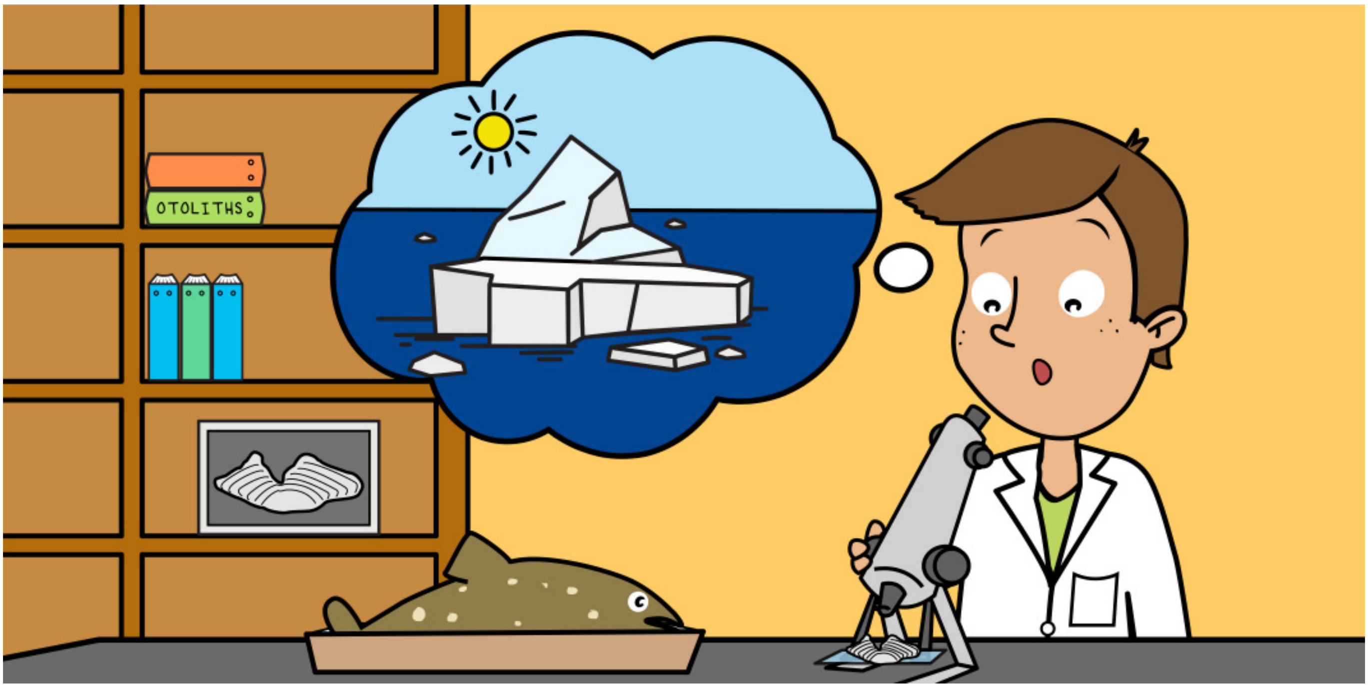
EARTH AND ITS RESOURCES
Published: 20 May 2022
doi: 10.3389/frym.2022.726495



FISH EAR STONES OFFER CLIMATE CHANGE CLUES IN ALASKA'S LAKES

Krista K. Bartz[1], Vanessa R. von Biela[2], Bryan A. Black[3], Daniel B. Young[4], Peter van der Sleen[5,6] and Christian E. Zimmerman[2]*

[1] Southwest Alaska Inventory and Monitoring Network, National Park Service, Anchorage, AK, United States
[2] U.S. Geological Survey, Alaska Science Center, Anchorage, AK, United States
[3] Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ, United States
[4] Lake Clark National Park and Preserve, National Park Service, Anchorage, AK, United States
[5] Wildlife Ecology and Conservation Group, Wageningen University, Wageningen, Netherlands
[6] Forest Ecology and Management Group, Wageningen University, Wageningen, Netherlands

