Ethnoforestry and adaptive management: generating new pathways to manage forests on the Olympic Peninsula, WA.

Courtney R. Bobsin

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington
2023

Reading Committee:
Bernard T. Bormann, Chair
Brian J. Harvey
Marc L. Miller

Program Authorized to Offer Degree:
Environmental and Forest Sciences

University of Washington

Abstract

Ethnoforestry and adaptive management: generating new pathways to manage forests on the Olympic Peninsula, WA.

Courtney R. Bobsin

Chair of Supervisory Committee:
Bernard T. Bormann
School of Environmental and Forest Sciences

In the last century, there have been significant changes to forest management policies in the Pacific Northwest. In the mid 1990s, the Northwest Forest Plan (NWFP) was developed and implemented, in part, to prioritize the protection of old growth habitat and species that depend on these forests. Adaptive management was a key component of the NWFP and was seen as a way to identify uncertainties, test new approaches, and learn from the results. Unfortunately, adaptive management was largely unrealized with few studies getting off the ground. In a changing climate and society, and uncertain future, creating and testing new approaches to forest management will be critical to expand our management toolbox and enhance our adaptive capacity. This dissertation seeks to demonstrate some methods of better incorporating and integrating sciences, both biophysical and social, into management decisions, to assist in

improving the collective capacity of managers, researchers, stakeholders, and tribes to adapt to a rapidly changing world.

In this dissertation, I first highlight an adaptive management experiment that was successfully implemented in the mid-1990s. This long-term ecosystem productivity study is located on the Olympic Peninsula, WA and includes two silvicultural approaches, 1.) an early-seral treatment planted with Douglas-fir and red alder; and 2.) a pure Douglas-fir plantation treatment. The first 25 years of overstory and understory growth were evaluated to understand stand development and differences between treatments. This study included extensive collaboration with forest managers during the design phase, which was an important step at the time. From what we know now, this approach to adaptive management might have been even more successful if it had included people as part of the ecosystem, rather than being driven by narrow research or management questions.

Our current approach began with developing an ecosystem wellbeing framework to drive adaptive management, where ecosystem wellbeing is made up of two key components that must be addressed simultaneously: community and environmental wellbeing. To apply this framework, I proposed the field of ethnoforestry to be an appropriate and useful way to study new approaches to forest management. Ethnoforestry, or a people-focused forest management, considers the knowledge, input, values, and beliefs of people who are affected by forest management outcomes. This, paired with collaboration with stakeholders and tribes, can lead to the co-development of research questions and studies that can be beneficial for the whole ecosystem, people and the environment. This approach is being applied to the operational-scale Type 3 Watershed Experiment and is also highlighted through a small-scale ethnoforestry field trial study located on the Olympic Peninsula that includes two ethnoforestry prescriptions where understory species beneficial to ungulates and nearby communities are planted alongside timber seedlings. Ethnoforestry prescriptions are compared to a standard practice of planting Douglas-fir and controlling competing vegetation, no-action controls, and several science-driven prescriptions.

Improving the quality and quantity of stakeholder engagement is also required to make ethnoforestry work in practice. I developed, with other team members, an approach to continue, expand, and focus engagement, called learning groups. This approach, derived from the discipline of social learning, prioritizes collaborating to address issues that could be studied while learning through the outcome of the work and learning about learning itself. Groups are focused on a particular topic (e.g., invasive species, cedar browse, etc.) and are made up of managers, researchers, stakeholders, and tribes. In this dissertation I detail the development and implementation of these groups and key insights to this approach.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The work and research covered in this dissertation required the support of so many people. First, I’d like to thank my advisor, Bernard Bormann, who guided me through a masters and PhD. I have learned so much about forest ecology, collaboration, community engagement, and asking the big-picture questions. Thanks for always being supportive, allowing me to pursue new ideas, and head in unusual directions. I learned more than I could have ever expected.

A huge thank you to my committee member Marc Miller, who helped me understand the importance of social science in my work. You always pushed me to think critically about asking the right questions, have a clear lexicon, and have confidence in my abilities. Thanks for always being in my corner. Thank you to my committee members Brian Harvey and Caren Crandell. Your guidance and expertise has been so valuable throughout this whole process. Teddy Minkova, thank you for teaching me and modeling how to be a successful woman in science and forestry. Thanks for your mentorship and help over the last several years. I have learned so much from you.

I want to acknowledge the many organizations who have supported this work. Portions of this dissertation was funded through grants from UW’s EarthLab, Population Health, and the Campus Sustainability Fund. In addition, much of this research was supported through the UW’s Olympic Natural Resources Center. This work was only possible through the continued collaboration of Washington Department of Natural Resources, especially Teddy Minkova, Bill Wells, Tracy Petroske, Kevin Alexander, Warren Devine, and Kyle Martens.

Thank you to all of the staff at the Olympic Natural Resources Center: Theresa, Linda, Deric, Jordan, Frank, and Gia. You have all helped me in tremendous ways, from creating new tools to help us with field measurements to always making sure I had a place to stay. It has been an incredible place to work. A special thank you to Frank Hanson, who taught me so much about building relationships on the outer coast.

An absolute huge thank you to all of my interns over the last eight years. I could not have possibly accomplished this work without you all. In addition to helping collect data with me, you pushed me to think more about scientific questions and inspired me to pursue new paths. A special thank you to Esaac Mazengia, Sarah Crumrine, and Thuy Luu, who volunteered countless hours to help support me and this work. You all are amazing, and I am forever grateful.

