their birthplace to begin the next generation. But how does the environment trigger their return trip? What factors lead salmon to queue up near an estuary and then migrate upstream?

Scientists including Rebecca Flitcroft with the USDA Forest Service, Pacific Northwest (PNW) Research Station, believe part of the answer is in the predictable seasonal patterns of water temperature and river discharge. Both factors tell salmon when the conditions are right for safe passage.

"They tend to hang out offshore until the time is right," she says. "Many of those fishes have to travel hundreds of miles, so they don't want to go too early or too late. They don't want to get stranded."

Flitcroft led a collaborative team of biologists, geographers, and hydrologists from the State of Oregon, Oregon State University, and Western Oregon University to learn more about the environmental factors that trigger salmon migration and how climate change may alter these factors. The researchers examined fish passage data gathered from dams in Oregon and Washington and analyzed it in conjunction with other data on daily water temperature and riverflow. They then developed a visual tool that shows how all three factors relate to each other. The new tool, which Flitcroft calls an "ichthyograph" (from the Greek *ikhthus*, meaning "fish"), integrates long-term datasets and provides a visual format for understanding the upstream behavioral movement and tolerances of native fish.

Dam managers, for example, could use information in ichthyographs to guide decisions about when to release water and under what conditions. For habitat restoration, ichthyographs also have potential utility in habitat restoration planning, indicating areas of focus that go beyond spawning sites, where overall streamflow could be maximized.

The work is particularly important as the climate changes. Seasonal flow patterns in rivers and streams are expected to change in the Pacific Northwest. In places with historically snow-dominated river discharge patterns, winter flows will likely be faster and higher as storms bring rain instead of snow. Without gradual snowmelt, summer flows will be lower. Likewise, places with rain-dominated river discharge patterns may experience intense storms leading to high flow events. To date, the changes have been happening gradually over decades, but the rate of change is expected to accelerate.

"Because salmon are biological creatures, they evolve. But whatever adjustability they have, we've pushed them to the limit," says Gordon Grant, a research hydrologist with the PNW Research Station, who played a pivotal role in the project.

Examining Salmon Migrations

Flitcroft first focused on fish passage data from Winchester Dam, located above the main confluence of the North and South Umpqua River in southwest Oregon. The dam was built in 1890 and contained power-producing turbines until 1923. Since then, its main function has been to form a reservoir. A fish ladder has been maintained at the dam since 1945.

Flitcroft, Grant, and other collaborators obtained streamflow data from the U.S. Geological Survey for the North Umpqua River at Winchester Dam from 1992 to 2013. They also obtained census counts for fish migrating upstream and water temperature data during the same period from the Oregon Department of Fish and Wildlife (ODFW).

Analysis of the 21-year record revealed that coho salmon midriver migration began when water temperatures drop to about 64 °F, which tends to happen in early fall after peak summer temperatures have occurred, but before the onset of significant fall rain.

Visualizing the Data

Flitcroft collaborated with others to plot temperature and discharge data together, forming a multicolored graph showing the conditions at the dam for each month of the year. The data points coalesced into a simplified triangle, the apex of which showed that the highest rates of discharge happened in fall and winter when water temperatures averaged about 45 °F.

She overlaid coho salmon fish passage data on the framework of discharge and temperature, creating an ichthyograph for mid-river upstream migration. She then conceptualized what an ichthyograph would look like for each of the coho salmon's life stages, and at each location of its migratory journey—from the headwaters, to the ocean.

The value of such graphical information is that it shows historical and current conditions that can form an understanding of what might happen under various climate change scenarios and different management practices.

"It's a visually accessible way to look at a huge amount of data, and it's intuitive," Flitcroft says, noting that she explored many examples of graphical displays before landing on a final product that was easy to interpret. "We always knew we wanted to somehow represent fish, discharge, and temperature. It was finding the right medium to be able to represent the data that was a challenge."

