

Why are Arctic rivers turning orange?

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Abstract

The Salmon River in Alaska's Kobuk Valley National Park is wild and scenic. Recently, scientists were surprised to find many of the streams in the park turning a bright, rusty shade of orange. What could cause such a change? One possibility is thawing permafrost. Permafrost is ground that normally stays frozen all year long. When it thaws, water can reach rocks that were inaccessible in the frozen ground for thousands of years. The water reacts with minerals in the rocks, making acid. The acidic groundwater carries

certain metals, like iron, to streams. We traveled to the headwaters of the Salmon River and rafted down the river. We took measurements along the way. Our data showed that the water quality has become worse since the streams turned orange. We found toxic levels of iron, aluminum, and cadmium in the water. This may be to blame for the lower numbers of salmon returning to the area in recent years.

Introduction

Alaska is a beautiful place, full of mountains, glaciers, vast forests, and crystal-clear streams. At least, the streams used to be clear. In 2019, scientists were surprised to see that many streams in Kobuk Valley National Park in northern Alaska were suddenly turning bright orange. What could be happening to the water? Where is the color coming from? And is the color a sign that the water is becoming less healthy for fish?

Streams are not the only thing that is changing in Alaska. As the Earth is getting warmer, Alaskan glaciers are getting smaller and winter snow is arriving later. Plus, importantly, the **permafrost** is starting to thaw.

Permafrost is soil that is frozen solid all year round. Could changing permafrost be to blame for orange streams?

Permafrost keeps the water at the surface from going deep underground. When it thaws, water can go deeper than before, carrying oxygen from the atmosphere. The **bedrock** in Alaska has many minerals that can react with



The Salmon River in 2020, soon after the water color changed to orange.

Photo: Ray Koleser

these waters. For example, **pyrite** (also known as fool's gold) is made of iron and sulfur. When pyrite is exposed to water and oxygen, it releases iron and sulfuric acid. This is a type of **weathering**.

We wanted to know why the color of the rivers changed. And we wanted to know whether the changes in water quality were harmful to fish and other aquatic life. We decided to venture into the park to find out!

