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Science FINDINGS

INSIDE

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

A Glimpse of the Future: Coho Salmon Response to Alaska's Recent Snow-Free Winters

Streams flowing from Alaska's Chugach Mountains into the Copper River Delta. Recent studies reveal how water temperature varies widely among the streams due to different water sources and climate variability and potential effects on incubation times for coho salmon eggs. USDA Forest Service photo by Luca Adelfio.

IN SUMMARY

The Earth's climate is warming most rapidly in the high latitudes of the polar and subpolar regions. Winter temperatures, in particular, are increasing.

This trend is being observed in Alaska's Copper River Delta, where scientists Steve Wondzell, Gordon Reeves, and Luca Adelfio conducted a multiyear study on the effects of changing stream temperatures on the incubation duration and emergence times of coho salmon.

During their 5-year study, winter conditions shifted from cold and snowy to cool and rainy. Modeling results showed that this would dramatically change the incubation time of coho salmon eggs in streams primarily fed by precipitation. During the warm winters of 2014, 2015, and 2016, simulated incubation time shortened in these streams by as much as 3 months whereas incubation time barely changed in streams fed by groundwater. The winter warming experienced from 2014–2016 was equivalent to the climate projected to be the norm for the area by 2040.

Significant shifts in the timing of life history events for coho salmon could create ripple effects throughout the delta ecosystems. In light of the habitat variability identified in this study, the USDA Forest Service Pacific Northwest Research Station, along with the Chugach National Forest and external partners, are investigating the genetic diversity of local coho salmon to help inform management strategy.

"In all things of nature there is something of the marvelous."

—Aristotle

Alaska's Copper River Delta is known for one of the world's most robust populations of Pacific salmon. And until recently, it was also known for its cold, snowy winters. Coho salmon (*Oncorhynchus kisutch*) deposit their eggs in the delta's streams, and many of those streams freeze in the winter, slowing egg development until the spring thaw. As a result, coho salmon eggs spend more than half the year incubating in the streambed gravels.

But the climate is warming in the delta. A recent study by Steve Wondzell and Gordon Reeves with the USDA Forest Service Pacific Northwest (PNW) Research Station, along with Luca Adelfio who was with the USDA Forest Service's Chugach National Forest at the time of the study, measured the changes in coho salmon habitat during some of the warmest winters on record for the Copper River Delta—temperatures that reached the projected norm for the area by 2040.

During the winters of 2014–2016, the climate shifted from cold and snowy to cool and rainy, and streams didn't freeze. Modeling suggested this would drastically shorten the incubation time of coho eggs in streams fed by precipitation, compared with streams fed by groundwater. Such a change could cause pronounced shifts in the life cycle patterns that have defined Alaska coho salmon for millennia.

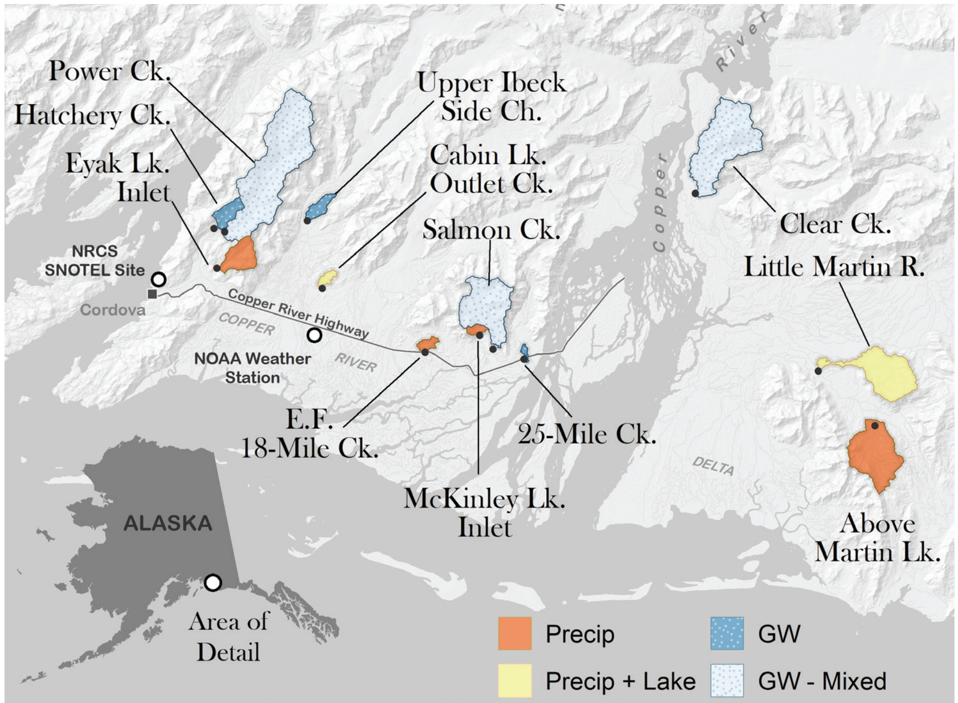
Few other studies have looked at those differences and how changing winter stream temperatures influence salmon life histories. These findings offer a glimpse of the future and point to challenges wildlife and forest managers face in their efforts to maintain salmon populations.

