

Science

FINDINGS

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"Science affects the way we think together."

Lewis Thomas

Using the Past to Inform the Future: Alaska's Changing Boreal Forest from a Tree-Ring Perspective



USDA Forest Service

An aerial view of some of the 115 million acres of boreal forest in interior Alaska. Coniferous white and black spruce and deciduous birch and aspen dominate different areas. Scientists are using field data to determine how warmer, drier conditions have affected growth rates of these species, and what this could mean for the composition of the boreal forest in the future.

*"Trees and stones will teach you
that which you can never learn
from masters."*

—St. Bernard of Clairvaux, Cistercian monk

Interior Alaska's 115-million-acre boreal forest is larger than California and Texas combined. With few roads, most of the region is accessible only by air and is considered one of the last true wilderness areas in the United States. The first systematic forest inventory of this vast area has been started by the USDA Forest Service's Forest Inventory and Analysis (FIA) program. Even with a sampling intensity of one plot per 30,000 acres, the inventory won't be completed until 2028.

Much of what is known about the dynamics of this boreal forest has been gleaned from ecological studies conducted in more easily accessed areas of the region, such as near the city of Fairbanks. "The forest of interior Alaska is a complex mix of both deciduous forest dominated by birch and aspen and coniferous forest dominated by black and white spruce," explains Patrick Sullivan, an ecologist with the University of Alaska Anchorage.

In interior Alaska, wildfires occur frequently. Black spruce trees (*Picea mariana*) are particularly flammable because their needles and branches contain a high level of resin. The wildfires are often intense, resulting in suitable

IN SUMMARY

In interior Alaska's 115 million acres of boreal forest, white and black spruce are the dominant tree species. Climate models suggest that the region is becoming warmer and drier, resulting in declining growth of black and white spruce, according to some researchers. These drier conditions also may lead to greater risk of stand-replacing wildfires, resulting in forests dominated by birch and aspen, which are early-successional tree species.

To compare long-term growth trends of the dominant coniferous and deciduous tree species, a team of researchers with the USDA Forest Service Pacific Northwest Research Station and the University of Alaska Anchorage analyzed tree cores collected from the Tanana Valley and measured tree-ring widths of these four tree species over the past 150 years. They also compared growth against monthly temperature and precipitation data to determine if there is a correlation between climate and growth.

The team found that white and black spruce have not experienced as rapid a growth decline as earlier studies suggested; instead, their annual growth remains near the long-term mean. Of the four species examined, aspen showed the greatest recent growth decline, likely reflecting a widespread insect outbreak. Among the climate variables that will affect the future growth of these species, summer rainfall was identified as a significant factor.

seedbeds for early-successional species such as light-loving birch (*Betula neoalaskana*) and aspen (*Populus tremuloides*) to fill in and dominate the forest before potentially being overtopped by spruce again.

Climate change is predicted to create warmer and drier conditions within the interior. As a result, some researchers hypothesize that the boreal forest will undergo a biome shift.

Recent studies suggest that “the forests in interior Alaska are on a trajectory toward greater dominance by deciduous tree species,” Sullivan says. “The combination of changes in climate and more frequent, severe wildfires has many researchers suggesting that we may never get back to the spruce forests. The forests might be stuck in the deciduous state for much longer than what was historically the case.”

Supporting evidence for this biome-shift hypothesis comes from tree cores collected from white (*Picea glauca*) and black spruce in accessible areas of the interior. After measuring the width of the tree rings, researchers argued that spruce species are already experiencing declining growth because of climate change.

When Sullivan’s colleague Robert Pattison, then working as a research ecologist with the U.S. Forest Service Pacific Northwest (PNW) Research Station, learned of an opportunity to collect tree cores from the interior’s Tanana Valley, he saw it as a means to test this biome-shift hypothesis.