Purpose of PNW Science Findings

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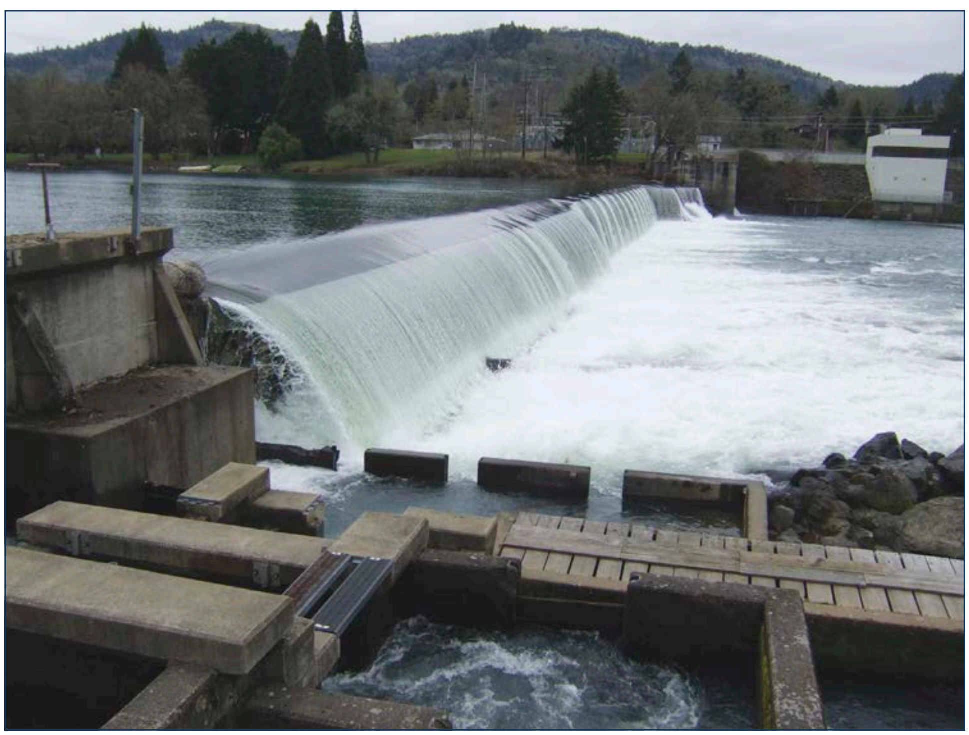


Rachel Lovell Ford

The Winchester Dam on the North Umpqua River, Oregon. Salmon migration data were collected from the counting station along the fish ladders in the foreground.

Another problem is getting the data. The kinds of data the team compiled on Winchester Dam are ideal, but uncommon, according to Flitcroft. A certain amount of extrapolation can be done by combining hydrologic data with existing knowledge of fish behaviors, but to get both in hard numbers generally only happens at dam sites.

So she expanded the research to include more locations.

In addition to providing more data, dams and other forms of water management can significantly alter seasonal patterns of temperature and flow volume—called the hydroregime—which change environmental conditions for migrating fish. By analyzing how salmon are currently behaving on their migratory journey, Flitcroft also wanted to analyze their vulnerabilities and resilience in the face of hydroregime changes brought about by water management and climate change.

She reexamined the data from Winchester Dam, and included three more locations: Willamette Falls on the Willamette River at Oregon City; Bonneville Dam on the Columbia River; and Ice Harbor Dam on the Snake River in Washington, near its confluence with the Columbia. Willamette Falls was the only one of the four that is not a dam; it is a natural waterfall where a fish ladder has facilitated salmon migration since 1913. Like dams, Willamette Falls is a data collection site maintained by government agencies monitoring fish counts and water temperature and flow.

Again, she focused on coho salmon because they are imperiled, and protected under the Endangered Species Act. Coho salmon also exhibit narrow migration timing compared to other salmon on the west coast.

