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EARTH AND ITS RESOURCES
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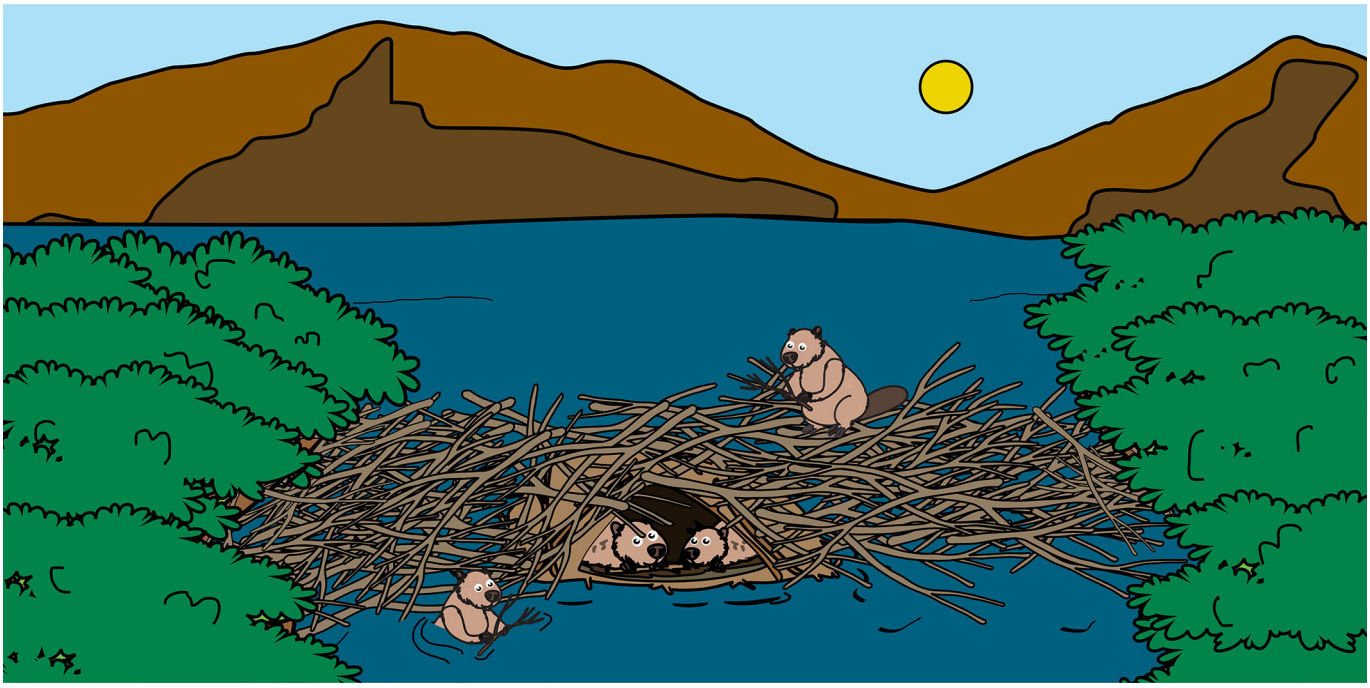

HOW BEAVERS ARE CHANGING ARCTIC LANDSCAPES AND EARTH'S CLIMATE

Jonathan A. O'Donnell[1*], *Michael P. Carey*[2], *Brett A. Poulin*[3], *Ken D. Tape*[4] *and Joshua C. Koch*[2]

[1]*Arctic Inventory & Monitoring Network, National Park Service, Anchorage, AK, United States*
[2]*U.S. Geological Survey, Alaska Science Center, Anchorage, AK, United States*
[3]*Department of Environmental Toxicology, University of California, Davis, Davis, CA, United States*
[4]*Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, United States*

YOUNG REVIEWERS:

DREW
AGE: 11

SPRINGHILL SCHOOL
AGES: 10–14

Beavers build dams that change the way water moves between streams, lakes, and the land. In Alaska, beavers are moving north from the forests into the Arctic tundra. When beavers build dams in the Arctic, they cause frozen soil, called permafrost, to thaw. Scientists are studying how beavers and the thawing of permafrost are impacting streams and rivers in Alaska's national parks. For example, permafrost thaw from beavers can add harmful substances like mercury to streams. Mercury can be taken up by stream food webs, including fish, which then become unhealthy to eat. Permafrost thaw can also move carbon (from dead plants) to beaver ponds. When this carbon decomposes, it can be released from beaver ponds into the air as greenhouse gases, which cause Earth's climate to warm. Scientists are trying to keep up with these busy beavers to better understand how they are changing Arctic landscapes and Earth's climate.

