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Science FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

Tangled Trends for Temperate Rain Forests as Temperatures Tick Up

Seth Ayotte

Warmer temperatures are generally increasing the overall potential for growth in the coastal temperate rain forest. Total live-tree biomass is increasing in higher elevation ecoregions of southeast Alaska.

"Complexity is the prodigy of the world. Simplicity is the sensation of the universe. Behind complexity, there is always simplicity to be revealed. Inside simplicity, there is always complexity to be discovered."

—Gang Yu

Through the ages, climate has played a key role in determining the types of plants and animals that inhabit various geographic areas. Long-term shifts toward wetter, hotter, drier, or more extreme conditions can prompt species to adapt and evolve. Mobile species can try to stay ahead of the changing conditions by looking for suitable habitat in new areas. The fate of less mobile species depends on their ability to adapt fast enough to survive the pace of sustained climate shifts. In the sweepstakes of future climate change, some species will likely adapt and thrive in new conditions, whereas others already at the biological limits of their survival capabilities will suffer.

In the Pacific Northwest, climate conditions in temperate rain forests from northern California to the Gulf of Alaska began to change a half-century ago. Average temperatures have risen, patterns of rain- and snowfall have shifted in complex ways, and the frequency of untimely weather events has intensified. The timing and length of growing seasons have been altered, throwing off the biologically programmed behaviors of many species. Although the general warming trend is predicted to heighten the overall potential for tree growth in the region, how individual species might respond to altered environments is still largely unknown.

IN SUMMARY

Climate change is altering growing conditions in the temperate rain forest region that extends from northern California to the Gulf of Alaska. Longer, warmer growing seasons are generally increasing the overall potential for forest growth in the region. However, species differ in their ability to adapt to changing conditions. For example, researchers with Pacific Northwest Research Station examined forest trends for southeastern and southcentral Alaska and found that, in 13 years, western redcedar showed a 4.2-percent increase in live-tree biomass, while shore pine showed a 4.6-percent decrease. In general, the researchers found that the amount of live-tree biomass in extensive areas of unmanaged, higher elevation forest in southern Alaska increased by as much as 8 percent over the 13-year period, contributing to significant carbon storage.

Hemlock dwarf mistletoe is another species expected to fare well under warmer conditions in Alaska. Model projections indicate that habitat for this parasitic species could increase 374 to 757 percent over the next 100 years. This could temper the prospects for western hemlock—a tree species otherwise expected to do well under future climate conditions projected for southern Alaska.

In coastal forests of Washington and Oregon, water availability may be a limiting factor in future productivity, with gains at higher elevations but declines at lower elevations.

At the Pacific Northwest Research Station, research forester Tara Barrett is looking for answers to such questions. Using a range of methods, from traditional forest inventorying to sophisticated climate envelope mapping, she and her colleagues have tracked trends in forest composition to understand how forests are changing and what the consequences might be for productivity and carbon sequestration. As the researchers have discovered, the impacts of ongoing change can be surprisingly complex, sometimes opposing, and even counterintuitive.

Paul Hennon

Western hemlock in Alaska is predicted to do well as climate warms, but so is hemlock dwarf mistletoe, a plant that parasitizes the tree.

KEY FINDINGS

- Live-tree biomass in higher elevation ecoregions of the Alaska temperate rain forest increased by 7 to 8 percent between 1995 and 2008.
- Western redcedar showed a 4.2-percent increase in live-tree biomass, whereas shore pine showed a 4.6-percent decrease.
- Continued warming in Alaska's temperate rain forest could lead to further biomass increases at higher elevations via faster growth, more trees, and uphill migration of tree species.
- Yellow-cedar, which has been widely reported to be declining due to climate, showed no significant change in live-tree biomass. Smaller yellow-cedar are more common at higher elevations, whereas dead trees are more common at lower elevations, suggesting an ongoing uphill migration by the species.
- Climate currently limits hemlock dwarf mistletoe in northern temperate rain forests. Moving from south (California) to north (Alaska), the peak infection rates for western hemlock occur at progressively lower elevations. Over the next 100 years, the potential habitat of the parasite is projected to increase from 374 percent to 757 percent.
- Modeling studies predicted that site quality in coastal forests of Oregon and Washington will generally increase over the next 100 years but will likely decline at lower elevations, while increasing at higher elevations. Losses in Oregon will be more substantial than in Washington.

