The Pacific Temperate Rainforest in a Changing Climate:

Past Degradation and Current Reforestation Strategies

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The Pacific temperate rainforest is the largest rainforest in the world, extending more than 2,000 miles along the Pacific Coast of North America.[1] It is a unique region, being the only sizable area on the planet where forest composition is dominated by conifers (cone-bearing trees) rather than flowering plants, and containing more biomass than any other region on the planet.[2] This forest range provides myriad ecosystem services and hosts an enormous amount of biodiversity. It is also home to an array of complex ecological interrelationships which humans are merely beginning to understand. Yet the current and looming threat of climate change, coupled with relentless historical deforestation and changing environmental and biological stressors, causes scientists to worry about the resilience of these forests and the long-term success of reforestation efforts across the region. With changes in climate occurring up to twenty times faster than previous climatic shifts in Earth's history, trees may not be able to adapt fast enough.[3] As such, scientists and practitioners will need to navigate many challenges to implement successful reforestation efforts. The regional context of these restoration efforts, including a history of degradation, shifting policies, and the debate around increasing forest resilience in a changing climate, is a topic that warrants further discussion.

First Nations have resided in the Pacific Northwest for thousands of years, keeping an ecological equilibrium while meeting their needs, but when European settlers arrived in the

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[1] "Pacific Coast Temperate Rainforests of North America," Radford University, accessed December 25, 2024, https://php.radford.edu/~swoodwar/biomes/?page_id=2247

[2] M.L. Herring, *Born of Fire and Rain: Journey Into a Pacific Coastal Forest* (Yale University Press, 2024), 3-5.

[3] "How is Today's Warming Different from the Past?," NASA, accessed December 25, 2024, https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php

1800s, their rapacious harvests of the area's resources – namely, timber and salmon – diminished these resources considerably. More than three-quarters of the rainforest in Oregon and Washington was cut down by the late 1900s.[4] Streams were cleared of large woody debris to help with timber transport, unknowingly removing an important component of riparian habitat, and suppression of wildfires caused fuel buildup in forests. Much of this occurred prior to the creation of the Environmental Protection Agency and the Endangered Species Act, and by the 1970s, views on natural resources had started to shift. The decline of the forest-residing northern spotted owl added fuel to the issue, sparking what would become known as the 'Timber Wars' between loggers and environmentalists.[5] By the 1990s, with the ESA listings of the northern spotted owl and marbled murrelet – two species that rely on old-growth coastal forests – opinions on logging had pivoted. Bill Clinton's 1994 Northwest Forest Plan ushered in an era where forests became recognized as complex, functioning ecosystems with innate value. The frantic rush to produce timber slowed and shifted to a focus on forest preservation and reforestation, not only for future timber production but also for the purposes of habitat restoration and endangered species protection.[6]

In the following decades, concerns about climate change grew and scientists began to look to forests as a way to alleviate environmental harm due to their numerous functions. Forests worldwide remove two gigatons of carbon each year; the Pacific temperate rainforest alone removes more than thirty million metric tons of carbon dioxide each year and stores it for several hundred years.[7] Additionally, geohydrologists predict that forests will play a fundamental role in producing clean water in future years. Already, twenty percent of the United States' water supply

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[4] Herring, *Born of Fire and Rain*, 29.
[5] Lisa Bramen, "Beyond the Timber Wars, *The Nature Conservancy*, July 31, 2015, https://www.nature.org/en-us/magazine/magazine-articles/beyond-the-timber-wars/
[6] Betsy L. Howell, *Wild Forest Home: Stories of Conservation in the Pacific Northwest* (The University of Utah Press, 2024), 2.
[7] Herring, *Born of Fire and Rain*, 72.

is sourced from National Forest Service Lands – with the largest contributor being the Cascade Mountain Range.[8] Riparian buffers are one of the most highly-targeted areas for restoration in part due to trees' ability to filter out pathogens in water. These are not to mention the direct benefits humans derive from forests: studies have shown that forests' scenic beauty can improve mental health and overall well-being. Evidence for this attraction are the 150 million average visits the American public pays to national forests annually, contributing more than $11 billion to the economy.[9]

However, possibly one of the most significant aspects of mature, intact forest ecosystems is their resistance to disturbance and outside stressors, and their capacity for recovery in the aftermath of such disturbances. In the past, young plantations consisting of monoculture Douglas firs were lauded as efficient and productive, while old-growth forests were cast off as frivolous and problematic. Yet studies show that mature rainforest is more resistant to wildfire and drought than young timber plantations, perhaps because of its many water-holding components.[10] As forests face water shortages and extreme wildfires, these capabilities may prove critical. Many of these strengths can be attributed to the bountiful ecological partnerships found throughout these verdant ecosystems. Fungal mycorrhizae attach themselves to tree roots and scavenge nitrogen, phosphorus, and water for the trees in exchange for sugars. Soil arthropods and societies of microorganisms break down organic matter and enrich forest soils in the process, which facilitates tree growth and further production of organic matter. Far above the ground, epiphytes such as mosses and lichens – in and of themselves a partnership between fungi and algae – rely on trees for support, and in exchange supplement the forest's water retention and nutrient

