



Science

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issue one hundred ninety six / may 2017

“Science affects the way we think together.”

Lewis Thomas

Look Again: Revising Ideas About the Greening of Alaska’s Arctic Tundra



Alan Krakauer/Flickr

A view of the tundra flanking the Toolik Field Station, managed by the University of Alaska Fairbanks. Analyses of field data and newer satellite data are furthering our understanding of the climate-driven changes occurring in northern Alaska.

*“One must be wise in knowing
what to prepare for and
equally wise in being prepared
for the unknowable.”*

— Yup-ik Alaska Native saying

Several years back, Robert Pattison, then a research ecologist with the U.S. Forest Service Pacific Northwest Research Station, was driving down a desolate road on his way to the Toolik Field Station, a tiny outpost on the Alaska tundra,

365 miles north of Fairbanks. In close-up aerial views the field station’s buildings—an herbarium, a tire shop, various labs and dorms, an EMT shack, a meeting tent, and even a sauna—seem to loom above the landscape. That’s because vegetation on the landscape rarely grows much past knee-height, one of many survival strategies of plants on the mostly flat and frozen North Slope.

As he drove, Pattison, now with the Bureau of Land Management, recalls thinking about recent reports of increases in shrubs growing on the warming tundra. Satellite data seemed

IN SUMMARY

Alaska’s Arctic tundra is one of the most rapidly warming regions in the world. For years, scientists have been working to interpret the effects of its changing climate and determine what these changes may mean for the rest of the planet. Coarse-scale satellite imagery of much of this region shows the tundra is becoming greener. This has been widely attributed to shrub expansion.

To better understand vegetation dynamics in the region, research ecologist Robert Pattison and his colleagues compared satellite imagery of this greening with data that Janet Jorgenson, a botanist with the U.S. Fish and Wildlife Service, collected for more than 25 years from field plots in the Arctic National Wildlife Refuge.

Their findings showed few changes in plant species composition from 1984 to 2009; increases in shrub cover were limited to a riparian shrubland plot. On the tundra, small differences in topography and substrate can make a difference in plant composition. A fine-scale assessment of the landscape is needed to develop a more complete picture of the patterns and determinants of change in the far north.

This research advances our understanding of the effects of climate change and may help in the management of various Arctic wildlife, including caribou herds that are important to the subsistence of Alaska Native communities.

to suggest that, over several decades, the North Slope was becoming greener. But that didn't fully match up with what Pattison was seeing. Sure, in some places on the tundra—which is more diverse than most people living below the Arctic Circle might realize—shrubs appeared to be advancing. But in other places, the land and its mix of low-lying plants adapted for short growing seasons and frigid, dark winters did not appear to have an increase in shrubs. How to explain the discrepancy?

Pattison remembered coming across the work of Janet Jorgenson, a botanist with the U.S. Fish and Wildlife Service. Jorgenson, he recalled reading, had been gathering data on tundra plant composition in the nearby Alaska National Wildlife Refuge since the 1980s.

“It just hit me: we could compare what the satellites were showing for her plots with her own data,” says Pattison. “If the satellites say there is an increase in greening but we know that there isn't a huge increase in shrubs on her plots, then we need to readjust the story a little bit.”

The new narrative is still being written, but at least two basic themes are already apparent: sweeping generalizations about climate change effects on the tundra are likely to be problematic, as is an over-reliance on remote sensing.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscriptions and change of address information to:

pnw_pnwpubs@fs.fed.us

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Science Findings is online at: <http://www.fs.fed.us/pnw/publications/scifi.shtml>

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KEY FINDINGS



- From 1984 to 2009, there were relatively few changes in plant species composition in nearly 30 repeatedly sampled research plots in the Alaska National Wildlife Refuge on Alaska's North Slope. This contrasts with other research showing “shrubification” as a climate change effect in the region. There were also few changes in total vegetative and bare-ground covers during this time period.
- Scientists confirmed that ground measurements of greenness, as reflected in the standard normalized difference vegetation index (NDVI) metric, showed a strong relationship with shrub cover on field plots. However, when they actually calculated NDVI based on plot shrub cover they did not see a change in calculated plot greenness from 1984 to 2009.
- In higher resolution Landsat satellite data, where each pixel corresponds to about 1,000 square yards on the ground, NDVI over the field plots did not change from 1984 to 2009. However, coarse-scale advanced very-high-resolution radiometer (AVHRR) data, where each pixel corresponds to about 25 square miles, did show significant increases in NDVI. The conclusion: the widely used AVHRR sensor fails to detect fine-grained changes occurring on the landscape.