SEEKING THE SOURCES OF SUSTAINED CHANGE

Many factors operating within and outside forests can trigger observable change. It's often difficult to pin down a single source, and quite frequently, disparate events interact. "Trees damaged by disease can be more vulnerable to wildfire," Barrett explains. "And heavy precipitation can saturate soils, preventing saplings from establishing deep roots, so they become more susceptible to strong winds." At small scales, environmental disturbances and recovery from them can appear relatively dramatic, but the effects on forest conditions are largely local. However, over broader scales, "some vectors of change, including climate, insect epidemics, and blowdowns of trees from extensive windstorms, can affect longer term regional trends," she says.

In Alaska, where dramatic reductions in sea ice and thawing permafrost are capturing headlines, Barrett analyzed variations in the temperate forests bordering the Gulf of Alaska (roughly 16,000 square miles) and the boreal forest of the Kenai Peninsula over a 13-year period. To do this, she compared two sets of records from 930 forested plots that were surveyed by the national Forest Inventory and Analysis program from 1995 to 2000, and then reappraised from 2004 to 2008. Barrett used these data to calculate the total amount of living tree biomass, levels and causes of tree mortality, annual rates of commercial tree harvesting, and the species composition of regional forests.

The results revealed that in higher elevation ecoregions—in particular, forests in the Chugach-St. Elias and Northern Coast mountains—the amount of biomass in live trees rose by 7 to 8 percent over the period analyzed. "That's a lot," Barrett notes. This surge in biomass could be due to accelerated growth in individual trees, more trees within forests, or a combination of both, she adds. On a regional scale, this growth more than offset losses from timber harvesting and other tree mortality. In one portion of the study area, the vast Chugach National Forest—where 98 percent of watersheds are roadless and little timber harvesting has ocurred—the amount of additional carbon stored annually in live trees was equivalent to the annual carbon dioxide (CO_2) emissions from half a million passenger cars.

"Seeing a biomass increase on unmanaged lands is surprising because the conventional wisdom is that for very large areas of old-growth trees, biomass is fairly constant over time. These findings serve as a good reminder that it's not only managed areas that show change in carbon sequestration," Barrett says. Other research conducted since 2008 confirms that live-tree biomass is on the rise throughout unmanaged forests in southeast Alaska.

The intriguing question is what's behind the unanticipated gains. "It's not unusual to see forest biomass increases; this is happening in many national forests in the West," Barrett

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Rhonda Mazza, editor; rmazza@fs.fed.us

C. Hugh Luce, layout; chluce@fs.fed.us

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says. "But those effects can be explained by forests responding to the historical suppression of wildfires and the more recent downturn in timber harvesting. In southeast Alaska, wildfire is far rarer, so suppression isn't a plausible factor. And because much of the biomass increase is occurring in areas with no prior logging, it can't be related to postharvest regrowth."

Part of the Alaska biomass boost could be linked to forested areas recovering from natural disturbance, such as unrecorded windstorms and insect epidemics such as the spruce beetles that plagued the Kenai Peninsula during the early 1980s. But those events likely would account for only a fraction of the gain.