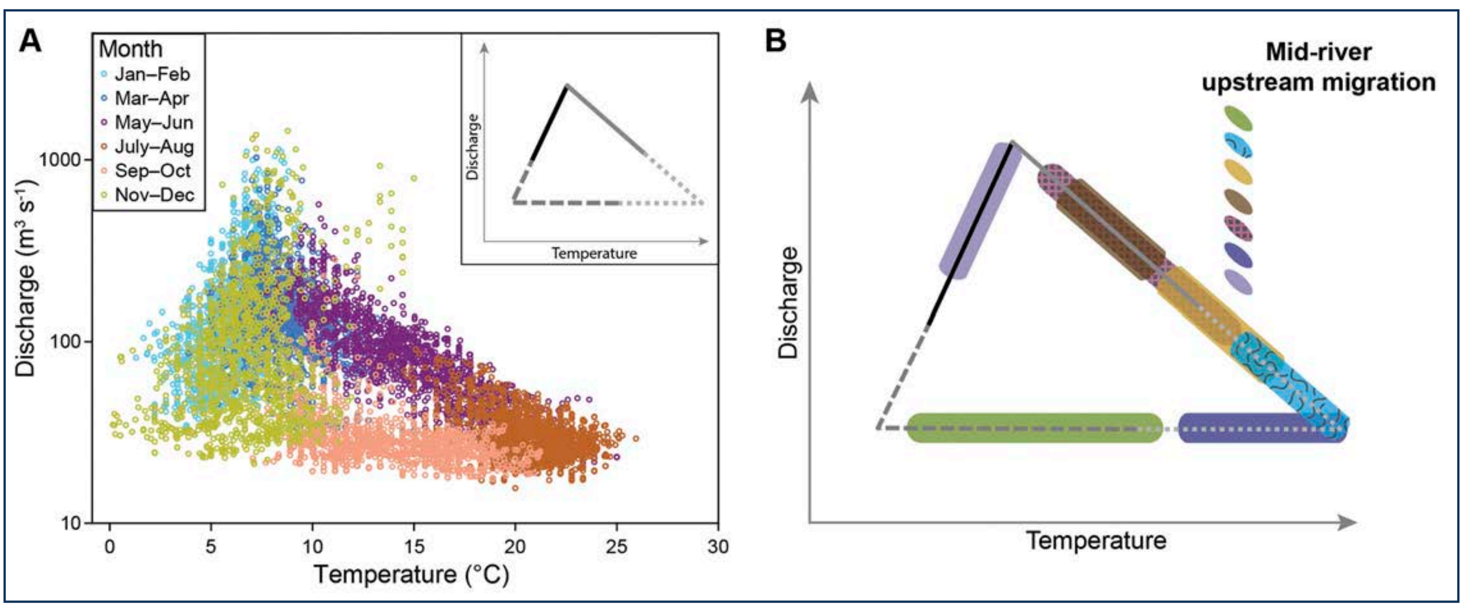
KEY FINDINGS

- Pacific salmon and other diadromous fish are subject to stresses in both freshwater and marine environments, making them particularly vulnerable to climate change.
- Current patterns of behavior indicate that challenges from climate change to long-term species persistence will vary across cohort, species, life stage, and environment.
- For coho salmon (*Oncorhynchus kisutch*), the range of future environmental conditions in some areas is projected to remain within the tolerable limits expressed by upstream migrating adults.
- In other locations, changes in streamflow and temperature are projected to occur during peak coho salmon migration and may affect survival of adult salmon returning from the ocean to spawn.

As before, Flitcroft plotted the monthly temperature and flow information into multicolored graphics, then she overlaid information showing coho salmon migratory activity. The salmon's migratory runs at each of the four study sites corresponded with optimal temperature and flow conditions. Adult coho salmon movement through these areas occurred when water temperatures were between 45 and 60 °F. Coho salmon in the Columbia River experience mortality at temperatures higher than about 70 °F; and for all salmonids, the lethal limit is often cited as roughly 79 °F.

Flitcroft's research team then showed how the flow rates at the four sites are expected to shift under different climate change scenarios. Currently, coho salmon pass Bonneville Dam starting in mid-May and extend their run to the beginning of October. Climate change predictions for flow by 2080 indicate that if run timing of these fish does not change, the main portion of the run will be moving during a time of decreased flow. For fish that migrate through Willamette Falls or Winchester Dam, climate projections indicate that the early portion of the run may be affected by lower riverflows.

In other words, for coho salmon to continue to migrate during the most ideal conditions of temperature and discharge, they may need to adjust their travel time as the climate, and its subsequent effect on river conditions, changes.



An example of an ichthyograph showing (A) temperature and discharge information at different months of the year and (B) fish migration patterns correlating with discharge and temperature fluctuations.

What Does This Mean for Salmon?