YOUNG REVIEWERS

7TH–8TH FRESHWATER BIOLOGY CLASS

AGES: 12–14

Otoliths, also known as ear stones, are small body parts that help fish with hearing and balance. Like tree rings, otoliths form one light and one dark band per year, creating rings. These rings can be measured to understand fish growth. The wider the ring, the greater the growth. In our study, we used otoliths to understand how one fish species—lake trout—responds to rising temperature in the state of Alaska. We found that warmer spring air temperature and earlier lake ice melt were related to faster lake trout growth. This finding is consistent with other studies that link warmer water temperature and earlier lake ice melt to increased plankton in Alaska's lakes. Together, these findings suggest that climate-driven increases at the bottom of the food web might benefit top predators like lake trout. However,

the relationship between warmer temperature and faster growth may not last.

THINGS WITH RINGS

Have you ever noticed the rings on a cross-cut tree trunk? Counting those rings can tell you the age of a tree. This is because each ring is made of two parts: a light-colored band of wood that formed in the spring and early summer, and a dark-colored band of wood that formed in late summer and fall. Therefore, a light band and a neighboring dark band represent 1 year of life for a tree.

But age is not the only thing revealed by tree rings. The width of the rings contains information about the growth of a tree and the environmental conditions it experienced. This is because trees respond to conditions like temperature, moisture, and **nutrients**. In warmer, wetter years, trees tend to grow more, and their rings are wider than in colder, drier years. Similarly, trees tend to grow more in years when nutrients like fertilizers are plentiful in the soil. Because trees stay in one place and grow for many years, their rings offer a record of conditions in that place over time.

NUTRIENTS

Chemicals that provide materials needed by living things to survive, grow, and reproduce. The nutrients that often limit growth at the bottom of lake food webs are nitrogen and phosphorus.

Believe it or not, other organisms also form rings every year that they live. For example, corals and clams create yearly growth rings in their skeletons and shells. Some fish also do so, within their scales and ear stones. Ear stones—also called **otoliths**—are small, flat structures that help fish with hearing and balance (Figure 1). They are located just under the brain in a fish's skull. Like tree rings, otoliths form one light and one dark band per year, creating a ring. These rings can be counted to determine fish age. They can also be measured to understand fish growth. The wider the ring, the greater the growth in a single year.

OTOLITHS

Small structures used by vertebrates for balance and hearing. In fish, otoliths grow by adding new layers of seashell-like material year after year, throughout life.

WHAT CONTROLS FISH GROWTH?

Fish grow faster or slower depending on how old they are and how well their environment meets their needs. Like humans, fish grow more slowly as they age. They also grow more slowly when they lack nutrients and energy from food. Unlike humans, fish grow more slowly in cold temperatures. The reason for this is simple. Most fish are **ectothermic** or cold-blooded, so their body temperatures are controlled by the water temperatures around them. When water temperatures are cold, everything in an ectotherm's body slows down, including its breathing, digestion, and growth.

ECTOTHERMIC

Cold-blooded. An ectothermic animal is one whose internal body temperature depends on external heat sources for warmth.

In our study, we used otoliths to explore the growth of one fish species—lake trout. We wanted to know how lake trout growth responds to temperature and nutrients. We were particularly interested

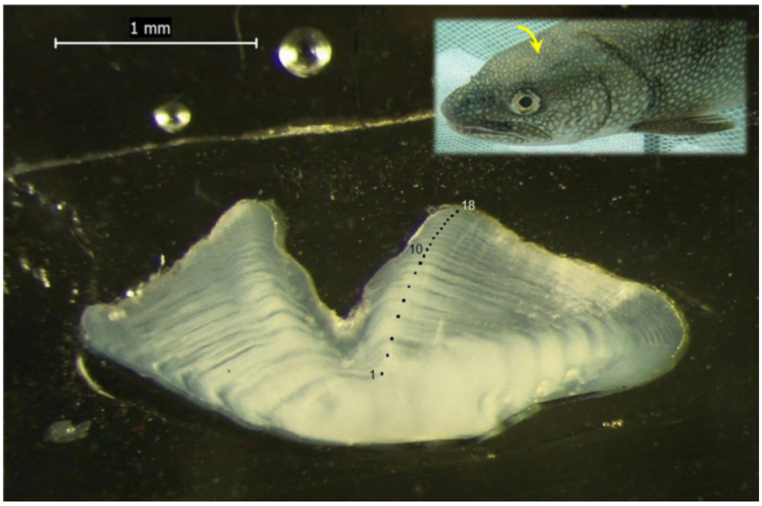


Figure 1

Figure 1

A magnified cross-section of an otolith from an 18-year-old lake trout. The black dots mark the edges of the rings. Rings for years 1, 10, and 18 are labeled. The white line shows the scale for this otolith (2.4 cm on the page is 1.0 mm in real life), and the yellow arrow shows its approximate location in a lake trout.