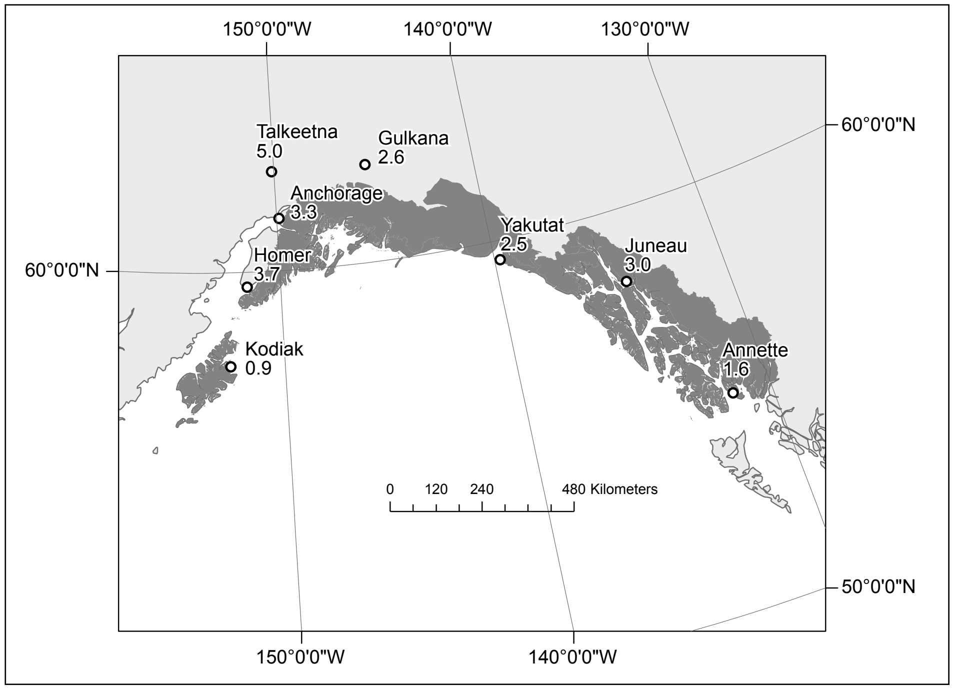
"My best guess for a primary cause in biomass gains is climate warming," Barrett says, "but we don't really know for sure." Weather station data from around Alaska's temperate rain forests show that average annual temperatures have risen by 2.7° Fahrenheit over the past 50 years. "This ongoing warming could be accelerating growth, increasing tree densities, or allowing species with the most growth potential—such as western hemlock and Sitka spruce—to migrate to higher elevations," she says. "It will be an ongoing detective story to sort out the mechanisms."

Barrett's analysis showed that across the region nearly all major tree species (both conifers and hardwoods) showed at least a nominal increase in live-tree biomass. Western redcedar (*Thuja plicata*), with a 4.2 percent increase in live-tree biomass, was the biggest winner.

Shore pine (*Pinus contorta*), however, showed a decline of nearly 5 percent. Like western redcedar, shore pine is at the northernmost edge of its range in Alaska, and both species might be expected to thrive as temperatures warm. To date, no single cause for this downturn has been identified, but researchers are investigating whether disease is the culprit.

Perhaps most unexpected was the picture that emerged for yellow-cedar (*Chamaecyparis nootkatnesis*). Since the 1880s, yellow-cedar forests have been in decline. During the 1970s and 1980s—a period marked by warmer winters—some areas of southeast Alaska experienced a spike in yellow-cedar mortality. Scientists have since learned that yellow-cedars suffer severe root damage during cold snaps in late winter and early spring. In years with little snow pack to insulates the tree's shallow roots, the root damage can be fatal.

Despite continuing attrition in some places, Barrett found no overall significant change in live tree yellow-cedar biomass over the study period. This implies that new growth and regeneration are counterbalancing ongoing tree losses, she says. "We did find that the ratio of yellow-cedar snags to live trees decreased sharply with elevation, suggesting that the species may be migrating upslope with changing temperature conditions."



Change in average annual temperature in degrees Fahrenheit between 1954 and 2008 at weather stations in southeast and south-central Alaska. Climate models project more warming at northern latitudes.

The biomass increases detected in the Alaska research generally point to higher growth rates and more carbon sequestration. But this may not be a consistent trend within the coastal temperate rain forest. A 2010 study by Barrett and her colleagues on future productivity for Washington and Oregon coastal forests found a more complicated pattern—one tied strongly to future projections of water availability. The modeling results showed that overall forest productivity can be expected to rise over the next 100 years, but gains at higher elevations will be partially cancelled out by declines at lower elevations, an effect that will be more pronounced in Oregon than in Washington. However, this study did not incorporate climate-related impacts from insects, fires, and other factors that could further complicate the picture, Barrett points out.

Kara Thies

Shore pine, found in muskegs in southeast Alaska, had significant decline in live-tree biomass from 1995 to 2008.