BEAVERS ARE ECOSYSTEM ENGINEERS

Beavers are ecosystem engineers that build dams. The dams change the way water moves between streams, rivers, lakes, and the land around them. Beaver dams in streams block the flow of water, making ponds that flood nearby soils (Figure 1). Scientific studies of beaver ponds in the western United States and Canada show that beavers can impact water quality. Beavers can change the amounts of nutrients (which act like fertilizers), carbon (from dead plant material), and harmful substances (like mercury) in streams and lakes [1]. Beavers can

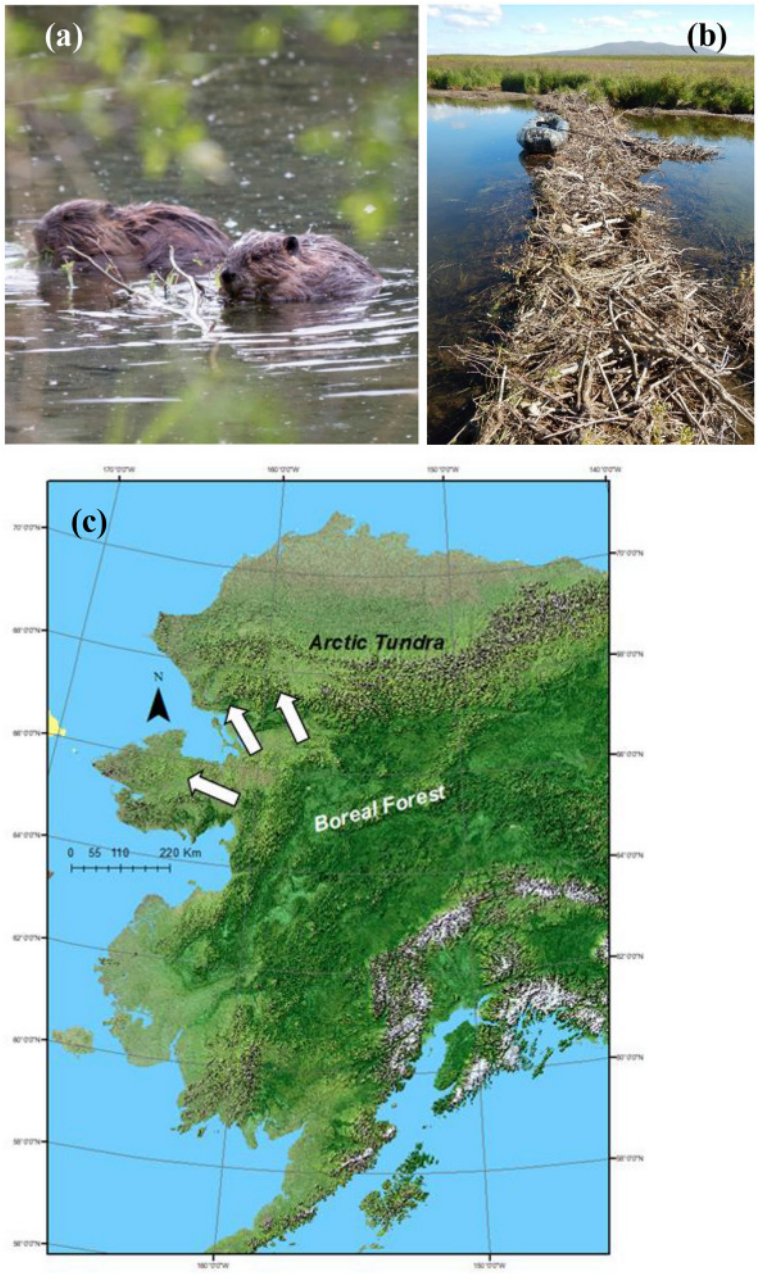

Figure 1

(a) Two beavers eating shrub branches in a pond near Glenallen, Alaska. **(b)** A beaver dam in Alaska's Arctic is made of small branches and twigs from shrubs. **(c)** In the past, beavers lived in regions with larger trees, like Alaska's forests (dark green on map). However, climate change has caused shrubs to grow in the Arctic tundra (light green), where there was previously mainly grass and moss. Beavers are moving north from the forests to the Arctic tundra in northwest Alaska (white arrows) and are using these shrubs to build dams (Photo credit: Ken Tape; map: https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1691).