Into the Cold Water

The researchers measured water temperature over several years in different types of streams throughout the delta. Three of the five winters during the study period were unusually warm, and those warm winters accentuated how climate change might affect different stream types.

"Some of the streams are only a few miles apart, but they have totally different temperature regimes," Wondzell explains.

The complex geology of the Copper River Delta gives rise to high variability in the types of streams present. Some places are dominated by groundwater aquifers that are replenished by glacial melt from the nearby Chugach Mountains and abundant precipitation—about 92 inches a year. Streams fed from these aquifers maintain a fairly consistent temperature throughout the year, in contrast to streams that are fed only by precipitation. Pacific salmon spawn in all these streams, but differences in the temperature regimes of the streams lead to differences in the timing of spawning, duration of egg incubation, and the time when salmon fry emerge from the streambed gravels. Because groundwater streams are thermally stable and rarely freeze in the winter, incubation conditions remain relatively consistent over time. In contrast, precipitation-fed streams are sensitive to climate variability, which can result in big differences in incubation from year to year.



The study area on the Copper River Delta in south-central Alaska. The scientists collected temperature data from a variety of stream types, including those fed mostly by precipitation (precip) and those fed by groundwater (GW). NRCS = USDA Natural Resources Conservation Service; SNOTEL = Snow Telemetry Network.

Wondzell, who helped design the study, and the other members of the research team collected water temperature data from 12 coho salmon spawning and rearing sites. The streams were divided into four categories depending on landscape attributes and hydrologic data: (1) precipitation fed, (2) precipitation fed with large upstream lakes, (3) groundwater dominated, and (4) groundwater-precipitation combinations in which groundwater made up the dominant flow in the winter and precipitation and snowmelt became dominant in the warmer months.

The researchers installed temperature sensors in each stream on the streambed and deep in the gravel where coho salmon lay their eggs. Depending on its size, a female coho will deposit her eggs 8 to 21 inches down in the gravel. Placing sensors below the streambed enabled the researcher to gauge the actual incubation temperature.

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Coho salmon spawning in one of the many streams flowing from the Chugach Mountains. USDA Forest Service photo by Luca Adelfio.

Key Findings

- During typical cold, snowy winters in south-central Alaska, precipitation-fed streams freeze, dramatically slowing the development of coho salmon eggs until the spring thaw. Groundwater-dominated streams rarely freeze so egg development continues all winter.
- The differences in egg development are offset by differences in spawn timing. At precipitation-fed sites, coho salmon typically spawn 2 to 3 months earlier than at groundwater sites. Following typical cold snowy winters, coho salmon fry emerge at nearly the same time regardless of stream type.
- During the atypically warm, rainy winters of 2014–2016, precipitation-fed streams did not freeze, and model simulations suggested that coho salmon fry would emerge as much as 3 months earlier than those in groundwater-dominated streams.
- The change from cold, snowy winters (2012–2013) to cool, rainy winters (2014–2016) was similar to the magnitude of change projected by climate models for the year 2040.
- Water temperatures and salmon emergence times were little affected by changing air temperatures at groundwater-dominated streams.