CLIMATE CHANGE COMPLEXITIES

For western hemlock (*Tsuga heterophylla*)—icon of the temperate rain forest and one of Pacific Northwest's most valuable trees—the future under projected climate change would seem bright, given the predictions of enhanced circumstances favorable to its growth. But as another recent study by Barrett and other scientists reveals, a nemesis of the hemlock—dwarf mistletoe—is also on the verge of expanding its empire.

Dwarf mistletoes (*Arceuthobium* species) are parasites that afflict many conifer species in North American forests, robbing their hosts of water and nutrients. Severe infection can hamper growth and the development of seeds and cones and spoil the quality of wood. Although infection doesn't usually kill a tree, it renders host trees more susceptible to pathogens and insect attacks. The annual economic costs from tree growth losses are estimated in the billions of dollars.

Yet dwarf mistletoes also generously support the lifestyles of myriad forest dwellers. From nuthatches and chickadees to thrushes and grouse, many types of birds consume the parasite's shoots and fruits, use their signature "witches' brooms" for cover and nesting, and disperse their seeds far and wide. Mammals such as deer, elk, chipmunks, and squirrels also graze on dwarf mistletoes, and many insects and fungi benefit from their presence. In fact, the structural and nutritional resources dwarf mistletoes provide and their pervasive influence on biodiversity has led some researchers to propose them as keystone species. If warming temperatures could aid the spread of dwarf mistletoe—as some studies have speculated—numerous other forest species may reap gains as well.

To understand how climate change could affect the distribution and abundance of hemlock dwarf mistletoe in the Pacific Northwest, Barrett and her colleagues used forest inventory data from California, Oregon, Washington, and Alaska to analyze the presence of dwarf mistletoe within the current range of western hemlock. "We found that mistletoe infection rates peaked at lower elevations as one goes from California to Alaska," she reports. "In Alaska, 20 percent of hemlocks were infected at sea level, whereas just 5 percent were infected at elevations around 650 feet." This distribution is expected to change under a warmer climate.

Weather fluctuations and particularly the length and warmth of the growing season are known to influence dwarf mistletoe population dynamics. The plants produce seeds during autumn—in explosive discharges. Snow and heavy rainfall can wash seeds out of trees before they can germinate. Cold temperatures can reduce pollen germination and prevent fruits (which take more than a year to develop) from maturing. "All of this supports the notion that as the climate warms we can expect greater opportunities for dwarf mistletoe to spread both horizontally beyond its current range, and vertically to higher elevations," Barrett says.

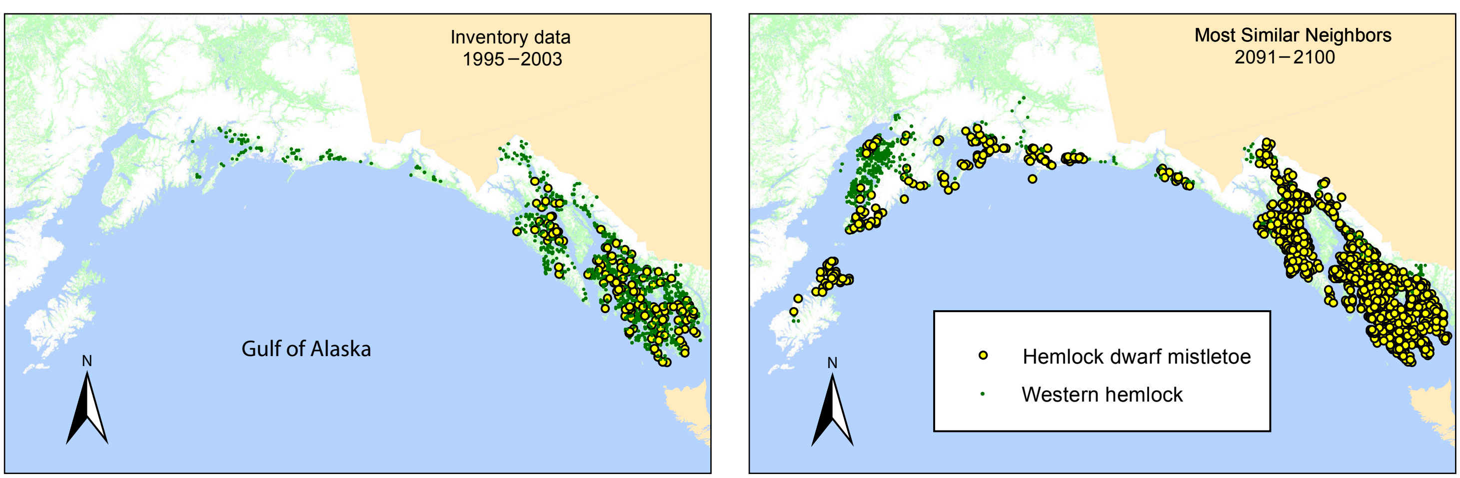
To gauge the possibilities for the future expansion of dwarf mistletoe in Alaska, Barrett's team employed an approach known as climate envelope modeling, which is based on the idea that every species faces climate-related limitations—such as specific ranges of temperature and precipitation—beyond which it cannot exist. "This climate envelope varies spatially over time, so species may need to migrate or adapt to endure," she explains.