also cause the spread of diseases like Giardia (sometimes called beaver fever). This disease makes people sick if they drink unfiltered water from streams. Beavers also create habitats for fish and wildlife, and they can also affect landscapes by encouraging growth of vegetation and limiting the spread of wildfires. Given all of this, there is good reason why people use the phrase "busy as a beaver"!

BOREAL FOREST

A large, forested region in the Northern Hemisphere. The boreal forest is dominated by conifer trees, like spruce and pine. Boreal trees and soils store lots of carbon.

ARCTIC TUNDRA

The region north of the boreal forest. Arctic tundra ecosystems are cold, with small plants (such as moss and lichen) and permafrost soils.

BEAVERS ARE MOVING NORTH IN ALASKA

Beavers typically live in regions with forests. They use trees, branches, mud, and rocks to build dams and lodges. In Alaska, beavers have mainly lived in the **boreal forests** in the lower part of the state. But scientists recently discovered that beavers are moving north, beyond Alaska's boreal forests and into the **Arctic tundra** [2]. Using satellite images, researchers can see that, over the last 30 years, beaver ponds have increased in northwest Alaska (Figure 2). Beavers are moving into new habitat in Alaska's Arctic national parks, including Bering Land Bridge National Preserve, Cape Krusenstern National Monument, and Noatak National Preserve.

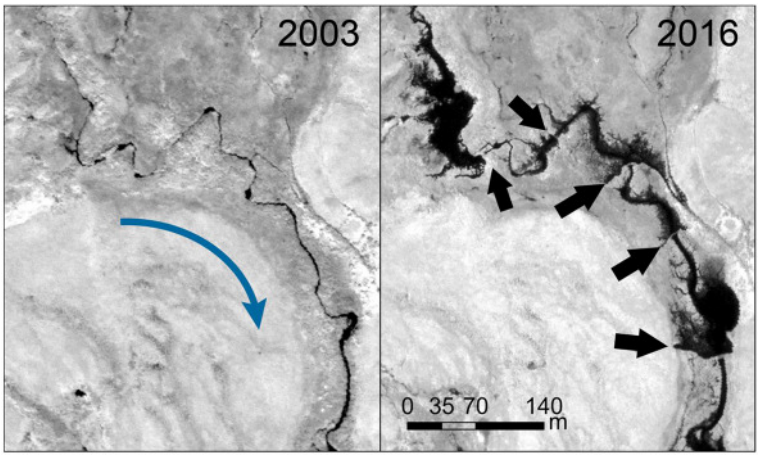

Figure 2

Satellite pictures showing the effects of beavers on an Arctic stream in northwest Alaska. The blue arrow shows which direction the stream flows. In 2003, there were no beavers and the stream channel was small. By 2016, beavers had built several dams (each black arrow points to a dam), creating a number of large beaver ponds [Image credits: Quickbird (2003; Digital Globe Inc.) and Worldview 2 (2016)].

Beaver numbers have changed due to both trapping and climate change. In the 1800s, people used to trap beavers for their valuable fur, which kept the number of beavers in the region low. By the 1900s, new laws slowed beaver trapping, which caused the number of beavers to increase. In the past, the Arctic was too cold and lacked both beaver food and the large sticks needed for building their homes and dams. But the climate is warming rapidly in Alaska—much faster than in the rest of the United States. As it gets warmer, trees and shrubs can grow farther north. This new growth provides the wood beavers can use to build dams and lodges. Other mammals, like snowshoe hares and moose, are also moving north as Earth's climate warms and shrubs grow bigger. **Climate models**—or computer simulations—predict that Alaska's climate will continue to warm for tens of years into the future.

CLIMATE MODELS

Complex computer programs that use math to understand Earth's climate. Climate models can be used to study how land, air, and oceans interact to affect the climate.

As a result, scientists believe that the number of beavers will continue to increase, and they will expand throughout the Alaskan Arctic. Scientists from the US Geological Survey, the National Park Service, and the University of Alaska Fairbanks are currently studying beavers to understand how they are changing Arctic lands and waters.