in lake trout from Lake Clark National Park & Preserve in southwest Alaska, USA.

WHY STUDY LAKE TROUT IN LAKE CLARK?

Lake trout are top predators that thrive in cold, deep lakes. We focused on this species for two main reasons. First, we chose lake trout because they are common in Alaska. This makes them easier to find than rarer species. Second, we chose lake trout because they have long lifespans (20+ years). This means their otoliths contain a longer record of growth than other common fish species in Alaska, like sockeye salmon.

Lake Clark National Park & Preserve is known for its cold, deep lakes and surrounding wilderness. Human impacts, like buildings and roads, are scarce inside park boundaries. However, like the rest of Alaska, the park is experiencing climate change. Average annual air temperature in Alaska is warming about twice as fast as the world-wide pace [1]. Warmer air temperature is shortening the number of days that lakes have ice in winter [2]. Both air temperature and lake ice affect the conditions experienced by fish.

The park is also known for the thousands of sockeye salmon that **spawn** there. Salmon begin and end their lives in fresh water. Between those endpoints, they gain most of their body weight in the ocean, where the waters are high in nutrients. When salmon return to fresh water to spawn and die, their bodies are like bundles of nutrients delivered from the ocean. Some scientists think that those bundles of salmon nutrients help other freshwater fish grow faster [3].

SPAWN

Reproduce, by adult salmon, through building a gravel nest, laying eggs in the nest, and fertilizing the eggs.

WHAT WAS OUR QUESTION AND APPROACH?

Lake trout are long-lived fish that prefer cold, deep lakes. Lake Clark National Park & Preserve has lots of cold, deep lakes, plus nutrients from dead salmon. However, Alaska's changing climate is warming its lakes. Therefore, we asked whether lake trout grow faster or slower in warmer years, and whether sockeye salmon nutrients affect lake trout growth as well.

To study this, we caught 240 lake trout from 7 lakes, during the summers of 2004, 2011, 2012, and 2013. All the lakes had cool waters with low levels of nutrients. However, they differed in one basic trait: only 4 lakes were accessible to salmon. The other 3 lakes were upstream of barriers to salmon migration, like waterfalls.

After catching the lake trout, we removed their otoliths by dissection. We then used a multi-step process to count and measure the otolith rings. First, we covered each otolith with a gel that dried to a hard, clear block. Next, we cut the blocks with a special saw, to obtain a slice about as thick as a fingernail from the middle of each otolith. Then, we glued the otolith slices to glass microscope slides and photographed the slides using a camera attached to a microscope. The microscope made each otolith slice look 40 times bigger in the photograph than in real life.

Using the magnified photographs, we counted the otolith rings to age each fish. We also assigned a year of formation to each ring by counting backward from the year we caught the fish. Then, we measured the ring widths on the photographs. By the end of this multi-step process, we had measured 964 otolith rings. Although 964 seems like a lot, it is fewer than expected because only 80 of the 240 fish had distinct otolith rings.

Next, we used **statistical models** to summarize the 964 ring widths from the 80 lake trout into a single width per year, applicable to all lake trout in our study. We called that summarized version our master growth record because it applied to many different fish, like a master key that opened many different locks. The master growth record showed years when fish grew less than average, about average, and more than average. It included years from 1990 to 2011.

STATISTICAL MODEL

A math "sentence" that compares two or more different pieces of information as numbers or categories to see *if* and *how* they are related.