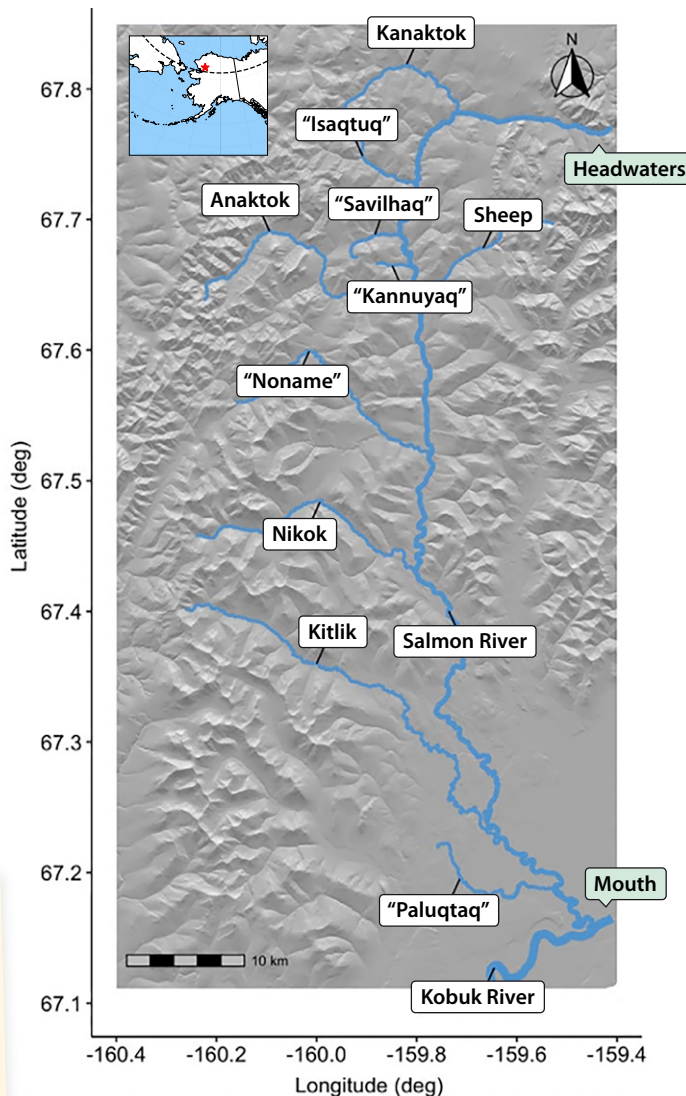
Methods

The Salmon River **watershed** is extremely remote! You can't just drive there. There are no good places to land a plane. We hiked to the **headwaters** twice, first in August 2022 and then in July 2023. On our third trip, in August 2023, we caught a ride with a helicopter crew that was working in the area. We carried small inflatable rafts and paddled them from the headwaters to the river's mouth (Fig. 1). **We collected water samples from the tributaries and headwater streams. We tested for 22 different elements in the water.** We compared our samples to National Park Service measurements from 2013, before the streams changed color.

We used **exposure thresholds** published by the US Environmental Protection Agency (EPA) to see if the water was unhealthy for fish. Exposure thresholds are the highest amount of a material that can be in the water before it harms living things.

We also needed to test if pyrite weathering was causing the changes in water quality. So, we compared the amount of **sulfate** to the amount of calcium in the water. Sulfate can result from pyrite reacting with oxygen from the atmosphere. A greater increase in sulfate than in calcium would suggest that the sulfate is coming from pyrite in the bedrock.

Figure 1: The Salmon River and its tributaries. Shading on the map shows the many hills and mountains in the area. Our expedition started at the north end of the Salmon River (the headwaters at the top of the map). We paddled to the river's mouth, where it joins the Kobuk River. We took samples at each tributary along the way.



Results

- There is a lot more sulfate in the Salmon River and most of its tributaries now than there was in 2013 (Fig. 2).
- Nine out of ten tributaries that we sampled had toxic concentrations of at least one metal.
- **Eight out of ten tributaries had high sulfate and sulfate**

- to calcium ratios. This tells us that the changes we measured likely came from weathering pyrite.** This leads to the release of toxic metals along with the sulfate.
- Even streams that didn't turn orange had dangerously high levels of metals.

Pyrite weathering produces sulfate. Do the measurements of water quality show signs of pyrite weathering?

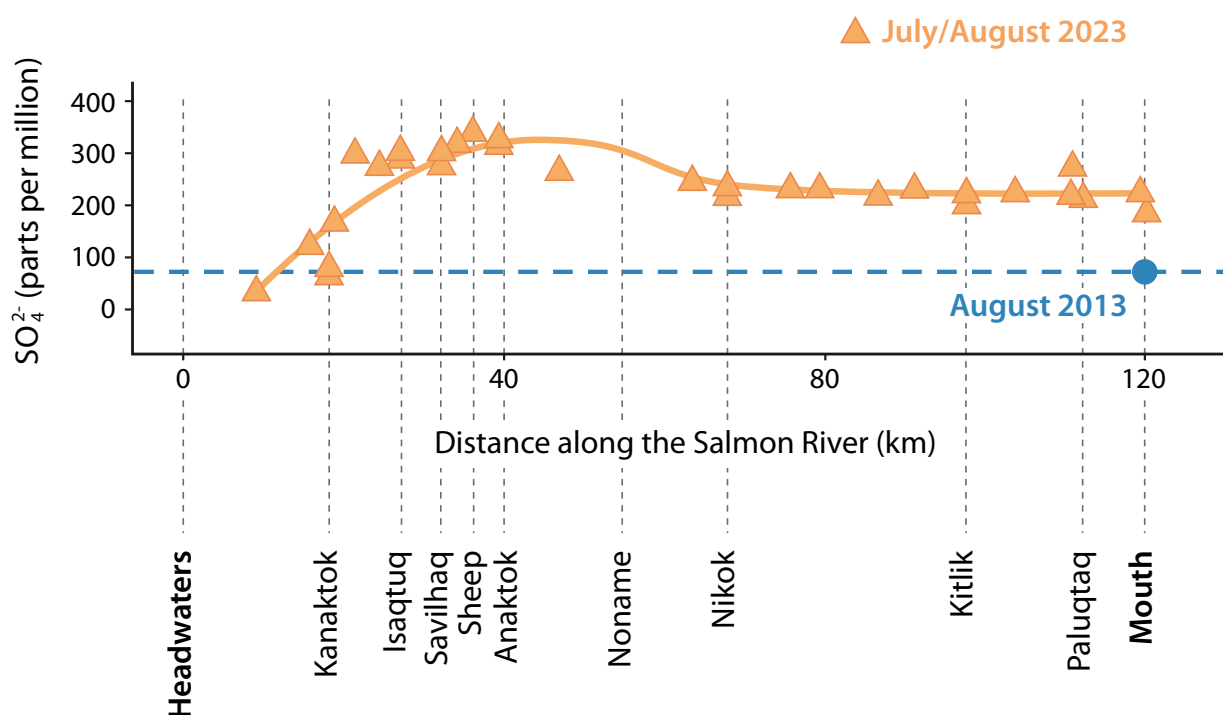


Figure 2: Measurements of sulfate levels in the Salmon River.