In Oregon, and much of the Pacific Northwest, climate is projected to warm from 1.8 to 7 °F by the 2050s—and possibly 3.6 to 11 °F by the 2080s, depending on future greenhouse gas emissions. For coho salmon returning from the ocean to their spawning grounds above Bonneville Dam on the Columbia River, the journey will likely become increasingly hazardous as water temperatures rise, leading to increased mortality from disease or the physical stress of high temperatures.

The salmon will be able to adjust up to a point, but beyond that it will be up to the people managing dams and irrigation to help provide the water conditions that mitigate the effects of the changing climate.

"Managing dam operations has immediate and direct effects on discharge and temperature," Flitcroft says. "It may be a critical mechanism to mitigate the impacts of climate change on streams in the coming century."

Ichthyographs may become important guides in this process because they inform how to match water conditions with critical life stages of fish. They can also help salmon hatchery managers manipulate fish run times to adapt to changing climate conditions.

Flitcroft is working with ODFW on how to link temperature and discharge patterns to the life cycles of coho salmon, which may influence a statewide salmon recovery plan that is currently in the works.

"ODFW has recently developed a climate change policy, which is now a consideration for all that we do," says Kara Anlauf-Dunn, an aquatic biologist with ODFW. "We are currently thinking about climate adaptation across the agency including understanding climate risks to our hatcheries and angling opportunities."

LAND MANAGEMENT IMPLICATIONS

- Ichthyographs are tools for matching seasonal water availability to life stages of fish, facilitating decisions about water management and climate change with regard to critical times in fish life cycles.
- Understanding patterns in the timing of fish migration with environmental conditions, and how that timing is changing, can provide important information for water regulation managers about the timing of water releases.
- The absence of information about physical and environmental habitat conditions for Pacific salmon in marine settings is a significant knowledge gap in conservation planning.

Anlauf-Dunn and her colleagues are currently mapping the rate and magnitude of change in stream temperatures across the state to understand the physiological tolerance of fish to changing temperatures. Flitcroft's work plays an important role in that effort.

"The ichthyographs that Becky devised really show the synchrony these anadromous fish populations have with their environment and how that influences migration and behavior," Anlauf-Dunn says.

In Oregon and throughout the Northwest, Flitcroft has been presenting her initial 2016 findings to agencies such as the National Oceanic and Atmospheric Administration, U.S. Forest Service, and ODFW as well as international professionals specializing in fish passage issues.

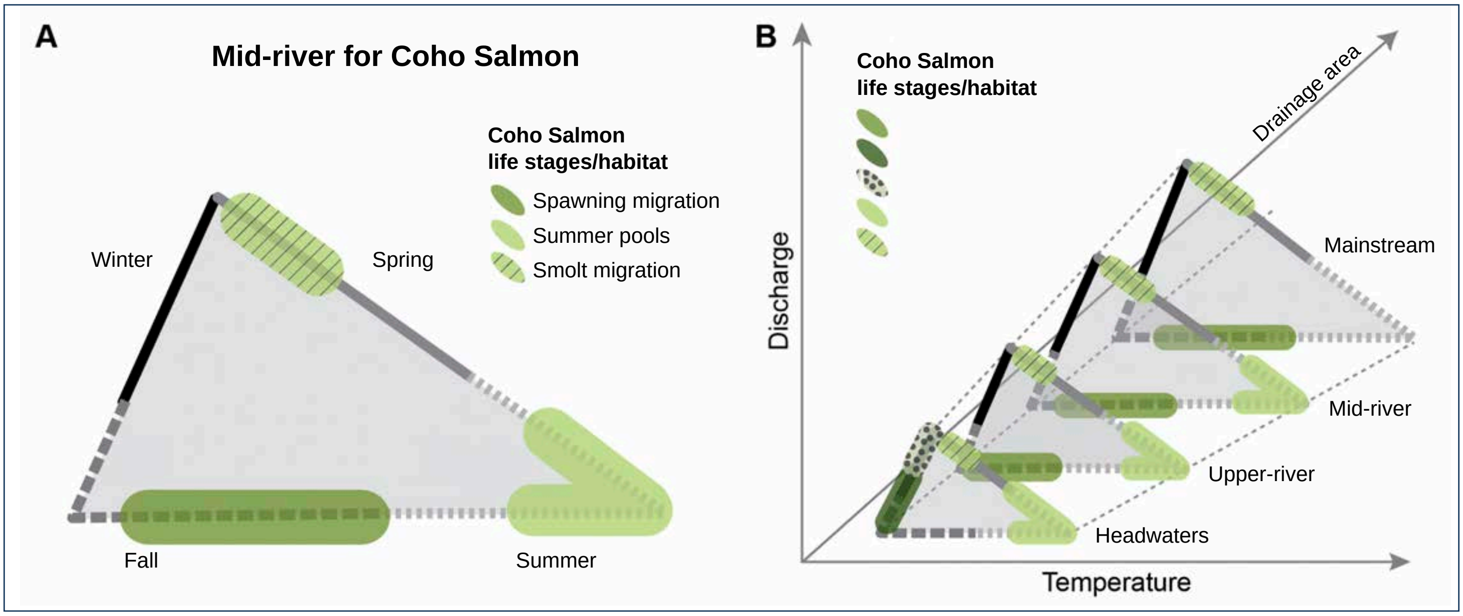
Flitcroft's current work relates to previous research she's done on the need for salmon to be able to reach connected stream branches in their migration.