Finally, we compared the master growth record to temperature, ice, and salmon **data** from the same years. This was challenging because these types of data were not measured at each of our study lakes that far back in time. Therefore, we used the best available data from other sources. For temperature, we used monthly average air temperature at a weather station near one study lake (Lake Clark). For ice, we used the date when lake ice melted at another study lake (Telaquana Lake). For salmon, we used the number of adult sockeye salmon returning to spawn downstream of those two lakes. Using these datasets, we

DATA

A group of facts, like numbers, measurements, or observations. The word "data" is the plural form of the word "datum," which is a single fact.

analyzed the relationships between lake trout growth, temperature, ice, and salmon.

WHAT DID WE FIND?

We found that lake trout grew faster in warmer years. In particular, lake trout grew faster in years with warmer air temperatures in April (Figure 2). This pattern existed in February and July too but was not as strong. Lake trout also grew faster in years with earlier dates of lake ice melt. However, we did not see a pattern between lake trout growth and salmon. Lake trout did *not* grow faster in lakes with salmon compared to lakes without salmon. In lakes with salmon, lake trout did *not* grow faster in years with more spawning salmon.

HOW DO OUR FINDINGS FIT WITHIN THE "BIG PICTURE"?

Our study found that lake trout grow faster in years with warmer air temperature in April because warmer air causes earlier lake ice melt. Warmer air and earlier melt probably increase spring water temperature at the lake surface toward the 9°C preferred by lake trout. At this preferred temperature, lake trout can eat more and grow more without overheating, if food is available.

Interestingly, more food might be available in warmer years (Figure 3). Other studies in nearby lakes have shown that **plankton** counts increase with warmer surface water and earlier spring melt [2, 4]. Warmer springs are also linked to higher counts and faster growth of

PLANKTON

Tiny organisms that drift near the surface of a body of water, like a lake or ocean. These organisms may be plant-like phytoplankton or animal-like zooplankton. Zooplankton eat phytoplankton.

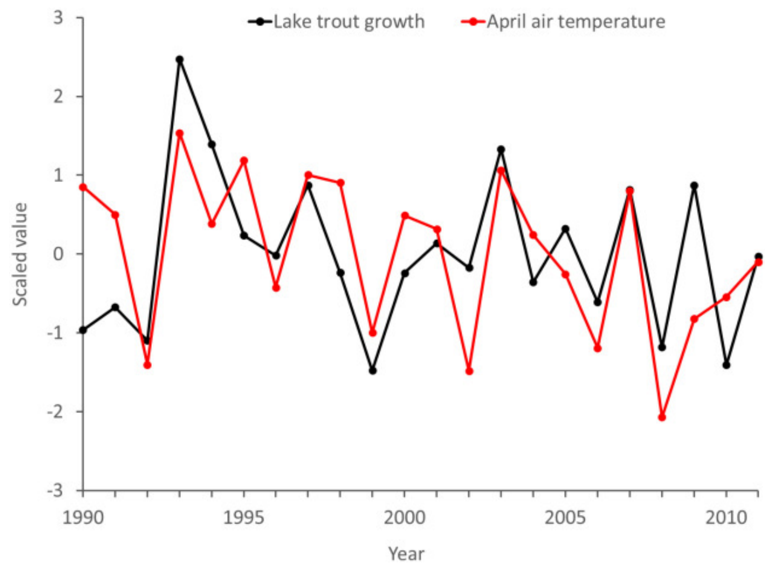


Figure 2

Figure 2

Our master growth record (black line) compared with average April air temperature (red line) for years 1990–2011. Both variables were scaled to a mean value of 0 and a standard deviation of 1 to make their original units of measure (millimeters of growth and degrees Celsius) equal. You can see that lake trout growth (in black) and April air temperature (in red) track each other across years.

Figure 3

Diagram of a simple lake food web showing phytoplankton, zooplankton, prey fish, and predator fish under two possible scenarios: cooler and warmer springs. We expect that warmer springs lead to higher plankton counts, increased numbers and size of plankton-eating fish, and faster growing lake trout.

