The world’s boreal forests may be shrinking as climate change pushes them northward

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Earth’s boreal forests circle our planet’s far northern reaches, just south of the Arctic’s treeless tundra. If the planet wears an Arctic ice cap, then the boreal forests are a loose-knit headband wrapped around its ears, covering large portions of Alaska, Canada, Scandinavia and Siberia.

The boreal region’s soils have long buffered the planet against warming by storing huge quantities of carbon and keeping it out of the atmosphere. Its remoteness has historically protected its forests and wetlands from extensive human impact.

A brown bear in a Siberian boreal forest. Logan Berner, CC BY-ND

These two traits rank boreal forests among the most important ecosystems on Earth. In addition, numerous species of mammals, fish, plants, insects and birds make these forests home.

For over two centuries, scientists have recognized that climate plays a key role in determining the geographic zones of plant communities. Because boreal forests and soils face subzero winters and short summers, these forests and the animals that live in them are shifting northward as temperatures rise.

However, boreal forests' northward advance has been spotty and slower than expected. Meanwhile, their southern retreat has been faster than scientists predicted. As scholars who study northern ecosystems, forests and wetlands, we see concerning evidence that as the world warms, its largest forest wilderness appears to be shrinking.

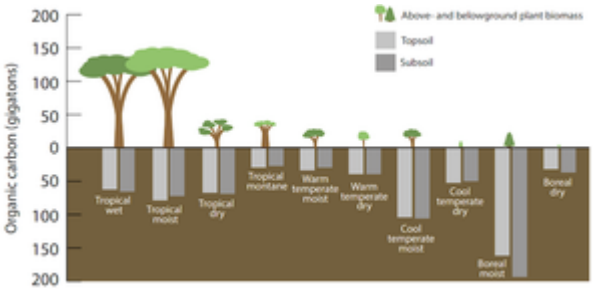
Youtube: The boreal forest biome, often known by its original Russian name, the taiga, stretches from coast to coast in Earth's far north.

The largest wilderness on Earth

Boreal forests contain billions of trees. Most are needleleaf, cone-bearing conifers, but there also are patches of broadleaf species, including birch, aspen and poplar. They support millions of migratory birds and iconic mammals like brown bears, moose and lynx.

These trees and the soils around their roots help regulate Earth's climate, in part by pulling carbon dioxide out of the atmosphere, where it would otherwise act as a greenhouse gas. The trees use this carbon to grow roots, trunks and leaves, which eventually turn into carbon-rich soil once the tree dies. Significant changes to the forests will translate to changes in global climate.

These forests are warming at rates well above the global average. Rising temperatures directly affect the growth and survival of trees and, in turn, their ability to store carbon.



Different forest types around the world store varying amounts of carbon. Warm tropical regions tend to store much more carbon in plants, while cool boreal forests have enormous carbon stores in soil. U.S. Forest Service

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Forests on the move

As atmospheric warming frees trees from the icy grip of cold temperatures, adult trees can respond by growing faster. Milder temperatures also allow young seedling trees in the most northern boreal

forests to gain a foothold where previous conditions were too harsh for them to become established.

In the warmer, southern boreal forests, the situation is quite different. Here, conditions have become too warm for cold-adapted boreal trees, slowing their growth and even leading to their death. With warming comes dryness, and water stress leaves trees more susceptible to insect infestation and fires, as Canada has experienced in 2023 and Siberia in 2019 and 2020.

If this happens at a larger scale, southern boreal forest boundaries will thin and degrade, thereby retreating farther north, where temperatures are still suitable.

If boreal forests expand northward and retreat in the south at the same rates, they could slowly follow warming temperatures. However, our combined research using satellite and field data shows that the story is more complex.

Flames from the Donnie Creek wildfire burn along a ridgetop north of Fort St. John, British Columbia, Canada, on July 2, 2023. Fire is part of the ecology of boreal forests, but climate change is drying out trees and making them more fire-prone.