"Building stream connections is an important—and sometimes neglected—element of salmon habitat restoration projects," she says.

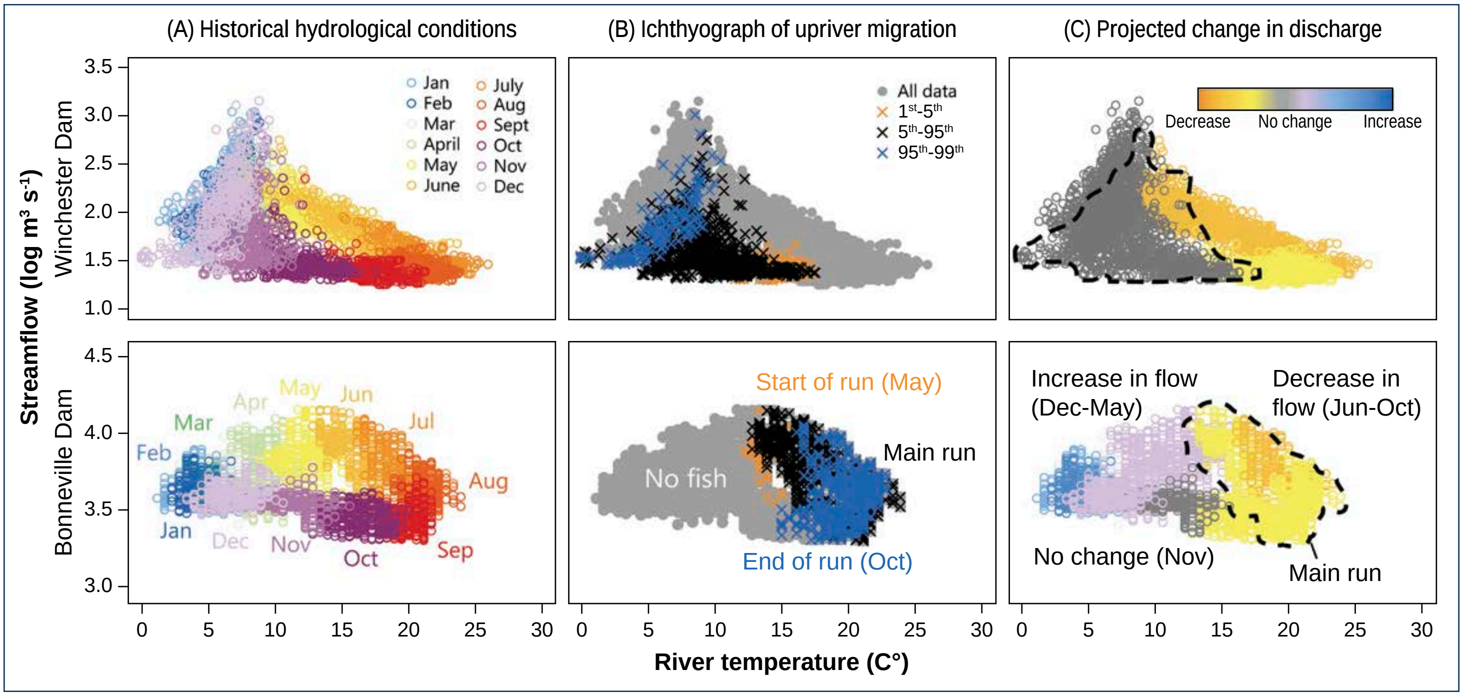
Her work on ichthyographs looks at connection from a different angle: one that examines hydrological conditions as an essential element in salmon's ability to connect with the entirety of their freshwater environment.