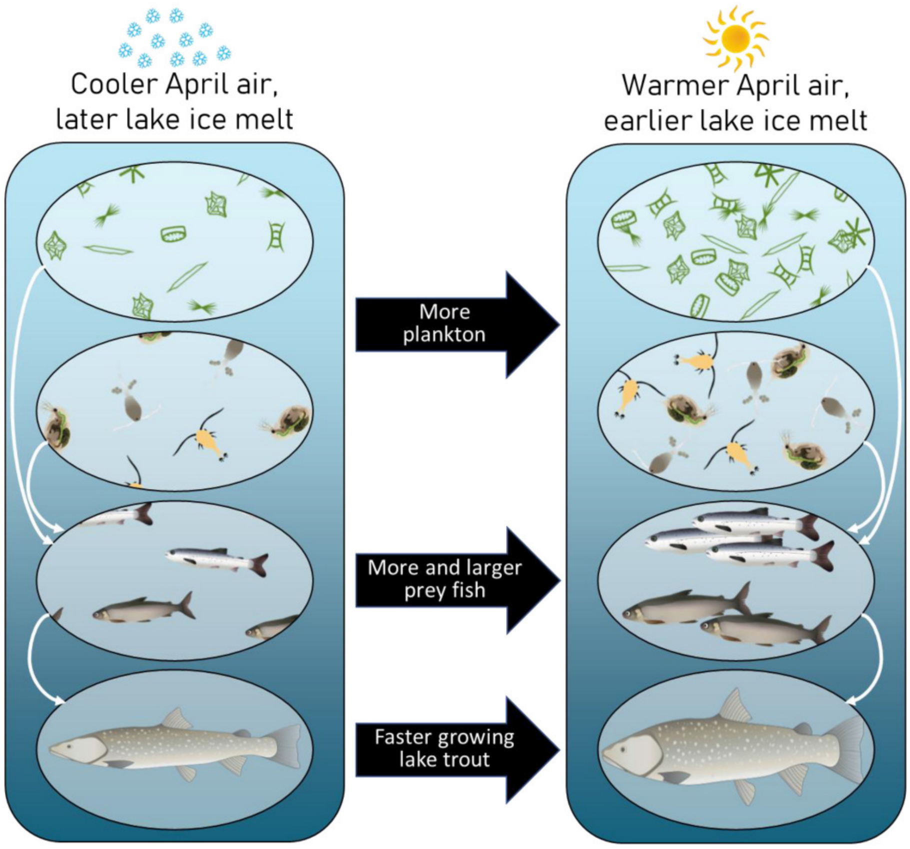


Figure 3

small plankton-eating fish, like young sockeye salmon [4, 5]. And guess what likes to eat young sockeye salmon as prey? Lake trout!

These results suggest that lake trout in Lake Clark National Park & Preserve might be climate change winners. They can benefit from the increased food linked to warmer water near the lake surface, while still having the option to use cooler water at deeper depths if they need to slow down their bodies to conserve food. These results hold true with or without the added nutrients from salmon. Whether these results will hold true over time, as climate warming continues, remains a question.

ACKNOWLEDGMENTS

We acknowledge the Natural Resources Protection Program of the U.S. Geological Survey for funding this project and contributing artists of the IAN Image Library (http://ian.umces.edu/imagelibrary/) for the clip art in Figure 3. Finally, we thank Nina Chambers, Jessica Levine, and our reviewers for helpful suggestions. Any use of trade names or products is for descriptive purposes only and does not imply endorsement of the U.S. Government.

ORIGINAL SOURCE ARTICLE

von Biela, V. R., Black, B. A., Young, D. B., van der Sleen, P., Bartz, K. K., and Zimmerman, C. E. 2020. Lake trout growth is sensitive to spring temperature in southwest Alaska lakes. *Ecol. Freshw. Fish.* 30:88–99. doi: 10.1111/eff.12566