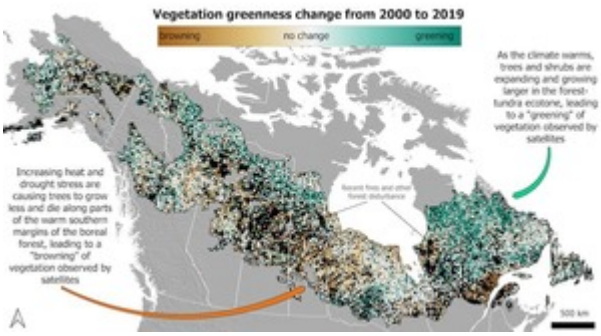
Tracking forests from space

Satellites are invaluable for tracking how boreal forests have changed in recent decades and whether these changes are consistent with an overall northward shift. Researchers can use satellites to monitor year-to-year changes in forest characteristics, such as annual tree growth and tree cover.

Our recent studies using satellite data showed that tree growth and tree cover increased from 2000 to 2019 throughout much of the boreal forest. These changes occurred mainly in the coldest northern areas. However, there was limited evidence to indicate that forests were expanding past current tree lines.

Our studies also revealed that tree growth and tree cover often decreased from 2000 to 2019 in warmer southern areas of the boreal forests. In these regions, hotter and drier conditions frequently reduced tree growth or killed individual trees, while wildfires and logging contributed to tree cover loss.

Satellite data makes it clear that climate change is affecting both the northern and southern margins of the boreal forest. However, if tree cover loss in the south occurs more rapidly than gains in the north, then the boreal forest will likely contract, rather than simply shifting northward.



Satellite measurements show that plant growth widely increased along the cold northern margins of the boreal forest in recent decades, but it often decreased along the warm southern margins − potential early indicators that the boreal forest is beginning to migrate northward. Logan Berner, based on results from Berner and Goetz 2022., CC BY-ND

Zooming in to understand forest change

Forests advance when individual tree seeds germinate and grow, but boreal trees grow slowly and require decades to reach a size that's visible from space. Finding young trees whose presence would signal tree-line movement requires data from the ground.

In the late 1970s, one of us (David Cooper) documented that young spruce trees were growing at altitudes hundreds of yards higher and locations miles north of the highest-elevation cone-bearing trees in Alaska's Brooks Range. Returning in 2021, we found those little trees had grown to be several yards tall and were producing cones. More importantly, 10 times the number of young spruces now grow above and beyond the tree line than during our first field forays.

Crisscrossing the boundary between Alaska's boreal forest and its Arctic tundra on foot, we have found thousands of young boreal trees growing up to 25 miles north of established tree lines. Most grow where deeper snows fall, due to an Arctic Ocean version of the "lake effect": Cold air moves across open water, picking up warmth and moisture, which then falls as snow downwind.

Retreating sea ice leaves more open water. This generates stronger winds that propel tree seeds farther and more snowfall that insulates seedlings from harsh winter conditions. The result is that trees in Alaska's Brooks Range are rapidly moving into the treeless tundra. However, these rapid expansions are localized and do not yet happen everywhere along the northern tree line.

A young white spruce colonist on the Alaskan tundra, with the Brooks Range mountains in the background. Roman Dial, CC BY-ND

The future face of boreal forests

Our combined research shows that boreal forests are, in fact, responding to rising temperatures. But rapid rates of climatic change mean that trees likely can't move northward at a pace that keeps up with their loss in the south.

Will trees in the far north ever catch up with climate and prevent forest contraction? At this point, scientists simply don't know. Perhaps the newly established trees in the Brooks Range herald such an expansion. It's also unclear whether the northern parts of boreal forests can accumulate enough carbon through increased growth to compensate for carbon losses in the south.

If boreal forests are indeed on the verge of contracting, they will eventually disappear from their current southern edge. This would harm many native and migratory animals, especially birds, by reducing their boreal habitat. The forests also are culturally important to several million people who call them home, such as Canada's aboriginal communities.

Monitoring boreal forests around the world more closely, using both satellite data and on-the-ground measurements, will help fill out this picture. Only then can researchers hope to glimpse the future of one of the Earth's last wildernesses.

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P.S.