[8] USDA Forest Service, *National Forest System Reforestation Strategy* (National Forest System, 2022). https://www.usda.gov/sites/default/files/documents/reforestation-strategy.pdf
[9] USDA Forest Service, *National Forest System Reforestation Strategy*.
[10] Herring, *Born of Fire and Rain*, 114 and 166.

cycling. Within the needles of conifers, microscopic fungal webs known as endophytes provide defense against foliage eating insects, and trees compensate them with carbon energy.[11] This network of symbiotic relationships within old-growth forests buffer them from outside stressors and help them recover from disturbances, but they are not invincible.

After a wildfire in Pacific Northwest forests, a new generation of plants is released. Fungi triggered by the intense heat sprout up, followed by a host of pioneering plants: lupine, fireweed, snowbrush, pearly everlasting, red alder, and rhododendron, to name a few. The messy progression of a forest's seral stages has begun, as it has for thousands of years. Contrary to conventional forestry policy of the last century, having varying seral stages within a forest can be beneficial. The lack of overstory invites wildflowers, salal, huckleberry, and other shrubby plants to establish, in turn providing food for insects and birds while also restoring soil properties.[12] These forests have evolved to recover after wildfire, similar to the way that partnerships formed within ecosystems to fight off pathogens and insects. They have fostered resilience through biodiversity and symbioses, and some areas are completely capable of natural regeneration. But other areas are too fragmented, or have been razed by wildfire – increasingly intense and frequent over the last decade – again and again without the chance to recover. Some species face exotic diseases that they have not evolved defenses for, which can be fatal, as evidenced by the American chestnut and American elm. Others face a slew of pests released by warming temperatures, have succumbed to record-breaking droughts, or struggle to grow through an aggressive blanket of invasive plants. It is these areas, which struggle to regenerate naturally, that are the focus of current reforestation efforts.

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[11] Herring, *Born of Fire and Rain*, 86-93.
[12] Matthew J. Reilly et al. "Fire Ecology and Management in Pacific Northwest Forests," in *Fire Ecology and Management: Past, Present, and Future of U.S. Forested Ecosystems*, part of the book series Managing Forest Ecosystems (MAFE, volume 39), eds. C.H. Greenberg and B. Collins, 416-417.

Young trees planted as part of reforestation efforts will arguably face even tougher challenges than those safely ensconced in mature ecosystems. One of the most pressing questions, therefore, is whether trees planted in 2025 and onward can survive an increase in temperature ranging from 1.4℃ to 4.4℃ in the next eighty years.[13] In comparison, trees throughout Earth's history have experienced changes of roughly 1℃ over a period of one thousand years.[14] As a direct response to these concerns, the idea of 'assisted migration,' or assisting the migration of plant species to facilitate better adaptation to future climates, emerged in scientific communities. While not a new idea – foresters have moved trees around for decades – it was a novel response to the issue at hand.

There are three main categories of assisted migration:

1) *Assisted population migration*, which involves moving and increasing a seed source or population within its historic range and is generally considered the least extreme option,

2) *Assisted range expansion*, which involves expanding the historic range of a seed source or population into nearby areas, mimicking natural dispersal, and

3) *Assisted species migration*, which involves the movement of seed sources or populations to a location outside of the established range of a species to places they would not naturally reach without human intervention, generally considered the most extreme.[15]

Numerous studies have been initiated to examine the effectiveness of assisted migration, some with nascent results. Harris (2024) conducted an experiment using three different genotypes, respectively, of three different species: Douglas fir, Garry oak, and shore pine. Stock of each species from Washington, Oregon, and California were planted in an irrigated and non-irrigated plot near Belfair, Washington. Plantings were monitored for 17 months, during which time no genotype consistently outperformed the others; however, the study lays the groundwork for

[13] IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp 1-34.
[14] NASA, "How is Today's Warming Different than the Past?"
[15] "Assisted Migration (forests)," USDA Climate Hubs, accessed December 27, 2024, https://www.climatehubs.usda.gov/hubs/northern-forests/topic/assisted-migration-forests

future research.[16] Other larger-scale studies include the Experimental Network for Assisted Migration and Establishment Silviculture (ENAMES) and the Desired REgeneration through Assisted Migration (DREAM) projects, neither of which have documented findings. Still other studies have relied on analyses of plant traits to create guidelines for which species and biomes are most vulnerable to climate change, thus helping to prioritize areas and plant types for restoration.[17]

