Forest Vegetation

SINCE BECOMING THE UNITED STATES' FIFTH NATIONAL PARK MORE THAN A CENTURY AGO, Mount Rainier National Park has continually protected some of the best examples of mature forests in the country. The park's forests grow without the threat of logging or human expansion, allowing the ecosystems to slowly develop through natural processes. A handful of trees in the park have stood for more than a thousand years, though even the 100 year-old trees reach remarkable heights, commanding a sense of veneration from admirers. The forests dominate the park's landscape with a serene, hushed authority.

Every summer, a team of two National Park Service (NPS) researchers tread through Mount Rainier's rough backcountry and high-elevation meadows, venturing to permanent plots where the NPS plans to monitor the health of these forests indefinitely. Getting to the survey site is often the most difficult part, and the job requires the researchers to be as physically fit as they are scientifically sharp. Off-trail in the lower elevations, they trudge through thick, damp understory of ferns and shrubs, and hike up muddy slopes. At high elevations, they deal with cold temperatures and long distances on-foot. When they eventually reach the study areas, the researchers must collect meticulous information on the changes these trees have faced in the past year.

Other teams of researchers mirror this effort at Olympic National Park and North Cascades National Park as well, working to gauge the health of the forests across the North Coast and Cascades Network (NCCN). Over decades, these forests are changing—not only in maturity, but in overall abundance of trees and species composition. As part of the NCCN's Vital Signs monitoring program, the NPS aims to carefully track these changes to better understand the underlying health of the parks and their surrounding region.

By: James Andrews

Program Objectives

1. Monitor trends in tree mortality, tree growth, and tree recruitment in park forests across a range of elevations to better understand the health of the ecosystems as a whole.
2. Track long-term changes to tree species composition and forest structure.
3. Share information on forest health with natural resource managers and the public.

Photo: NPS scientists review standard operating procedures while helping to establish a new plot in the Carbon River area of Mount Rainier National Park. NPS/MORA

Forests are the foundation of the Pacific Northwest's ecosystems. From the moss-draped spruces of the Olympic Peninsula to the green islands of subalpine fir that punctuate subalpine meadows all along the Cascade Mountain Range, the life cycles of the region depend on its trees. They serve as habitat to a myriad of wildlife, they recycle massive amounts of carbon and other nutrients, and they naturally filter pollutants from water systems. They preserve our environmental health and nourish this region in a priceless variety of ways. Their sensitivity to environmental change and their role in connecting so many of the region's natural elements also make the forests essential indicators of ecosystem health, as well as invaluable assets to human interests.

In the NCCN, the forest vegetation monitoring program was designed to identify long-term trends in tree mortality, growth, and recruitment (the production of viable saplings) across the forests of western Washington. While the program currently operates at the network's three large parks, it will also be implemented at Lewis and Clark National Historical Park and San Juan Island National Historical Park in the near future. Beginning in 2008, teams of forest monitoring technicians at each park have been monitoring tree mortality annually, while tree recruitment and growth are recorded every five years.

Noticeable changes to forest demography occur very slowly, typically over many decades. In some cases, a forest will see little or no visible change in a span of 50 years or more. Recent trends, however, indicate that the rate of tree mortality among mature, protected forests in the western United States has continually increased over the last half-century. Currently, more trees are dying than are being added to the population, and leading hypotheses target a warming climate as the most significant contributor to the trend.

"As the temperature increases—all other things being equal—there is less water due to higher evaporative demand," said NPS ecologist Dr. Steve Acker, lead researcher on the forest monitoring program. "In order to maintain adequate water, the trees have to shut down gas exchange. That means less carbon dioxide, less photosynthesis, decreased growth. The less carbon the trees are fixing, the less they grow."

As a given number of trees in an area compete for limited water resources, trees become physiologically stressed, which then makes the more susceptible to insects and disease. Coinciding with projections of rising global temperatures, the stresses imposed on trees are expected to increase in the 21st century, likely leading to fewer trees per unit area, and therefore altered habitat for wildlife and reduced carbon storage. Tracking changes to Pacific Northwest forests is one of the most crucial aspects to the NCCN Vital Signs monitoring program, as the health of the region's ecosystems directly relies on the health of its forests. Through consistent, detailed monitoring, NPS researchers can

Forest at North Cascades National Park, as viewed from above. NPS/Pickard

identify early warning signs of changes to forest demography, helping natural resource managers understand effects that might ripple through every other facet of the parks and the surrounding region.