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Ronny (Ron) Rotbarth is a PhD candidate at Wageningen University in The Netherlands. He holds a Bachelor degree in Environmental Science and Ecology from the University of Stirling (Scotland) and a Master degree in Forest and Nature Conservation from Wageningen University. Ron is interested in the response of northern ecosystems to global change. In particular, he studies the resilience and potential shifts of boreal forests in the face of climate change and increased disturbances. His research uses (1) satellite and aerial images to analyse global and continental boreal forest change and (2) fieldwork data from the mountain birch forests in northern Norway to evaluate the recovery potential of these forests following mass insect outbreaks. His experiences include field data collection from northern ecosystems (north-eastern Siberian tundra and Norwegian boreal forests), machine learning methods, analyses of satellite images and mathematical models. Ron's long-term objective is to see his research inform management and policy decisions to

increase the resilience of socio-ecological systems to future challenges. He is also interested in exploring ways to communicate scientific output to a wider audience

David J. Cooper. I work on ecosystems characterized by a perennial, seasonal or periodic abundance of water, including peatlands (fens and bogs), streams/rivers and their floodplains, marshes, springs, wet meadows, and salt flats. My specialty is mountain wetland ecology and hydrology and I have ongoing and recent projects in the Rocky Mountains, Sierra Nevada, Cascades, Coast Range, Andes, and Carpathian Mountains (Poland and Slovakia). Study sites range from the wettest to the driest climate regions, from the arctic to the tropics, from lowland to mountain tops, and wilderness to urban landscapes. Research projects address theoretical issues in ecology and hydrology, as well as applied problems in land and water management and restoration. We work with all levels of government (federal, state, county, city), for large and small for-profit and non-profit companies, as well as water management agencies, ski areas and mining companies, individuals and conservation organizations to address questions and problems in wetland ecosystem formation, persistence, functioning, management and restoration. Almost all of my work involves graduate students at Colorado State University.

Logan Berner. Assistant Research Professor of Global Change Ecology, Northern Arizona University. I am an ecologist who studies tundra and forest ecosystems, particularly ecosystem responses to environmental change. My research blends field measurements, satellite remote sensing, and ecological informatics. I hold a PhD in Forest Ecology and am a research professor at Northern Arizona University, through previously worked as a NASA Earth and Space Science Fellow and for the Woodwell Climate Research Center.

Roman Dial. Professor of Biology and Mathematics, Alaska Pacific University. For me, the best part of being an academic is when I share in the learning experience. That is, when I learn too. And this happens best with a group of seven to ten students who are adventuresome and eager to discover new ideas, perspectives, and stories—who seek not a dry recitation of facts, but an uncovering of understanding through the direct experience of learning. After my first winter as a college freshman in Alaska, I nearly left the state, never to return. The dark and the distance from home isolated me. The apparent lack of culture – perhaps simply the over-dominance of the human by the natural – disoriented me. But after a summer climbing mountains, working canneries, and hitching the empty highways, I realized I had to stay. That was over 40 years ago. Through the late 70’s, 80’s and most of the 90’s, I pursued a near obsession with Alaskan wilderness, while simultaneously nurturing an academic intrigue with ecology. I scaled rock and ice, skied glaciers, paddled rivers. I studied for four degrees, two in mathematics (B.S., M.S.) and two in biology (B.S., Ph.D). I learned to “packraft,” “hellbike,” and “glacier skate.” I learned to integrate, analyze, and communicate. Magazines and newspapers ran my hyperbole and exploits; peer-reviewed journals published my theory and data. For me the wild side feeds emotion and spirit; the analytic side feeds intellect and family. So now, a professor at Alaska Pacific University, I feel blessed with an eclectic convergence. I indulge in my passions at will. I can take a class to the tropics or the arctic, where we can lie on our bellies and watch musk ox or dangle from ropes and watch monkeys. We can even move from tree to tree – “canopy trek” – collecting observations en route. We can paddle autumn rivers into Canada. Or read Sir Robert May on chaos, Benoit Mandelbrot on fractals and Per Bak on complexity. We can do wilderness and travel. We can do math and statistics. We can do nature and science. And we can find surprise and delight and challenge in it all.