The scientists incorporated the data on current hemlock and mistletoe distributions with weather data from the past 50 years and potential climate variables—including solar radiation during the growing season, winter temperatures, snow and rain, autumn freezes, and low temperatures during pollination. This information was fed into three different computer models to estimate potential habitat for dwarf mistletoe under three widely used scenarios for climate change typically used in general circulation models.

The results varied markedly among the different models, but all strongly indicated that climate currently limits hemlock dwarf mistletoe within the temperate rain forest. "For Alaska, the climate envelope analysis projects that over the next 100 years dwarf mistletoe habitat will increase by a whopping 374 to 757 percent—depending on the climate scenario and modeling approach," Barrett explains. More modest increases of 7 to 41 percent were projected for western hemlock habitat.

The wide range within the modeling results attests to the considerable uncertainty inherent in making such predictions. "It's actually helpful to show there's a huge range in the predictions, so that people can understand the uncertainty involved," Barrett says. "But the take-home message here is that there's a high probability that potential mistletoe habitat in Alaska will expand greatly under climate change."

The study did not address how birds and mammals might influence the distribution of the parasite through seed dispersal. "Long-distance seed dispersal has happened in the past because islands in Alaska that were covered in ice thousands of years ago now have dwarf mistletoe. This process could require very long timespans, but in areas where mistletoe is already present, all it needs to spread is a marginally higher rate of survival, reproduction, or dispersal, so the potential is pretty high," Barrett explains.



The map on the left shows where dwarf mistletoe and western hemlock are currently found. The map on the right shows the increase in potential habitat westward along the Gulf of Alaska, based on climate envelope modeling.

The researchers' findings clearly suggest that dwarf mistletoe could become more of a concern for managers of northern forests. "In the past, because of the longer reproductive cycle and low levels of infection rates above 650-foot elevations, mistletoe has been perceived as less of a problem in southeast Alaska than in Oregon or Washington. But in the future, silviculturists will want to be on the alert for dwarf mistletoe and consider measures to curb its spread, such as manipulating the species mix in uneven-aged silviculture and paying close attention to the type of trees left after harvests," Barrett says.

The research by Barrett and her colleagues has been published in prominent scientific journals and the findings have captured coverage by major media outlets, helping to inform the public as well as other researchers on the outlook for Pacific Northwest forests. The discovery of the decline of shore pines in Alaska has prompted scientists with the State and Private Forestry branch of the Forest Service to begin investigating possible causes. As well, in other work, Barrett and her colleagues have made recommendations related to improvements in federal agency programs for monitoring climate-related impacts to northern ecosystems.

"Prediction is difficult, especially of the future."