DO BEAVERS CAUSE PERMAFROST TO THAW?

PERMAFROST

Soil that has remained frozen for at least two straight years, although most permafrost has been frozen for much longer.

THERMOKARST

When icy permafrost soils thaw, the ground surface can collapse. This process is known as thermokarst.

Beaver ponds in the Arctic are different from beaver ponds in the rest of the US due to the presence of **permafrost**. Permafrost, or frozen soil, is an important feature of Arctic regions like Alaska. Permafrost forms in cold climates. Most permafrost has remained frozen for hundreds or even thousands of years. But recent climate warming in the Arctic is causing permafrost to thaw. Perhaps permafrost is not permanent after all! When permafrost thaws, the ice melts, water flows away, and the ground surface can collapse. In Arctic towns and cities, permafrost thaw can also cause houses to collapse and roads to break.

New beaver ponds flood the surrounding Arctic permafrost soils. During summer, the relatively warm pond water causes the permafrost to warm and rapidly thaw in a process known as **thermokarst** [3]. This permafrost thaw can occur beneath ponds, making ponds deeper over time. Permafrost thaw can also happen around the edges of ponds. This increases the surface area of beaver ponds as the pond banks thaw, collapse, and erode over time (Figure 3). It is clear how beaver ponds can change the land and streams. How can they impact water quality and climate change?

Figure 3

Aerial view of a beaver pond in the tundra. The picture shows a large beaver dam (white arrows) that blocks water from flowing downstream. You can see how the pond floods nearby soils. The pile of sticks in the middle of the pond is the beaver lodge, their home (Photo credit: Ken Tape).

BEAVER EFFECTS ON WATER QUALITY AND FISH

Permafrost stores large amounts of **organic carbon** and nutrients. Think of carbon and nutrients as food for stream plants and **algae**. Algae grow attached to rocks and wood or they float in the water. Algae and other water plants make up the base of the food web. They support bugs, fish, and all other animals that eat plants. For example, moose are often spotted eating plants out of beaver ponds. When carbon and nutrients are frozen in permafrost, it is like storing food in a freezer. When permafrost thaws, it is like you are transferring the food from the freezer to the refrigerator. When the food thaws, it can be eaten, or it can decompose.

As we discussed earlier, beavers can cause permafrost soils to thaw by building ponds. In that way, beavers cause the release of carbon and nutrients from permafrost into ponds and streams. Water quality is a measure of how safe that water is for people or an ecosystem[1]. Scientists do not yet know the consequences of beaver ponds on water quality and stream food webs. A recent study found carbon from thawing permafrost in the muscles of Arctic fish species. Species called Arctic Grayling and Dolly Varden had **permafrost carbon** in their muscles because it was in their food [4]. Permafrost carbon enters the food web through algae and moves up the food chain through bugs to fish. It is possible that beaver ponds are a great place for some fish species because permafrost carbon can support their growth and energy needs.

One concern of scientists, national park managers, and fishermen is the release of mercury, a metal, from thawing permafrost into beaver ponds. In addition to carbon and nutrients, permafrost stores large amounts of mercury. Some forms of mercury are toxic and can be taken up by stream food webs. To better understand this release of mercury, we visited beaver ponds in northwest Alaska to make scientific observations and collect water and fish samples. Our research on Arctic beaver ponds in national parks shows that beaver ponds can be "hotspots" for toxic mercury. For instance, we found that toxic forms of mercury can account for up to 80% of total mercury in beaver pond sediments. If people eat fish with high amounts of mercury, it can negatively affect their health. Therefore, it is important to determine if beaver ponds are causing mercury to accumulate in Arctic fish.

CAN BEAVERS IMPACT EARTH'S CLIMATE?

When permafrost thaws and carbon moves from the freezer to the refrigerator, this thawed carbon can also move from the soil to the air. Soil bacteria can decompose the thawed carbon, similar to the way animals chew and digest food. By doing so, these bacteria produce the greenhouse gases carbon dioxide (CO_2) and methane (CH_4). These

ORGANIC CARBON

Carbon that forms from living things, such as plant or animals. In the Arctic, soils store lots of organic carbon.

ALGAE

Simple plants that grow in streams and lakes. Unlike many land plants, algae do not have stems, roots, or leaves. "Algae" is plural, and the singular term is "alga."