What Happens at Sea?

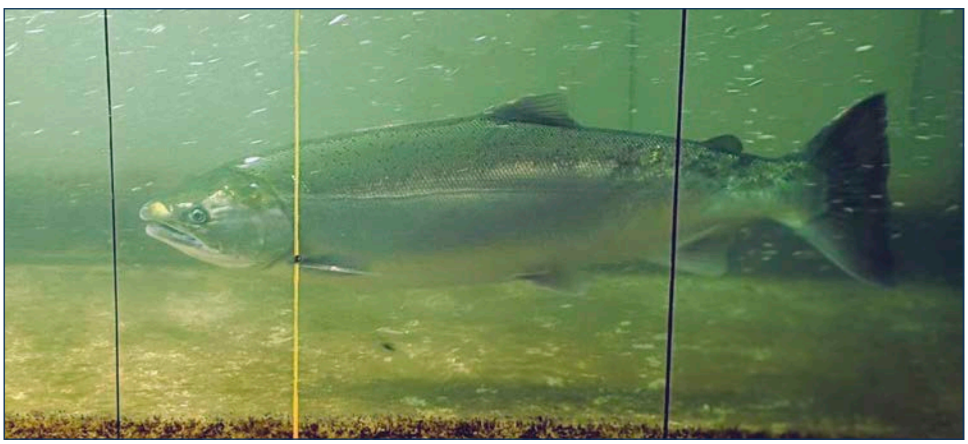
Understanding why salmon behave the way they do, including the environmental factors that trigger their strategic moves in their migratory journey, requires understanding their interaction with the marine environment in which they live most of their lives. That piece of the larger picture remains a bit of a mystery.



An ichthyograph showing activity of coho salmon at various life stages as they move downstream toward the ocean within the context of discharge and water temperature.



Ichthyographs of two study areas, including scenarios of how conditions could be altered by projected climate change.



A coho salmon in the viewing window as it moves through the ladders at Bonneville Dam on the Columbia River.

Although many studies have examined the effects dams, roads, and other physical barriers have on salmon in freshwater environments, fewer studies have looked at the habitat connectivity between freshwater, estuarine, and marine environments—and salmon need all three.

Part of the problem lies in the challenges of gathering fish data in the ocean.

"It's a black box," Flitcroft says. "The smolts go in and the salmon come out; and what they do in the ocean is hard to track."

Catch surveys of salmon caught by recreational and commercial fishermen are the primary source of ocean-related data. But that method is fairly random—a far cry from the much more precise tracking that happens at fish ladders adjacent to dams.

More precise methods for understanding fish habitat use and drivers of migration from the ocean to fresh water will develop in the future. For now, the work Flitcroft's team developed in the freshwater portion of the salmon life cycle shows promise in giving managers a window into environmental characteristics of freshwater systems that are important drivers of migration in ocean-returning adult coho salmon.

"We've known about the overall patterns of salmon behavior for a long time, but the jury is still very much out about what the specific triggers are," Grant says. "Yes, temperature is important, and yes, flow is important. But how can we use these large datasets to more clearly illuminate what these fish are keying in on?"

"The best way to observe a fish is to become a fish."
–Jacques Yves Cousteau

For Further Reading

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GORDON GRANT is a research hydrologist with the Pacific Northwest Research Station. He began his research career with the Forest Service in 1985 after a decade-long career as a whitewater river guide on Western U.S. rivers. His research goals are advancing understanding of how stream networks, watersheds, and entire landscapes respond to changes in streamflow, sediment transport, and wood entrainment.

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