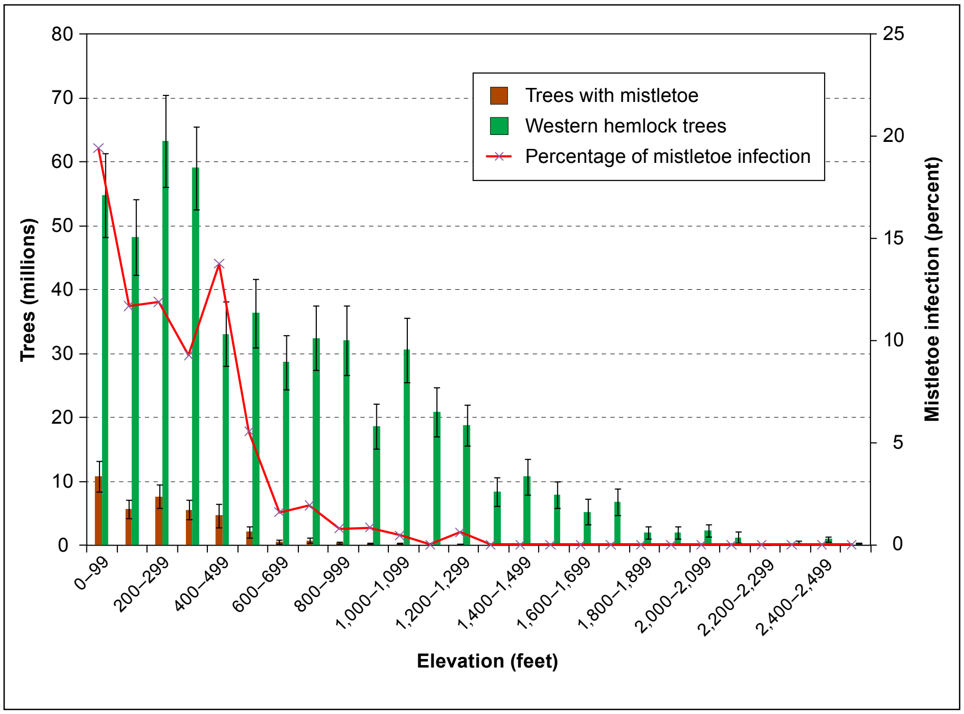
—Mark Twain

LAND MANAGEMENT IMPLICATIONS

- Increases in forest biomass can help sequester more atmospheric carbon, offsetting fossil-fuel emissions. The recent increase in carbon stored in live trees on the Chugach National Forest was equivalent to the annual CO_2 emissions of half a million passenger cars.

- Given the potential for dwarf mistletoe to expand its range in southeast Alaska over the next 100 years, it may become more of a management consideration than it is currently. During harvest operations, for example, land managers may want to select leave trees that are not infected or species that are not as susceptible to the parasite. During pre-commercial thins, susceptible species may be considered for removal.

- Site quality is an important determinant of timber yields and economic returns. Numerous factors beside climate (including insects, disease, fire, species mix, and management choices) affect forest productivity, and models use many simplifying assumptions, so projections of site quality changes in Oregon and Washington are best viewed as hypotheses. These projections can serve as guides for more targeted investigations as to whether changes in management strategy would be advisable.



Twenty percent of western hemlock are infected by dwarf mistletoe at sea level. The rate of infection is less than 5 percent above 650 feet of elevation, indicating that the colder climate is currently limiting dwarf mistletoe to a subset of its host species in Alaska.

FOR FURTHER READING

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WRITER'S PROFILE

Noreen Parks is a science writer based in Port Townsend, Washington. She can be reached at noreen.parks@gmail.com.

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U.S. Department of Agriculture
Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890

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SCIENTIST PROFILE

TARA BARRETT is a research forester with the Threat Characterization and Management Program. She earned her Ph.D. in wildland resource science from the University of California, Berkeley. Some of her current research focuses on identifying change in biomass and carbon mass for different tree species and ecoregions in forests in southeast and south-central Alaska, and predicting how climate change may affect forests in the future.

Barrett can be reached at:
USDA Forest Service
Pacific Northwest Research Station
1133 N. Western Ave.
Wenatchee, WA 98801

Phone: (509) 664-1715
E-mail: tbarrett@fs.fed.us

COLLABORATORS

Paul Hennon and Andy Gray, Pacific Northwest Research Station

Temesgen Hailemariam, Greg Latta, Darius Adams, and Bianca Eskelson, Oregon State University