KEY FINDINGS



- In interior Alaska, white and black spruce, aspen, and birch all experienced a growth peak in the mid-20th century, which has since tapered off. In the past two decades, white and black spruce growth was near the long-term mean, while birch and aspen growth was 16 percent and 48 percent lower, respectively, than the 20th-century mean.
- Declining aspen growth beginning in the 1990s was driven, in part, by a widespread outbreak of aspen leaf miner (*Phyllocnistis populiella*), a herbivorous moth.
- Black and white spruce and birch grew more during years with more summer precipitation compared to years with less. This suggests that these species may be more sensitive to warm and dry conditions than the deciduous aspen.
- The warm and dry conditions may have predisposed aspen to insect attack because correlations between climate and growth showed increasing sensitivity to warm air temperature among aspen prior to the leaf miner outbreak.

Tree Ring Revelations

The source of these tree cores was a joint NASA-FIA pilot project to determine the feasibility of combining remote sensing and field data to inventory the interior. In summer 2014, FIA field crews placed inventory plots within the Tanana Valley State Forest and Tetlin National Wildlife Refuge. On each plot, crews followed the standard FIA protocol of measuring trees and coarse woody debris, and collecting soil samples, along with measurements of lichens, moss, and other ground cover.

“Robert recognized the potential to get a lot more information out of those tree cores,”

Sullivan says. “He was able to convince FIA crews to bring back the tree cores, rather than discarding them on the plots.”

A tree core contains a trove of information that researchers are still unlocking. A tree’s age is the easiest piece of information to discern. One can count the dark-colored rings, which is the latewood grown in summer, to determine a tree’s age. Foresters and scientists also analyze the width of each ring to determine how fast the tree is growing. Under ideal conditions, when water, nutrients, and sunlight are plentiful, young trees have wide rings. As the tree grows larger, the rings become narrower

USDA Forest Service



Sun-loving aspen regenerates after a wildfire in interior Alaska

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A Forest Inventory and Analysis crew member uses an increment borer to take a core sample from the tree. Researchers later used tree cores to create a tree-ring chronology to determine growth trends for different species.

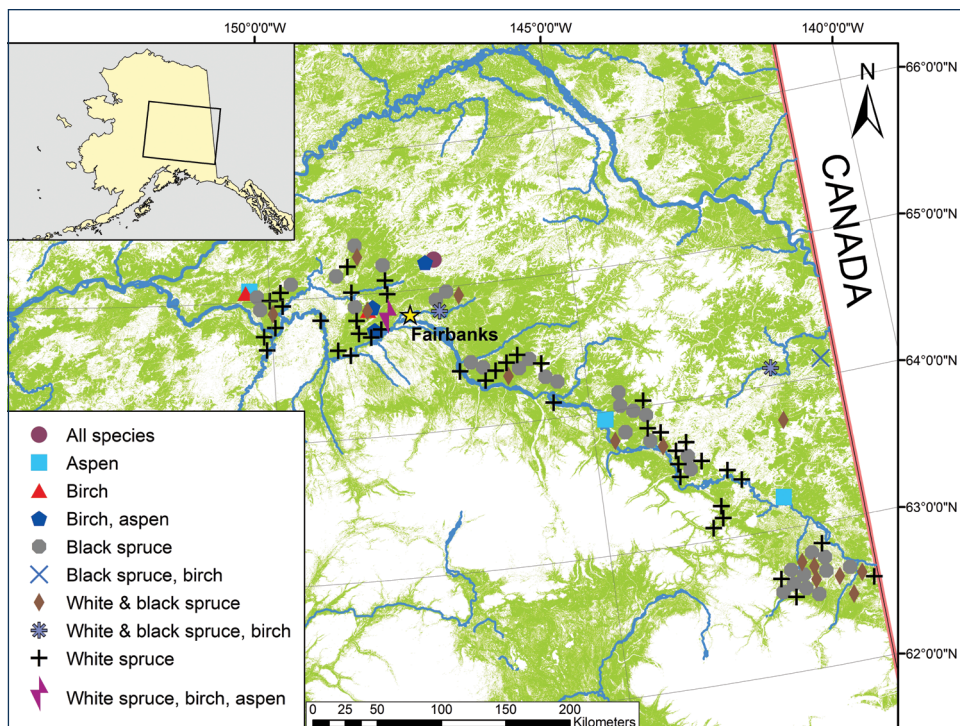
because there is a larger diameter for the new wood to encircle.

However, narrow rings may also provide a record of stress experienced by the tree. Using energy to withstand drought or insect attacks, for example, diverts energy from new growth. Competition between neighboring trees also affects ring size because the trees are competing for resources.