Discussion

Our measurements show that water quality in the Salmon River watershed has gotten a lot worse. It's very likely that the changes to the water quality are from pyrite weathering. The orange color is from iron. The sulfur released from pyrite weathering turns into sulfuric acid. Sulfuric acid is **corrosive**. It dissolves other rocks in the bedrock. These rocks can have toxic metals in them, like aluminum and cadmium.

We expect to see more and more permafrost thawing in Alaska and other northern regions. What caught us by surprise is the consequence of thawing permafrost. How will the change in water quality affect salmon? People

living in the area depend on salmon for food and income. Salmon are travelers. They spend much of their lives in the ocean, but they travel hundreds of miles up rivers into the mountains to **spawn**. That's why the health of mountain streams is so important for salmon. Recently, fishing crews have not been able to catch as many salmon. It's hard to say for sure whether the low harvest is because of the water quality in the Salmon River. We know that exposure to iron, aluminum, and cadmium in water can harm fish, especially their gills. Although there may be other causes, **we think it's likely that salmon are being harmed by the poor water quality linked to thawing permafrost.**

Conclusion

Scientists have known for a long time that Alaska is warming up. But we didn't expect that permafrost thaw would turn rivers orange and make them less safe for fish! Other streams in Alaska have not seen these effects yet. It's really important to visit these other sites and make

measurements so we can tell when and where changes happen. Climate change is impacting the world around us in lots of ways. What signs can you see where you live? Measuring and tracking these visible changes could be very valuable data!

Glossary of Key Terms

Bedrock - the layer of rocks beneath the soil.

Corrosive - chemicals that can destroy, weaken, or dissolve something.

Elements - materials that can't be broken into simpler components. For example, hydrogen and oxygen are elements. But water is not an element, because it's made of hydrogen and oxygen. It is a molecule.

Exposure thresholds - the largest amount of a substance that can be present without harming living things. If there is more of a chemical than the exposure threshold, then living things can get hurt by it.

Headwaters - where a river or stream begins. Often, the headwaters are where many tiny streams join together.

Permafrost - ground that stays frozen solid all year round.

Pyrite - a common mineral made of iron and sulfur with the nickname "fool's gold" due to its shiny yellowish gold appearance.

Spawning - when fish lay and fertilize eggs.

Sulfate (SO_4^{2-}) - a product resulting from the reaction of pyrite with water and oxygen and related to the generation of sulfuric acid.

Tributaries - streams and rivers that join a larger stream or river.

Watershed - an area of land where all the rain, snow, and water drain into the same river, lake, or ocean.

Weathering - deterioration of rocks and minerals by exposure to water, air, or sunlight.

REFERENCES

Patrick F. Sullivan, Roman J. Dial, David J. Cooper, Charles Diamond, Christopher J. Tino, Daniel D. Gregory, Russell E. Wong, and Timothy W. Lyons (2025) *Wild, scenic, and toxic: Recent degradation of an iconic Arctic watershed with permafrost thaw*. Proceedings of the National Academy of Sciences of the United States of America.

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NASA: What is permafrost?

<https://science.nasa.gov/kids/earth/what-is-permafrost/>

Rivers.gov: Salmon River

<https://rivers.gov/river/salmon-alaska>

Acknowledgment: This article's adaptation was supported by the Moderna Foundation.



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Check your understanding

1 How did we get to the study sites?

2 What results of climate change did we expect to see? What did we find surprising?

3 How did we determine that pyrite weathering was the cause of the changes to the water?

4 The article mentions how water quality may harm fish and make it harder for fishing crews to find as many salmon. Think of a body of water near where you live, like a river, pond, or lake. How does the water quality affect people in your community?

5 Have you ever noticed adults talking about how things were different when they were young? Talk with your classmates and make a list of things that parents, grandparents, or other grown-ups have noticed changing in the environment since they were kids.