[1] For more information about water quality, see: https://www.usgs.gov/special-topic/water-science-school/science/water-quality-information-topic.

PERMAFROST CARBON

Carbon, or dead plant material, stored in permafrost. When permafrost thaws, large amounts of carbon can be released into the air as greenhouse gases.

greenhouse gases are the main reason why Earth's climate has been warming so quickly over the last 40–50 years. Beaver ponds and other shallow Arctic lakes release lots of methane to the atmosphere [5]. We expect that permafrost will continue to thaw and more carbon will be released to the atmosphere as beavers move north. By adding more greenhouse gases to Earth's atmosphere, beavers may be contributing to Earth's warming climate! However, scientists do not know how large of an impact beavers will have on climate. We will continue to study these ecosystems to better understand the importance of beavers to the Arctic and to Earth's climate.

As ecosystem engineers, beavers have a large effect on ecosystems. Now that beavers have moved north into the Arctic tundra, their effects could be even greater. The combination of beavers and permafrost thaw makes tundra streams exciting places to study. It is important to understand the effects of these changes throughout the food web, to the climate, and to people. We are just now beginning to understand all the different things that change when beavers make a tundra stream their home. In the future, we will collect more water and fish samples to better understand the effects of beavers on mercury and greenhouse gases. Now, scientists are as busy as beavers.

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ORIGINAL SOURCE ARTICLE

Tape, K. D., Jones, B. M., Arp, C. D., Nitze, I., and Grosse, G. 2018. Tundra be dammed: beaver colonization of the Arctic. *Glob. Change Biol.* 24:4478–88. doi: 10.1111/gcb.14332

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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.

YOUNG REVIEWERS

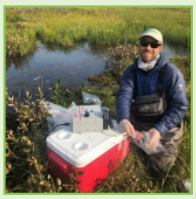
DREW AGE: 11
Hi, I am Drew! I love science, especially animals, dinosaurs, and the Museum of the Rockies. My favorite sport is soccer, I love to fish, and skiing is awesome. My Gramps got me hooked on birds, and my family calls me eagle eye.

SPRINGHILL SCHOOL, AGES: 10–14
We are a one room schoolhouse just north of Bozeman, Montana. We have 14 students currently in grades one through eight. We are a school who operates as one team even though we have many different grades. Our older students often step in as "mini teachers" and help younger students understand difficult concepts and complete challenging activities. This allows our students to grow in their leadership abilities and develop skills in teamwork.

AUTHORS

JONATHAN A. O'DONNELL
Jonathan A. O'Donnell is an ecologist with the National Park Service in Anchorage, Alaska. He monitors streams, rivers, and lakes in the Arctic. He also conducts research to understand how climate change is impacting Arctic ecosystems. In his free time, Jon enjoys camping with his family, skiing, and playing guitar. *jaodonnell@nps.gov

MICHAEL P. CAREY
Mike P. Carey is a Research Fish Biologist at the U.S. Geological Survey Alaska Science Center in Anchorage, AK. He works in Arctic and Subarctic ecosystems to understand how changes from climate warming and invasive species influences aquatic food webs. He is particularly interested in understanding how changing ecosystems influence fish communities that live in the rivers and lakes or use these habitats at different stages of their life. When he is not thinking about fish you can find him skiing or mountain biking trying to keep up with his kids.



BRETT A. POULIN
Brett A. Poulin is an assistant professor and scientist at the University of California, Davis. His work aims to understand how the chemistry of water influences chemicals and metals that are toxic to humans and wildlife. He uses this information to guide the management of environments to improve them and understand how these environments will respond to new pressures (e.g., climate change). He gets excited about his work because he can make measurements at the small scale of atoms and relate his observations to processes at the scale of ecosystems.

KEN D. TAPE
Ken D. Tape is an Arctic ecologist. He studies how the landscape is responding to climate warming, and how these changes affect an assortment of wildlife. Lately he has studied the impact of beaver colonization on aquatic and terrestrial environments of the Arctic.

JOSHUA C. KOCH
Josh C. Koch studies water for the United State Geological Survey in Alaska. He went to school until he was 32 years old to get the training needed to do his job. He measures the amount of water flowing in streams and rivers and the volume of water in lakes. Josh measures how water flow and volume change in time and looks at the chemistry of the water to understand where the water has been and how it is used by ecosystems.