Salmon eggs deposited in streambed gravel. Incubation time can vary by months depending on stream temperature. USDA Forest Service photo by Luca Adelfio.

The sensors gathered temperature data every hour for 5 years: from the first of October 2011 to the end of September 2016. The region experienced enough difference in water temperature, air temperature, and snowpack that the researchers were able to divide the 5 years of data into two winter types: (1) cool and snowy and (2) warm and rainy.

The first two winters were cooler than the historical average, but temperatures in the final three winters swung the opposite direction. The 2014–2016 winters had virtually no sea-level snowpack, and most streams did not freeze in the locations where salmon spawn. The air temperatures during those warm winters were the second and sixth warmest on record.

The researchers converted the temperature data into "accumulated thermal units" (ATUs), a unit of measurement commonly used in hatcheries to determine stages of egg development and predict hatch dates. Each day's water temperature is added to the total of the previous days, producing an ever-greater number of ATUs.

They found that the sites with large shallow lakes upstream were the most sensitive to air temperature changes. There, the average ATU increased by 161 percent during the warm winters. The second greatest change occurred in the precipitation-only streams, where the average ATU rose 98 percent. Meanwhile, the groundwater and groundwater-mixed sites rose only 17 and 38 percent, respectively.

Small changes in water temperature can mean big changes in incubation times. At 35 °F, incubation time is about 250 days. Raise that temperature by just two degrees and incubation time drops by 50 days.

The model simulations showed that the incubation time for eggs deposited in groundwater streams varied by less than 30 days a year even as winters heated up. Contrast that with streams fed by precipitation or a combination of precipitation and lakes. There, simulated incubation times in the cool, rainy winters of 2014–2016 differed from the previous cold, snowy winters by nearly 3 months, suggesting that the young fish would have emerged much earlier than the fish from the groundwater streams.

Cascading Effects

As warmer winters become more frequent in Alaska, the life cycle of the coho salmon could be affected. "I think we can expect spawn times to change, but we don't know by how much and in which direction," Adelfio says.

Why does this matter? If all coho salmon populations in the Copper River Delta are spawning at the same time, regardless of stream type, the population becomes less diverse and therefore more vulnerable to any disturbance that happens to coincide with a major life event.

Steve Wondzell installs a device that will log temperature data from a coho salmon spawning stream that flows into the Copper River Delta. USDA Forest Service photo by Luca Adelfio.

Wondzell describes the increased diversity created by more spread-out spawn times as a "portfolio effect," much like a diversified investment portfolio.

With investments, a well-diversified portfolio can survive if one of its several financial sectors experiences a downturn. But a portfolio composed of stocks from the same sector is much more vulnerable to crippling loss if that sector tanks.

"You don't want to put all your fish eggs in one basket," Wondzell says, explaining that fish all returning from the ocean at the same time would be much more vulnerable to a short-term environmental event (landslide, heat wave, etc.) than if different populations migrate at different times.

And it affects more than just the fish. Brown bears looking to fatten up on spawning salmon will find their feeding opportunity compressed by as much as 2 months if the salmon all return at the same time.

Simply put, changes in water temperature trigger changes in incubation time and fry emergence and could create a domino effect affecting fish for the rest of their life cycle.

"The timing of one life event has important implications for the next one," Reeves says. He points to a long-term study initiated in the 1970s showing that stream temperatures on Vancouver Island rose after a timber harvest.

"As a result, coho emerged 2 to 6 weeks early. Instead of spending 2 years in fresh water, many spent only 1. And because of warmer temperatures, many migrated to the ocean earlier in the spring, which reduced ocean survival. This finding was a surprise—people thought faster growth would increase survivability, but no. One change in life history can affect other life changes down the road," Reeves says.

"Warmer water can influence the size of the fish when they emerge," Reeves says. "If you increase the water temperature by a degree or two, metabolism speeds up, the emerging fish use up their egg yolk faster than they normally would, putting more energy into metabolism than growth."

These findings provide a more nuanced understanding about coho salmon runs in the Copper River Delta, which may help fishery managers tasked with maintaining coho salmon populations.