Monitoring Strategy

The simple fact that a tree can stand in place for several hundred years, despite dramatic weather cycles and countless environmental pressures, is a testament to their unmatched stability and strength. A tree does not die without a good reason, and that is exactly why the NCCN's forest monitoring program is interested in the ones that do.

In the early succession stages of a forest, tree mortality is regularly attributed to competition between the young trees as they vie for sunlight and soil, trying to gain precious space among the crowd. In mature forests, mortality is much more often caused by external factors such as intolerable changes to air temperature and precipitation, diseases, pests, or severe weather. These are the types of deaths that NPS researchers wish to track. To best monitor for external pressures on trees, the program focuses exclusively on mature forests, defined in this project as those in which the dominant trees are at least 80 years old. Forest stands in the program range from just over the age of 80 years to several centuries.

Currently, researchers have established 35 permanent plots scattered across the network's three large parks, with 12 each at Olympic and Mount Rainier and 11 at North Cascades. Each plot covers an area of 1 hectare (2.5 acres or 10,000 m^2—an area roughly equal to the inside of an Olympic running track) and they range in elevation from sea level to 1,800 meters (6,000 feet). The program established an additional six plots at Lewis and Clark in May 2011 and plans to establish six at San Juan Island and one more at North Cascades.

The program emphasizes monitoring forests equally across a range of elevations because forest types tend to differentiate according to environmental factors associated with various elevations. For example, Sitka spruce forests generally grow near sea level, where they face much different environmental conditions than do mid-elevation western hemlock and Douglas-fir or subalpine fir forests at higher elevations. One of the program's main goals is to identify differences and similarities between forests at these varying elevations and precipitation levels.

To achieve this goal, the program's designers have categorized the plots according to 300-meter bands of elevation. For example, Olympic contains six plots of Sitka spruce between the elevations of 0 and 300 meters, while its other six plots are composed of western hemlock forest between 600 and 900 m. The other two large parks divide their plots similarly, having half designated as subalpine fir between 1,500 and 1,800 m, while their other half consist of western hemlock between 600 and 900 m, a common elevation/forest type shared by all three parks.

Dividing the plots over distinct elevations and forest types ensures both breadth and depth in the data. To enhance the potential for detecting meaningful forest changes, the program requires multiple examples of each distinct forest type contained within these identifiable bands. To avoid site-selection bias, the program's coordinators use a randomizing algorithm to determine each plot's location. The algorithm limits the potential survey areas to within these elevation bands and assures the ability to make statistical inferences across parks.

At the lower elevations of the large parks, the Sitka spruce plots represent the "warm and wet" end of the spectrum, with thick understory predominantly populated by oxalis and sword fern. These forests serve as winter feeding grounds for Roosevelt Elk, and they thrive on high volumes of precipitation. The spruces typically grow alongside western hemlock.

At the other end of the spectrum, the high-elevation subalpine fir plots represent the "cold and dry" areas of the NCCN. The subalpine is a transition zone between the dense forests of lower elevations and the alpine tundra on which trees cannot survive. As elevation climbs, trees grow shorter and tree density grows sparser, giving way to areas of open meadow. Subalpine forests respond the most noticeably to climate change, expanding into higher elevations as the climate warms or retreating if it cools.

Screenshot from the Science Minute Movie about Forest Monitoring. The film can be viewed at www.nwparkscience.org. Photo courtesy of Eric Rejman

The western hemlock plots represent the middle ground, a "Goldilocks" elevation band shared between all three parks. This forest type is the most common throughout the NCCN, and so observations made at this level will apply the most broadly to the network. Hemlocks produce a hefty amount of foliage in proportion to their size, making this forest type especially shady and restricting the understory to mosses and shade-tolerant species. Western hemlocks themselves are a highly shade-tolerant tree and can easily survive under the canopies of taller Douglas-firs.