Why the Tundra Matters

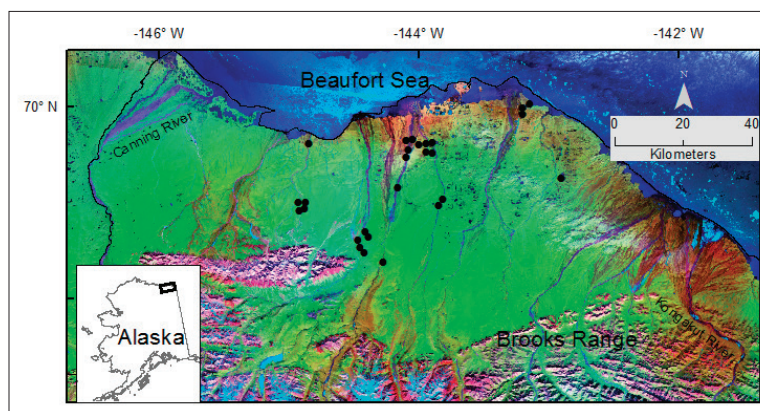
The tundra is a focal area for many climate scientists. This treeless land found at latitudes 55° to 70° north covers about 20 percent of the Earth's surface and stores a significant amount of the world's carbon. As a major carbon sink, it stores more carbon than it releases into the atmosphere, and helps mitigate the accumulation of greenhouse gases such as carbon dioxide (CO₂) and methane (CH₄) that are leading to climate change.

Because most of the Arctic year is so cold, plants on the tundra decompose slowly when they die after the short growing season. Much of the plant material freezes as winter descends and becomes part of the permafrost. This essentially locks up the carbon in undecomposed organic matter rather than releasing it into the atmosphere. Scientists estimate permafrost is storing more than twice the amount of carbon than is in the atmosphere today.

But the climate is warming, and in some places permafrost is thawing. As permafrost thaws, carbon from plant remains thousands of years old is released. This accelerates warming trends and creates a feedback loop leading to further thawing and ultimately amplifying global climate change.

If the tundra were to shift suddenly from less snow and ice to more grasses and shrubs, this would fuel another, similar feedback loop, this one related to the Earth's albedo, or reflectivity. Snow and ice reflect more solar energy back into space than does the greenery of plants, so a shrubbier tundra would absorb more heat and contribute to a warming planet.

Pattison and Jorgenson emphasize that nothing about their work calls into question the fundamental reality of a warming climate. Their findings, published in 2015 in the journal *Ecosystems*, do offer hope that some regions of the Arctic and some tundra ecosystems may be more resilient than previously thought.



Janet Jorgenson

Landsat image of northern Alaska. Each pixel corresponds to a 98 by 98 foot square, a much finer resolution than was available from satellite imagery in the early 2000s.

Twenty-Five Years of Field Data

“I got a phone call from Robert out of the blue,” says Jorgenson. “He’d read one of our papers and was interested in doing something with our data. At some point, I said ‘why don’t you just come out with us?’”

Field research in Alaska is not for the faint of heart. One rub in Jorgenson’s offer was that there generally are no roads where she works. Her 27 plots on the coastal plain of the Arctic National Wildlife Refuge are accessible only by helicopter. Field research here means being dropped into a remote locale, setting up camp, hiking to a plot, and then spending many hours each day wrestling equipment and hunching over the tundra’s pint-size vegetation.

Pattison, who once sailed around the world with his father, and is no stranger to empty space and solitude, jumped at the chance.

One of Pattison’s field tasks was to record data gathered on the abundance of various plant species on Jorgenson’s plots, each of which measures about 13 feet by 98 feet. What was most striking when Pattison, Jorgenson, and their colleagues later compiled and analyzed these data and compared them to previous years was how little the species composition had changed over time. Where were the shrubs suggested by the satellite data?

A big part of the answer, Pattison subsequently realized, was that the previous studies had asked way more of coarse-scale satellite data than that data could reasonably deliver.

The Problem With Coarse-Scale Images

Many studies throughout the 2000s on the greening of the tundra rely on data from advanced very-high-resolution radiometer (AVHRR) instruments onboard satellites operated by the National Oceanic and Atmospheric Administration (NOAA). These instruments make various measurements of the Earth’s electromagnetic radiation—basically, the light and heat reflected off the planet’s surface into space.

This technology yields decidedly coarse-scale images. Each pixel corresponds to about 25 square miles, about the same size as the city of Hillsboro, Oregon, west of Portland, which is home to about 100,000 people.

Scientists knew that various evergreen and deciduous shrubs on the tundra could disproportionately affect greenness showing up on



This 13 by 98 ft study plot in the Alaska National Wildlife Refuge has a high level of vegetative diversity. Mosses and lichens form a dense ground cover with sedges, forbs, and deciduous and evergreen shrubs.

Martha Raynolds, University of Alaska Fairbanks



Robert Pattison makes ground-based measurements of the surface normalized difference vegetation index (NDVI). These data were compared to satellite NDVI measurements.