However, many studies on assisted migration mainly focus on plant survival and growth, when there are other important characteristics that could be monitored. For example, Harris's 2024 study using different species and genotypes examined not only plant survival and growth, but also the colonization of ectomycorrhizae (ECM) on plant roots. ECM form sheaths around plant roots and not only facilitate the uptake of minerals and water, but also protect the plant roots from pathogens and heavy metal toxins, produce antibiotics, hormones, and vitamins, and promote soil structure.[18] As part of the underground network that connects trees into forest communities, mycorrhizae could be critical for the well-being of young reforestation plantings, and are worth examining. Research on arbuscular mycorrhizae (AM), a more common type of mycorrhizae that grows inside of roots rather than around them, has indicated that AM can promote plant biodiversity, particularly in areas of high AM species richness. This finding may have ramifications for post-disturbance soils that are being altered by non-native invasive species, as well as soils in high wildfire frequency zones or areas where plants are dying due to stressors.[19]

[16] Chelsea Harris, "Restoring Forest Habitat Using Assisted Migration as a Climate Change Adaptation" (Thesis, Western Washington University, 2024).
[17] Peterson, Kerns, and Dodson. "Climate Change Effects on Vegetation in the Pacific Northwest: A Review and Synthesis of the Scientific Literature and Simulation Model Projections."
[18] Michael Amaranthus. "The importance and conservation of ectomycorrhizal fungal diversity in forest ecosystems: lessons from Europe and the Pacific Northwest."
[19] Hebel, Smith and Cromack Jr. "Invasive plant species and soil microbial response to wildfire burn severity in the Cascade Range of Oregon," *Applied Soil Ecology* 42, no. 2 (2009): 150-159.

Another topic which warrants further study is that of epigenetics in forest species. Epigenetics, technically defined as the study of processes affecting the expression of genes without altering the DNA sequence, can be simplified into the idea of trees 'learning' or adapting new strategies over their lives and incorporating it into the expression of their genes. Epigenetics can help a tree adjust to its environment in a similar way to phenotypic plasticity, but it goes one step further in adjusting the way the DNA of the tree is read. These alterations may be able to be passed down to the tree's offspring and could effectively engineer the next generation to be better adapted to the current climate than to the historic climate. In one study by the Swiss Federal Institute, seeds were taken from two groups of Scotch pine trees: one group that had been watered as needed for three years, and another group that had endured drought-like conditions for three years. The seeds were planted and deprived of water, and the group of seedlings whose parents had also endured water deprivation outperformed the group of seedlings whose parents had been pampered.[20] Seemingly, the parents had passed a lesson on drought tolerance down to their progeny. If this were the case for some of the trees in the Pacific temperate rainforest, the need for assisted migration may be reduced or largely eliminated.

While ecologists worry for the fate of trees in a quickly changing environment, they simultaneously hesitate to interfere in nature's processes, fearful of repeating the hubristic mistakes of the past. With this consideration in mind, perhaps the most important precursor of forest preservation is to protect intact old-growth forest ecosystems. Despite large swaths of clearcuts, millions of acres of Pacific temperate rainforest still stand relatively untouched, mostly on U.S. Forest Service land.[21] But while the acknowledgement of the value of these ecosystems

[20] Bose et al., "Memory of environmental conditions across generations affects the acclimation potential of scots pine." Plant Cell Environ. 43, no. 5 (2020): 1288-1299.
[21] Herring, *Born of Fire and Rain*, 11.

is increasing, the White House's 2024 Executive Order to improve climate resilience of federal forests and protect old-growth stands did not ban logging mature forest.[22]

The answers to scientists' fears for forests – managing pest and disease outbreaks, coping with extreme wildfire regimes, the ability to tolerate heat and drought and invasive species – may be tangled within the remaining rainforest. It is a functioning outdoor laboratory, still full of mysteries. For reference on the health of young reforestation efforts, there may be no better baseline to look to than an intact healthy ecosystem. Perhaps some of the oldest Douglas firs, Sitka spruces, western hemlocks, Western red cedars, or grand firs already hold the key to engineering the next generation, or perhaps a species-rich network of mycorrhizae can shield their host trees from the worst impacts. The region's history of deforestation and constant pendulum of public policy will continue to impact the fate of these forests; much of the rainforest's future may depend on policy-makers and funding at federal, state, and local levels, as well as the effort put toward preservation and restoration. But relying on existing ecosystems as a paradigm for reforestation efforts, and continuing to research the functions of mycorrhizae, endophytes, epigenetics and manifold other factors within these forests, is the approach scientists and practitioners must fall back on for now.

[22] The White House. "Executive Order on Strengthening the Nation's Forests, Communities, and Local Economy."

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