"It's true that they're all the same species," Adelfio says, "but I think this research raises an important question: Is a coho salmon a coho salmon, or can they be separated into groups that are genetically adapted to certain streams?"

As a result of the research, the PNW Research Station, Chugach National Forest, and partners are investigating the genetic diversity of the local coho salmon to help inform management strategies for fisheries harvest.

Scientists do not yet know if (or how) warming winters might affect fish survival, but the changes they've observed give cause for concern; they emphasize the importance of management actions that can help make fish populations more resilient to climate change.

"Creating more habitat connectivity could be an important way to help these fish adjust," Adelfio says.

That means widening culverts, removing dams, and other measures that help salmon access more stream habitat.

"We're actively doing that now on the Copper River watershed. We're helping the fish find the environment they need," Adelfio says.

Matt Sloat, science director at the Wild Salmon Center, an international conservation organization based in Portland, Oregon, says the same shifting of spawning times is happening in the lower 48.

"Timing is everything with these fish, and as environmental conditions change, they need to respond," he says.

For example, prolonged and extreme drought in California is forcing spawning time to shift much later in the year as the salmon wait for more abundant waterflows.

Sloat explains that the Wild Salmon Center is doing research on the West Coast that is similar to the work of Wondzell and his colleagues in Alaska. In the lower 48, much habitat maintenance and restoration is focusing on conserving wide, forested riparian zones in logged areas to maintain shade and keep salmon streams cool.

"The name of the game is protecting cold water," he says.

LAND MANAGEMENT IMPLICATIONS

- Vulnerability of coho salmon to climate change varies greatly across watersheds in the Copper River Delta. Accounting for these local differences will be key to successful landscape-scale management plans and actions.
- Earlier emergence of coho salmon fry during cool, rainy winters may have cascading effects on the viability, growth, and timing of seaward migration for juveniles. In the short term, these changes may affect the number of salmon that survive to adulthood and return to their spawning streams; over the long-term, they may alter spawn timing.
- Local adaptation of coho salmon to their spawning streams creates life-history diversity within the population. This diversity could be lost as the climate changes, with negative consequences for coho salmon in south-central Alaska.

A bear with a freshly caught salmon. Changes in the timing of life cycle events for coho salmon could have cascading effects throughout the food web. U.S. Fish and Wildlife Service photo by Lisa Hupp.

Adapting to Warmer Winters

When Wondzell, Reeves, and Adelfio set out to take temperature measurements in Alaska, they didn't know that they'd capture some of the warmest winters on record. But climate data show that some of the fastest changes in the world are happening during winter in historically cold places such as Alaska.

Between 1981 and 2010, the mean annual temperature in the Copper River Delta was 39 °F, with subfreezing temperatures between November and March. Climate models project the average temperature will rise to about 49 degrees by 2100, with the greatest change happening in the winter. By 2050, the models predict the mean temperature will be above freezing throughout the entire year, contributing to a reduction of snowpack of as much as 40 percent at elevations below 1,600 feet.

"What we captured was likely a proxy for the future environment," Adelfio said.

Over the short term, fish accustomed to precipitation-fed streams may face large challenges as they adapt to changing conditions. This makes thermally stable groundwater streams appear to be refuges for spawning.

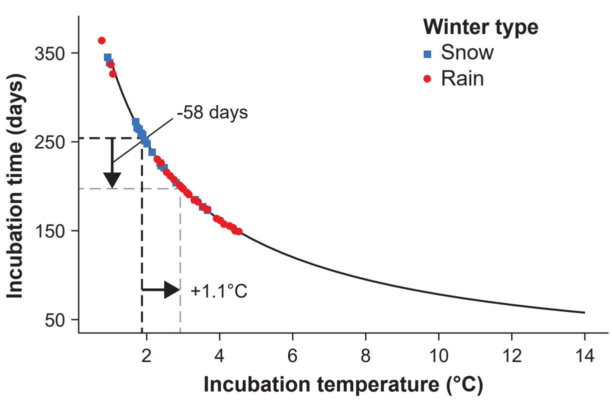
But Alaska's groundwater temperature is not immune to climate change. Over time, the temperature of underground aquifers will rise as the water that recharges them warms. Glaciers are also melting and retreating. Yet, the effects of decreased glacial melt on stream temperatures, and how these changes might influence spawning habitat for salmon, remain poorly understood.