Within the 35 plots, the program includes specimens from 21 tree species—nearly every type found in the NCCN parks. In the near future, Lewis & Clark's plots will contribute another six examples of low-elevation Sitka spruce, while San Juan Islands will focus on 6 plots of low-elevation western hemlock.

The overarching utility of these plots is for researchers to track the mortality and recruitment of the trees within them, extrapolating trends that illustrate the health of the parks' forests on a large scale. The program's protocol requires annual surveys of tree mortality, which involves inspecting each tree inside each plot to see which ones have died since the previous year. This might seem like an excessive frequency for monitoring trees, considering the relatively slow rate at which they grow and the survey intervals of comparable studies such as those by the U.S. Forest Service, which typically measure plots for tree mortality every five to ten years. The same applies to tree recruitment:

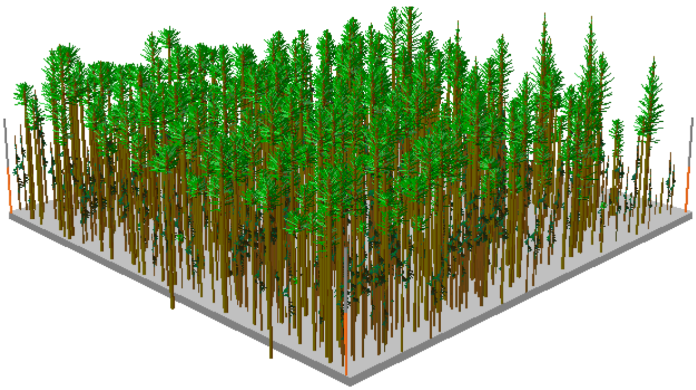
Why should the NPS measure recruitment and growth every five years when trees take nearly a hundred years just to be considered mature?

"There are various signs and symptoms that help identify [a tree's] death soon after it occurs. If you wait five to ten years, it's quite a bit harder to determine the cause of death," Acker explained. "With our hypothesis of a changing climate being a major cause of mortality, we need to have annual evidence or it becomes difficult to associate the connection. For recruitment, measuring every five years rather than every ten years allows us to capture more variability in growth. It gives us a better idea of the dynamics of small trees."

By surveying each plot every year, NPS researchers have an incredibly detailed account of changes to forest demography, giving them a greater chance to track the patterns of various causes of death. Combined with data from other Vital Sign monitoring programs such as climate monitoring and landscape dynamics, forest monitoring data will allow researchers to forge connections between observed trends in mortality/recruitment and the trends observed among the other vital signs. Understanding future changes to the parks' forests requires ample amounts of data to distinguish the natural range of variation in tree mortality.

Data Collection

At its core, the forest monitoring program revolves around data, and lots of it. Trends of importance include tree mortality, growth, recruitment, diameter, height, causes of death, and species, among other factors. Collecting such a



The stand structure and species composition of a typical plot in the middle-elevation stratum is depicted here using Stand Visualization System software developed by R.J. McGaughey of the PNW Research Station of the US Forest Service. Tree heights are predicted from diameter, using either statistical models built using data from the plots, or published models for the region. The vertical scale symbols in the corners represent 25 m.

spectrum of data, however, involves a considerable amount of physical effort.

"One of our biggest challenges in this program is collecting rigorous scientific information in a remote and rugged landscape," Acker said. "But I think the single-most difficult aspect is finding people who have the skills as biologists and the skills as backcountry travelers. They have to have the interest both in biology and in working in these kinds of landscapes. It's not easy to find people who have the right constellation of skills."

For the purposes of this program, trees are organized into three categories: saplings, small trees, and large trees. These categories are based on the diameter of the tree's trunk at the measurer's breast height, referred to as diameter at breast height, or dbh. (In the U.S., breast height has been standardized as 1.4 meters.) Saplings are defined as young trees with a dbh between 2.5 and 12.6 centimeters. The dbh of small trees lies between 12.7 and 76.2 cm, while any tree with a dbh greater than 76.2 cm is considered large.

The forest plots sit on the landscape as slope-corrected 100 x 100 meter squares (1 hectare), marked in the four corners and the center with rebar stakes. Within this plot, there is a central 50 x 50 m intensive plot, which is further divided equally into 25 10 x 10 m subplots. The corners of the 50-m plot are also marked with rebar, while the 10-m plots are marked with wooden stakes.