For Sullivan and his team, their goal was to determine if a trend of declining growth resulting from climate change was observable over a larger swath of landscape.

“The advantage that we had with our sampling method was that the FIA plot network is a random sample of the landscape, which is a common sampling design. But from a tree ring perspective, it’s really unique,” says Sean Cahoon, a research ecologist with the PNW Research Station who was a member of Sullivan’s research team while a postdoctoral researcher at the University of Alaska Anchorage. “Historically, many scientists have sought out more climate sensitive trees growing at the altitudinal or latitudinal limits of their range to pick up a stronger signal in the tree rings, but those trees might not represent what’s going on in the forest in the middle of their range.”

Analyzing tree ring widths to determine tree growth isn’t as straightforward as it appears. “Trees have their own inherent biological



Study plots where tree cores from different species were collected throughout the Tanana Valley, Alaska. Source: Cahoon et al. 2018.

growth patterns that we had to address in our analysis,” Cahoon says.

One of these growth patterns is related to age, which makes tree-ring data tricky to work with. “You have to statistically remove the age effect in the tree-ring data before you can look at the effect of climate,” Sullivan explains.

Even under ideal growing conditions, tree rings will narrow as the tree ages. To account for this factor, the scientists used a statistical method called “detrending” to remove the age effect and create a tree-ring chronology that charts the ring width over time. The team tested several detrending methods to determine how each approach removed the age effect from the data, and eventually selected a method called multiple-curve regional curve standardization.

They used this method on 552 tree cores, some of which were taken from trees more than 300 years old, to create a tree-ring chronology for both black and white spruce. Then they compared it to total August rainfall and May-August temperatures to see if these variables correlated with growth.

Because there was reduced growth associated with lower precipitation, they turned to the technique of measuring carbon isotopes within the cellulose to determine if there were changes in water use efficiency.

“Using carbon isotopes is a way to look retrospectively at the physiology of the trees at the time the ring was formed,” explains Sullivan.

“When trees are moisture limited, they tend to close their stomata to reduce water loss, and that stomatal closure is fingerprinted in the carbon-13 signature of the tissues that the tree produces.”

An analysis of tree-ring chronologies revealed that overall tree growth isn’t declining strongly as the climate becomes drier and warmer.

“We noticed a decline in the latter half of the 20th century, but it was a decline from a peak in growth in the 1940s and 1950s,” says Cahoon. “The decline from that point didn’t reach historically low growth levels for the white and black spruce. Instead it has settled around a long-term mean.”

The reason for this period of pronounced growth hasn’t been fully figured out, Sullivan admits. “It was definitely a time when the climate was a little bit cooler and a little bit wetter, but not quite cool and wet enough to explain the size of the growth peak that we see in the tree-ring-growth chronology.”

For the white and black spruce, greater summer precipitation was associated with increased growth, which suggests these species may be sensitive to warmer and drier conditions. However, because the precipitation data from 1915 to present do not show a decreasing trend, Sullivan concluded that the current moisture-driven growth decline hypothesis is a bit of an overstatement. “While the black and white spruce are not taking advantage of the warmer climate, I don’t think they’re going to disappear from the landscape anytime soon,” he says.

Adding Deciduous Trees to the Story

To fully understand the current dynamics of the boreal forest, it wasn't enough just to analyze the spruce species.

"From the Tanana pilot, we obtained lots of white and black spruce cores, and we were able to gain a lot of insight as to how those trees have been responding to changes in climate," Sullivan says. "We felt we were missing part of the story by not having any tree cores from birch and aspen."

"Surprisingly, there wasn't much or any multiple species comparison of tree growth among these four dominant species," adds Cahoon. What was in the literature suggested that birch and aspen might be better adapted to warmer and drier conditions, which would yield a positive growth response.

Cahoon set about collecting the tree cores of birch and aspen to create this missing dataset. The FIA crews hadn't collected birch and aspen tree cores during the inventory because their protocol only required collecting tree cores from late-successional tree species. The team augmented the FIA dataset with tree cores collected from plots maintained by the Bonanza Creek Long-Term Ecological Research program and a partnership with NASA that sought ground-truth data to corroborate satellite and airborne estimates of forest productivity.