Martha Raynolds, University of Alaska Fairbanks

sensor data. Shrubs also were expected to be among the winners of a warming Arctic. In some instances, modest increases in temperatures have caused stunted shrubs on the tundra to suddenly grow to the height of small trees, referred to as pop-up forests.

“Basically, they put two and two together and said, ‘Well, all the greenness you see on the North Slope must be due to shrubs,’” says Pattison.

A closer look reveals a much more complicated picture.

While in the field, Pattison also made close-up measurements of surface normalized difference vegetation index (NDVI) using a handheld spectral analysis device—this is the same index that had been applied to the AVHRR satellite data. He was then able to model how this index, measured just a few feet off the ground, corresponded to the plant species mix he recorded with Jorgenson. Confirming other

studies, he found that evergreen and deciduous shrubs were the most important determinants of NDVI values. Because Jorgenson's data showed that shrubs had not really changed in 25 years, the model suggested that surface NDVI was similarly unchanged over the same period.

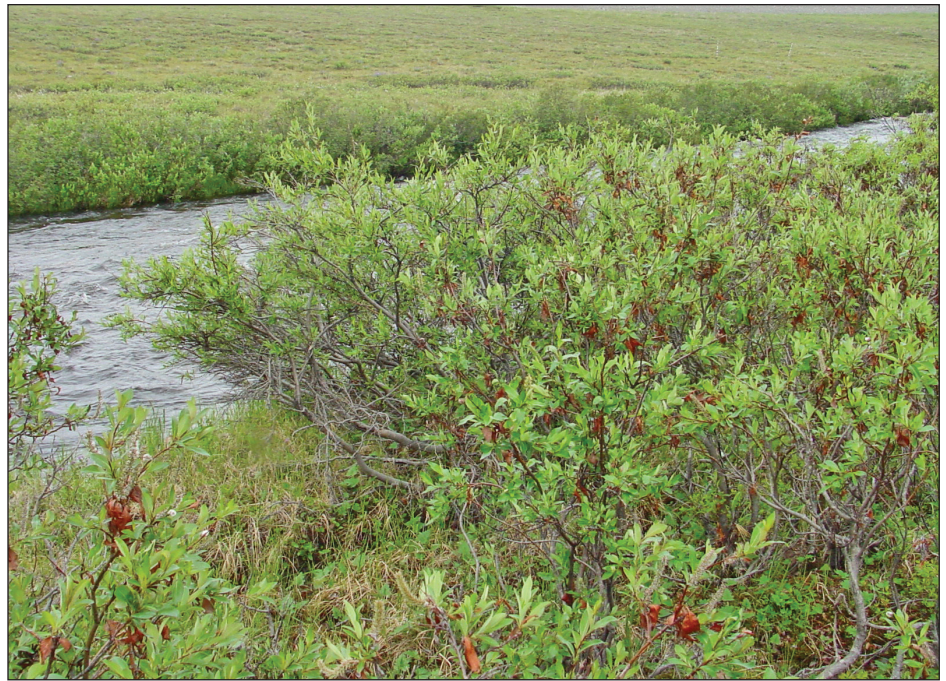
Many studies have found that over the past few decades the planet is invariably getting greener as viewed from space. Pattison doesn't dispute this broad trend. He just questions whether all of the types of tundra vegetation are showing increases in greenness and the assumption that shrubs are expanding everywhere. He suggests that it is likely that some tundra types (e.g., those in riparian areas) are greening faster than others, and that these increases are driving trends seen in coarser satellite imagery. In short, the greening occurring in coarse-scale (large pixel) data appears to be driven by isolated patches of shrub expansion. He also suggests that some areas are changing more rapidly than others—for example, the eastern portion of the Alaska North Slope may not be changing as rapidly as other regions.

Pattison and his colleagues, Martha Raynolds at the University of Alaska Fairbanks, and Jeffrey Welker at the University of Alaska Anchorage, also looked at much higher resolution Landsat satellite data, where each pixel corresponded to a square of ground measuring 98 feet on a side. These fine-scale Landsat images similarly showed no increase in greenness over many of Jorgenson's plots.

"This result suggests that there is fine-scale heterogeneity in trends in greening," says Pattison. "In some cases, even Landsat data may not be at a high enough resolution to capture changes occurring on the landscape."

For example, Pattison and colleagues noted places where small ponds have appeared. Water registers as zero on the NDVI scale, so one might think greening would actually decline in these pixels. But around the edges of these new mini waterways, plants, particularly sedges, thrive. The end result is that even at the higher resolution Landsat scale these trends are not noticed because the zero values of the water are countered by the increased NDVI of the sedges.