Each 100-m plot is dissected to this degree because its subplots serve varying purposes depending on the size of tree measured. At the 10-m plot scale, for example, there are nine plots that form criss-crossing lines through the center of the 50-m plot, and only within these nine plots do researchers monitor saplings. Within the entirety of the 50-m plot, all small trees are monitored, but only large trees are monitored throughout the entirety of the 100-m plot.

This arrangement creates a hierarchy within the plots, with all three sizes monitored near the center, but only the larger trees being counted as the researchers spread to the outer edges. The plots are organized this way to minimize disturbance and maximize efficiency, as monitoring every sapling and small tree over a 10,000 m^2 area would simply take too much time and is not necessary in order to detect trends among trees of that size. At Lewis and Clark and San Juan Islands, the entire monitoring area will consist of the 50-m plot and its inner subplots, forgoing the 100-m plots due to the relatively small size of the historical parks.

With all of these parameters in mind, two-person field crews are tasked with visiting each plot, clipboards and datasheets in-hand, ready to record every painstaking detail necessary. When the plots were established in 2008, each tree of appropriate size was marked with a numbered aluminum tag hanging from a small nail in the trunk. During years in which only tree mortality is monitored, the crew checks each tree to confirm whether or not it has died since the previous year. If it is still living, they write an 'L' in the datasheet and move on to the next. When they find a newly dead tree, they mark it as 'D' and record signs and symptoms that may allow them—or forest health experts at a later date—to determine the cause of death. Even for experts, however, the sheer number of variables that go into tree mortality often make determining a cause of death incredibly challenging.

"Tree mortality is a very difficult phenomenon for which to prescribe a cause," Acker said. "I've been doing this for 20 years now, and I'm not a tree pathologist, but I've worked with several. Even experts have trouble determining why a tree died."

Trees can die from fungal diseases, insufficient water, root rot, insect attack, competition from other plants, or severe splintering from extreme weather such as high winds or heavy snows. Deaths arise from multiple other factors, or they can arise from several pressures acting together. Due to the difficulty in identifying causes of death by sight, it is not uncommon for the field crew to record a death as unknown.

Trees can remain standing for years after death. In these cases, a dead standing tree is counted as a 'snag' until it falls over or leans at least 45 degrees from its original upright position, at which point it is marked as 'fallen' on the datasheet and is no longer monitored.

Every five years, researchers re-measure growth characteristics of the plot's trees, including height of a subset of trees (measured using a laser rangefinder). At this time, new saplings over 2.5 cm in diameter are added to the database, while some established trees have new diameter measurements that advance their size from either sapling to small tree or small tree to large tree. As sampling continues, researchers will begin comparing mortality and recruitment data to identify network-wide trends in the health of our forested ecosystems.

Current Trends

After a three-year pilot study, the forest monitoring program officially began in the summer of 2008, tagging trees within each of the 35 plots. The first tallies of tree mortality took place a year later. Approximately half the plots exhibited no tree mortality between 2008 and 2009. Overall, the average rate of tree mortality was 0.6 percent, which is within the expected range for older forests in the Pacific Northwest in the absence of severe wind damage. In 2013, researchers plan to conduct their first growth and recruitment

survey, being able to report changes after the next survey in 2018, and able to report initial trends in growth and recruitment in 2023. Clearly, tracking the changes in these forests is a long-term, ongoing process.

In the meantime, the interconnected nature of the Vital Signs monitoring program will reveal insights into the health of the parks' forests. The well-being of elk, landbirds, and fish assemblages all directly relate to the health of the trees that define their habitat. Changes to the climate—monitored in every park—will undoubtedly be reflected in the changes observed in the forests in the coming years. As our forests change, the rest of the ecosystem follows.

"Forests are fundamentally the structure of the ecosystems, and the national parks have some of the most significant remaining natural forests," Acker said. "They give us wildlife habitat, protection of watersheds, high water quality. They sequester carbon, and they also have tremendous aesthetic value. Basically, the ecosystems depend on the forests."

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