The team again created a tree-ring chronology for each of the four species, which was then analyzed against the precipitation and temperature data. These results also countered the biome-shift hypothesis.

"We expected the birch and aspen to show a relative increase in the past few decades in response to the warming and drying trend," says Cahoon. "What we found was that birch growth was below the long-term mean." This species experienced a mid-century growth peak and subsequent decline similar to that of black and white spruce. Birch also had a negative response to warmer temperatures and a positive response to greater precipitation.

It was aspen's growth pattern that surprised everyone. Cahoon describes it as "one of the more novel outcomes of this work." Aspen too had a growth peak in the middle of the 20th century, followed by a sharp decline, and

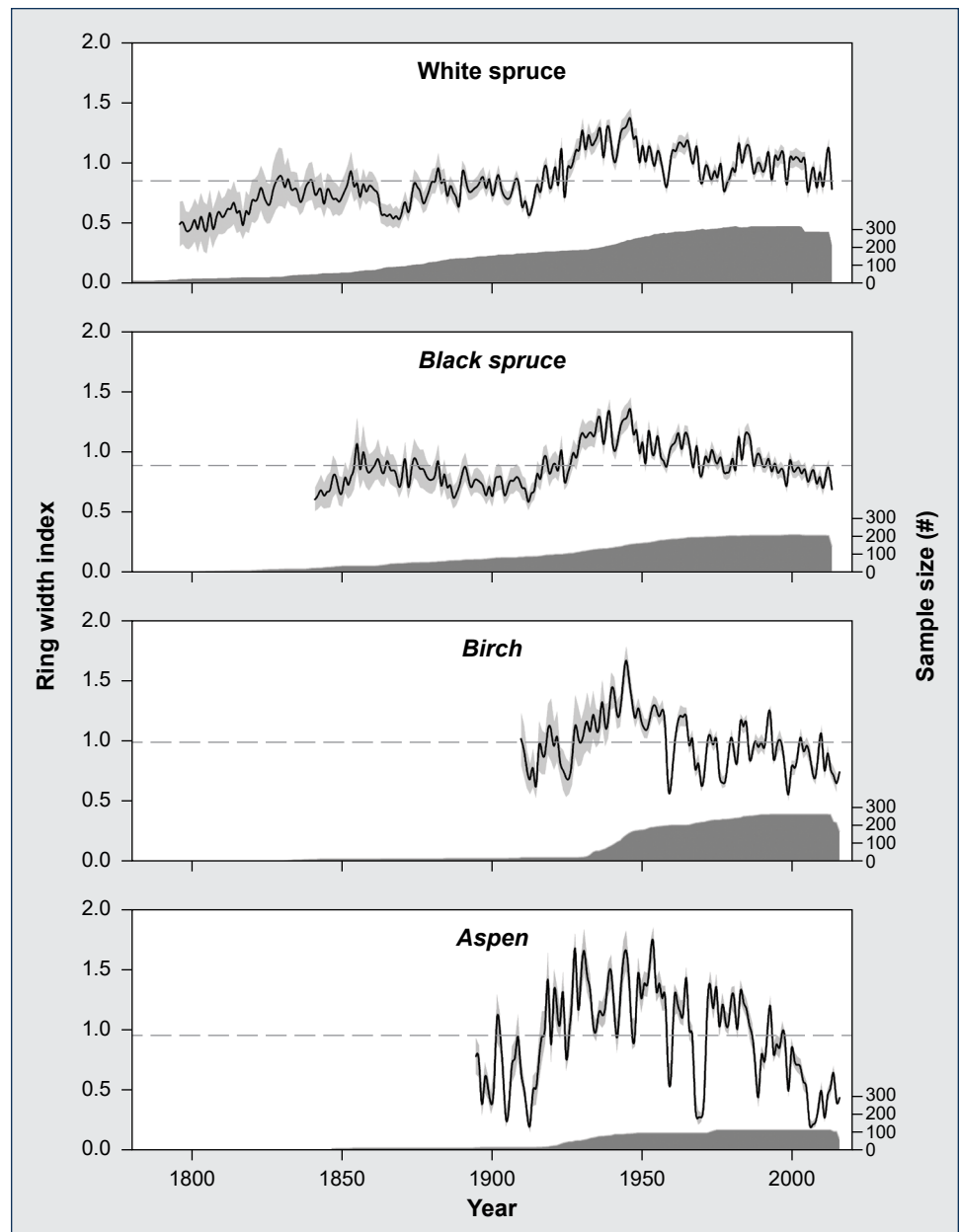
Tree-ring chronologies for four tree species common in interior Alaska. The chronologies indicate that the growth rates of white and black spruce are not declining as suggested by other studies, but are near the long-term average (the dashed line). In contrast, from about 1970 to present, growth rates for birch and aspen have been lower than the 20th-century average. Adapted from Cahoon et al. 2018.