REFERENCES

1. Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., et al., eds. 2018. "Fourth national climate assessment, volume II – impacts, risks, and adaptation in the United States," in: *Chapter 26, Alaska* (Washington, DC: U.S. Global Change Research Program). p. 1185–241. doi: 10.7930/NCA4.2018.CH26
2. Carter, J. L., and Schindler, D. E. 2012. Responses of zooplankton populations to four decades of climate warming in lakes of southwestern Alaska. *Ecosystems* 15:1010–26. doi: 10.1007/s10021-012-9560-0
3. Wipfli, M. S., Hudson, J. P., Caouette, J. P., and Chaloner, D. T. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. *Trans. Am. Fish. Soc.* 132:371–81. doi: 10.1577/1548-8659(2003)132<0371:MSIFE S>2.0.CO;2
4. Schindler, D. E., Rogers, D. E., Scheuerell, M. D., and Abrey, C. A. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in Southwestern Alaska. *Ecology* 86:198–209. doi: 10.1890/03-0408
5. Rich, H. B., Quinn, T. P., Scheuerell, M. D., and Schindler, D. E. 2009. Climate and intraspecific competition control the growth and life history of juvenile sockeye salmon (Oncorhynchus nerka) in Iliamna Lake, Alaska. *Can. J. Fish. Aquat. Sci.* 66:238–46. doi: 10.1139/F08-210

SUBMITTED: 17 June 2021; **ACCEPTED:** 26 April 2022;
PUBLISHED ONLINE: 20 May 2022.

EDITOR: Nina Chambers, National Park Service, United States

SCIENCE MENTOR: Andrew Ray

CITATION: Bartz KK, von Biela VR, Black BA, Young DB, van der Sleen P and Zimmerman CE (2022) Fish Ear Stones Offer Climate Change Clues In Alaska's Lakes. Front. Young Minds 10:726495. doi: 10.3389/frym.2022.726495

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

COPYRIGHT © 2022 Bartz, von Biela, Black, Young, van der Sleen and Zimmerman. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

YOUNG REVIEWERS

7TH–8TH FRESHWATER BIOLOGY CLASS, AGES: 12–14

We are the 7th/8th grade mixed class of 2021 at Gruening Middle School in Eagle River, Alaska, just a few miles north of Anchorage. We have a relatively small class of only 21 people who work well together. Our class is an eclectic bunch made up of many students from military families and a few Native Alaskans. We all are proud to live in Alaska and enjoy the many resources and adventures available just out our front doors.

AUTHORS

KRISTA K. BARTZ

Krista Bartz is an aquatic ecologist with the National Park Service Southwest Alaska Inventory and Monitoring Network. There, she oversees long-term monitoring of freshwater indicators in three southwest Alaska parks—a job she began in 2013. The indicators include water quality, water quantity, and fish contaminants. She has two children, ages 9 and 12. *Krista_Bartz@nps.gov

VANESSA R. VON BIELA

Vanessa von Biela is a research fish biologist at the U.S. Geological Survey Alaska Science Center. Her areas of expertise include both freshwater and marine ecology, with topics as diverse as kelp in marine fish food webs, heat stress in migrating adult salmon, and arctic ecology. She started working for the USGS in 2007 and completed her PhD in 2015. She has 3 children, ages 7, 5 and 5 (twins!).

BRYAN A. BLACK

Bryan Black is an associate professor at the University of Arizona's Laboratory of Tree-Ring Research. His work focuses on growth rings formed in the hard parts of marine and freshwater species. He uses the rings to understand patterns in growth, sometimes across multiple species. He also links the patterns in growth to climate and other variables. He has one child, age 10.

DANIEL B. YOUNG

Dan Young is a fish biologist with the National Park Service and has been affiliated with Lake Clark National Park and Preserve since 1999. During that time, he has collected data on the abundance and timing of sockeye salmon returning to spawn in the park. He has also studied less popular species, like least cisco and humpback whitefish. He has two children, ages 16 and 18.

PETER VAN DER SLEEN

Peter van der Sleen is a researcher and lecturer at the Wageningen University in the Netherlands. His research activities include studies in tropical, temperate, and arctic regions, and involve trees and fishes. Across these biomes and organisms, his main focus has been on growth, and how growth rates are influenced by environmental conditions. He has two children, ages 4 and 6.

CHRISTIAN E. ZIMMERMAN

Chris Zimmerman is the director of the U.S. Geological Survey Alaska Science Center. He has worked there since 2001 in various roles, including research fish biologist, leader of the Fish and Aquatic Ecology Program, and leader of the Water, Ice and Landscapes Dynamics Office. In his spare time, Chris enjoys being a private pilot.