"When you look at photos of the tundra, it looks kind of like a flat plain of greenness, but in actuality the tundra is so diverse," says Pattison. "There are differences in soil substrate age and landscape features—and all these affect which plants thrive."



Shrubs did increase in cover on several riparian plots, a phenomenon potentially driving increases in greening shown in lower resolution satellite imagery.

Martha Raynolds, University of Alaska Fairbanks



Tundra polygons in the in Alaska National Wildlife Refuge, as seen from a helicopter (approximately 500 feet in the air). These features are formed by the freezing and thawing of the soil. Increased thawing of the permafrost is leading to small pond formations that are lined by greener vegetation. These types of changes can go undetected even with higher-resolution satellite imagery as the lower values of normalized difference vegetation index from water are countered by higher values of greening by plants.

Martha Raynolds, University of Alaska Fairbanks

The lesson is that despite advances in technology, field studies remain critical. Approaches that combine remote sensing on repeatedly measured field plots may provide insights into Arctic tundra changes that are not apparent

with either approach alone. Field data remain a challenge to collect in Alaska, which has by far the lowest density of roads per square mile in the United States. (In comparison, Nevada, number 49 on the list, has 10 times the road density of Alaska).

Colder Soils in a Warmer World

The absence of roads isn't the only thing that conspires against fieldwork. The formidable Alaska winter does, too. Winter temperatures in Barrow, the largest North Slope city, rarely climb above 0° Fahrenheit, and its 4,300 residents do not see the sun for more 60 days beginning in late November.

Among the questions about climate change is how subtle changes during the winter, especially related to snowfall, might affect plant ecosystems. On the tundra, in particular, a gradually warming climate has meant reduced snowfall, in part, because more of the annual precipitation is falling as rain.

To explore just what this means for plants in the region, Pattison and Welker used data from a 14-year experiment at the Toolik Field Station. The experiment relies on a simple snow fence, which forces windblown snow to accumulate behind it. The pile gradually diminishes farther away from the fence, allowing researchers to, in effect, simulate how differing amounts of winter snow affect plant growth later during the short spring and summer.

The results, published in 2014 in the journal *Oecologia*, confirm one of the paradoxes of climate change in the Arctic.

"It's colder soils in a warmer world," says Pattison. "Winter snow cover is an insulator of sorts. So as temperature warms and you get less snow cover, roots of plants in these ecosystems are more susceptible to severe spring-



Martha Raynolds, University of Alaska Fairbanks

Whorled lousewort (*Pedicularis verticillata*) blooms during the short Arctic summer in one of the study plots.



LAND MANAGEMENT IMPLICATIONS



- Greening of the tundra appears to be arising from localized changes in shrub cover that are being ascribed to larger land areas when assessed with coarse-resolution remote sensing tools.
- Localized patterns of greening has implications for the management of caribou—an important subsistence resource for Alaska Native communities in the region.
- Physiographic (microtopography, hydrology, erosion, etc.) and biological drivers of shrub community response to climate warming need to be better understood to effectively assess and plan for potential greening at fine, meso, and coarse scales.

time freezing events." In addition, colder soils tend to lead to less productive ecosystems as a whole.

Pattison and Welker found that less snow was bad news for plants, particularly for various species of shrubs and grasses, including the diamond-leaf willow (*Salix pulchra*) and tussock cottongrass (*Eriophorum vaginatum*). As snow depth declined, so too did general productivity of these species throughout the growing season.

"We found that the soils were much colder when you didn't have a deep snowpack on them," says Pattison. "The effects weren't just in the early spring; you saw the effects all the way through the whole growing season on these ecosystems."

Understanding just what's happening on the tundra—whether shrubs are taking over and just how grasses and other plants are struggling—has to do more with the carbon cycle, Earth's albedo and other much-studied climate change phenomena. It's also key for the management and stewardship and wildlife species, especially the vast caribou herds that help sustain Alaska Natives.

Each spring caribou migrate hundreds of miles north across the Brooks Range to the coastal plain where Pattison and Jorgensen gathered their data. The concern is that due to earlier springs, caribou migration may now be out of sync with the timing of key food-resources and forage availability. This is an example of a phenological mismatch—others are cropping up elsewhere because of climate change, affecting species of butterflies and migratory hummingbirds in more temperate climates.

In the United States, the road to a changing climate cuts its broadest swath through the extremes of Alaska, which is warming about twice as fast as the rest of the country, and

where 2016 was the warmest year on record. This creates an imperative, Pattison says, to continue to "ground-truth" data about how these changes are playing out.

"Definitely, there's climate change up there," says Pattison. "It's such a dynamic and complex area that it's hard to make sweeping generalizations about it over such vast areas."

*"Line in nature is not found;
Unit and universe are round..."*

— Ralph Waldo Emerson, "Uriel"

For Further Reading

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