LAND MANAGEMENT IMPLICATIONS



- Although white and black spruce and birch are sensitive to drought conditions, there does not appear to be strong evidence of a rapid growth decline throughout the region. However, continued warming without concurrent increases in precipitation may increase the number of wildfires in interior Alaska.
- Moisture limitation may inhibit white spruce's ability to defend against bark beetles, a pest that devastated Alaska's Kenai Peninsula in the late 1990s. A recent outbreak just south of the Alaska Range may place the interior's spruce forests at risk.
- Outbreaks of aspen leaf miner that coincide with warm and dry conditions will likely negatively affect aspen growth. Leaf miner damage is rarely fatal; however, the damage can weaken trees, making them less able to take up carbon through photosynthesis and leaving them more susceptible to other environmental stressors such as drought.





An aspen leaf damaged by aspen leaf miner. The insect damage impairs the tree's ability to photosynthesize and eventually can lead to its death. An aspen leaf minor outbreak that began in the 1990s in interior Alaska continues today.

a subsequent precipitous decline in the late 1990s. When looking at the climate data to explain the growth decline, a weak negative response to increasing temperatures was seen, yet not with precipitation.

"It made us scratch our heads a bit. If climate isn't playing a huge role in aspen decline, then what is?" Cahoon says.

A literature search revealed that a major outbreak of an insect called the aspen leaf miner (*Phyllocnistis populiella*) started in the late 1990s and is ongoing. To tease out the relationship between the leaf miner outbreak and the growth decline, Cahoon compared the annual estimated affected acreage to ring width and found a strong negative relationship: as the outbreak spread, aspen growth declined. He went a step further to run a climate-growth correlation in relation to pre- and post-outbreaks. "It seemed that moisture limitation was leading up to the outbreak," Cahoon says. "Although we were working with a small sample size, these results do seem to hint at that possibility."

Collectively, this evidence showed that aspen isn't responding as expected to these warmer and drier conditions. "It's been hit pretty hard by this herbivorous moth, and it's resulting in a significant decline of growth," explains Cahoon.

What's Next?

With their findings being relatively new and not widely known by the management community, Cahoon and Sullivan are actively sharing their tree ring and climate research at meetings.

Stephen Burr, formerly an entomologist with the Forest Service's Alaska Region and now the Forest Health Monitoring Coordinator for the Eastern Region, says that understanding what's happening inside the trees is important, as well as understanding the relationship between moisture limitation and how spruce beetle outbreaks will affect the boreal forest.

"Historically, there haven't been a lot of spruce beetle attacks in the interior," Burr explains. "Over the last 40 years, 660,000 acres have been affected, as opposed to more than 1 million acres in just the last 3 years in south-central Alaska. The possibility of a changing climate, with some models predicting increasing temperatures, which is a driving factor for spruce beetle outbreaks, could be bad for the spruce, especially white spruce."

And although potential spruce beetle outbreaks attract more attention, Cahoon isn't forgetting about the aspen. He intends to continue explor-

ing the relationship between climate and leaf miner outbreaks and determining the extent of the outbreaks. Aspen doesn't have economic value as a source of timber, but Cahoon says it has other important values, such as aesthetics and habitat. "Leaf peepers love to watch the leaves change color in the fall," he explains. "Aspen provide important habitat for birds, and its young growth is a good browse species for moose."

"Land is not merely soil, it is a fountain of energy flowing through a circuit of soils, plants and animals."

—Aldo Leopold

For Further Reading

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