Other effects of climate change range from changes in the emergence of insects to a predicted loss of productivity in the oceans.

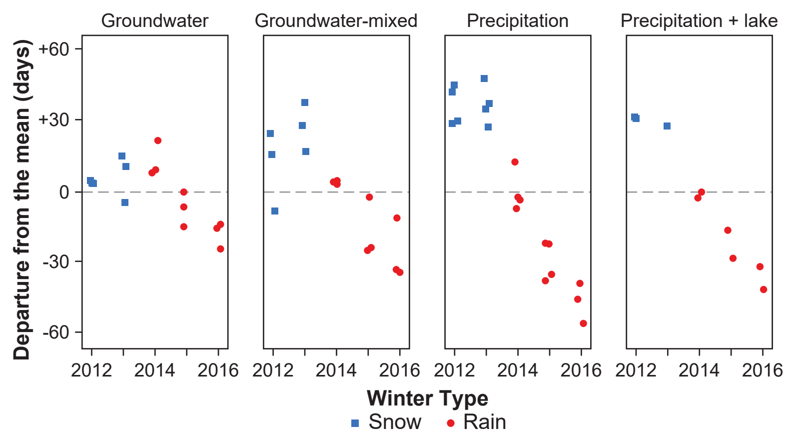
"But we can help," Wondzell says, pointing to the need to protect the diversity of salmon in the Copper River Delta. One of the defining features of that diversity is the coho's ability to adapt to changing conditions, including those presented by the temperature variations in the area's spawning streams.

"Local adaptations developed in thermally contrasting streams, such as those found on the Copper River Delta, provide a deep well of life history diversity for coho salmon," Wondzell says. "Management actions that protect life history diversity will be increasingly important as the climate warms."

"Salmon are incredibly resilient and adaptable animals, so it very well may be they will weather our changing climate," he says.



Projected incubation times for coho salmon eggs calculated from observed water temperatures at 12 study sites for five spawning years. Blue squares represent data collected during cold-winter years (n = 2). Red circles represent data from warmer-winter years (n = 3). The average water temperature differences observed between warm and cold winters (1.1 °C [34 °F]) shortened the average incubation period by 58 days. Adapted from Adelfio et al. 2019.



The departure from the 5-year mean duration of incubation in days calculated for each year and site combination, grouped by water-source category. The coldest, nonglacial-fed sites during the cold, snowy winters became the warmest sites during the warm, rainy winters. Adapted from Adelfio et al. 2019.

> *"What is past is prologue."*
>
> —William Shakespeare

For Further Reading

Adelfio, L.A. 2016. Geomorphic and climatic controls on water temperature and streambed scour, Copper River Delta, Alaska: implications for understanding climate change impacts to the Pacific salmon egg incubation environment. Corvallis, OR: Oregon State University. M.S. thesis. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/4j03d234z

Adelfio, L.A.; Wondzell, S.M.; Mantua, N.J.; Reeves, G.H. 2019. Warm winters reduce landscape-scale variability in the duration of egg incubation for coho salmon (*Oncorhynchus kisutch*) on the Copper River Delta, Alaska. Canadian Journal of Fisheries and Aquatic Science. 76: 1362–1375. https://www.fs.usda.gov/treesearch/pubs/58964.

Campbell, E.Y. 2017. Influences of thermal and trophic heterogeneity on phenology, growth, and resource use by juvenile coho salmon. Corvallis, OR: Oregon State University. 169 p. Ph.D. dissertation. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/9z903466m.

Campbell, E.Y.; Dunham, J.B.; Reeves, G.H.; Wondzell, S.M. 2019. Phenology of hatching, emergence, and end-of-season body size in young-of-year coho salmon in thermally contrasting streams draining the Copper River Delta, Alaska. Canadian Journal of Fisheries and Aquatic Sciences. 76(2): 185-191.https://www.fs.usda.gov/treesearch/pubs/64962

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