There have been so many graduate students who helped to support me throughout this process. I appreciate all the support of my lab mates Bryan Pelach and Ally Kruper. Bryan, it has been so helpful to be on the PhD journey together and I am grateful for the perspective and insight that you have brought to our group. So much of this work would not have been possible without you. Ally, it has been so great to work with you first as an intern and capstone student and now as a collaborator in our lab. Your fresh perspective, technical skills, and ability to get us all organized has been so helpful. I am very grateful that we've gotten to work with each other so much over the last few years. A huge thank you to Catherine Kuhn who has always been my cheerleader, supporter, and sounding board, and who has helped to limit my imposter syndrome throughout this whole process. Thank you to Stacey Dixon, whose friendship, positivity, and expertise has helped get me through so much.

A huge thank you to my friends, family, and partner, Mikhael, who have helped to boost my morale, give me confidence to keep going, and supported me throughout my whole graduate school experience. I could not have done any of this without your help and never-ending patience.

PUBLISHED MATERIALS

A portion of this dissertation has been published through the peer-review process. This article is reproduced in full here with a CC-BY license.

Bobsin, C. R., B. T. Bormann, M. L. Miller, and B. D. Pelach. 2023. Perspectives: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest. *Forest Ecology and Management* 529:1–10.

Chapter 1: Introduction

Management of natural resources in the Pacific Northwest, varies by land ownership. Public forest lands are managed by federal and state agencies. Reservation forest lands are managed by sovereign tribes. Private sector forest lands include those owned by timber businesses and small woodland parcels owned by individuals or families. Finally, some land with forest resources is managed by nongovernmental and environmental organizations.

During the Progressive Era, federal Forest Reserves administered by the General Land Office were transferred to the US Forest Service at the time of its creation 1905. In the same year, Chief Forester Gifford Pinchot and the "Use Book Committee" revised and published regulations regarding resource management in a volume titled *The Use of National Forest Reserves.* This influential publication—which has come to be known as the *Use Book*—has been expanded many times and today is a multi-volume compendium of principles and procedures. The *1905 Use Book* introduced a forestry ethos:

> "In the management of each reserve local questions will be decided upon local grounds; the dominant industry will be considered first, but with as little restriction to minor industries as may be possible; sudden changes in industrial conditions will be avoided by gradual adjustment after due notice, and where conflicting interests must be reconciled the question will always be decided from the standpoint of the greatest good of the greatest number in the long run." (p.11).

This ethos articulated in the *1905 Use Book* can be seen as entirely compatible with understandings that public forests are to be managed as multiple-use places where human communities and natural resources are to be sustained as elements within a single ecological system.

The Multiple-Use Sustained-Yield Act of 1960 recast the mandate for federal forest management so forests would be managed for multiple uses, including recreation, wildlife, watershed, range, and timber. This Act designated that each of these multiple uses should be valued equally (Williams 2005). Although this opened the door to alternative management priorities, people and communities were not explicitly mentioned, other than recreation. This was followed by several other conservation and environmental protection-oriented legislation that would be implemented in the following decade, including the Wilderness Act of 1964, the National Environmental Policy Act (NEPA) in 1969, and the Endangered Species Act 1973 (Williams 2005). These Acts set the stage for the significant changes in forest management in the Pacific Northwest that would be initiated in the 1990s following the listing of the marbled murrelet (*Brachyramphus marmoratus*) and the northern spotted owl (*Strix occidentalis caurina*).

The Northwest Forest Plan (NWFP) created a path forward to manage federal lands. National Forests under the NWFP were refocused primarily on protecting and increasing late seral and riparian habitat. On the outer Olympic Peninsula, harvests were also lowered on state trust lands in response to increased endangered species protections and due to the high and locally unsustainable harvest rates between the 1960s and 1980s. Trust land mandates required WA Department of Natural Resources (WA DNR) to focus on producing revenue for trusts efficiently through intensive, medium to long conifer rotations.

Adaptive management was a key element of the NWFP. This process emphasizes identifying uncertainties, testing various new approaches, and learning from the process and outcome to inform future work (Walters 1986, Walters and Holling 1990). However, thirty years after the NWFP was enacted, there are still only limited examples of adaptive management projects being implemented (Stankey et al. 2003a, Bormann et al. 2007b, Rapp 2008). Adaptive management projects require collaboration amongst scientists and managers, large enough available forested areas to establish an experiment, and consistent funding to create and monitor the study through time. All of these contribute to the difficulty of establishing these types of studies. Many other iterations have been proposed, including active adaptive management (Larson et al. 2013), options forestry (Bormann and Kiester 2004), and collaborative adaptive management (Fernández-Giménez et al. 2019), but none have pushed the needle much further. There have, however, been a few examples of operational-scale adaptive management experiments that has been established since the creation of the NWFP. I highlight one example of this in chapter 2 of this dissertation.

Chapter 2 is focused on the long-term ecosystem productivity (LTEP) study. This is a network of adaptive management research sites with replicates in western Washington and Oregon. This chapter is focused on the site located on the Olympic Peninsula on lands managed by the WA DNR. I evaluate two treatments, an early-seral treatment planted with a mix of red alder (*Alnus rubra* Bong.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and a Douglas-fir plantation treatment planted with pure Douglas-fir. In this chapter, I analyzed changes and interactions in the overstory and understory over the first 25 years since treatment implementation.

Red alder is often considered a weedy species by land managers and has historically been removed from sites due to concerns of unwanted competition with timber trees. However, red alder is a timber tree itself and can fix atmospheric nitrogen, improve soil health, allow better access to nitrogen for nearby plants, increase understory biodiversity, and improve nutrient cycling (Tarrant and Miller 1963, Hanley et al. 2006, Perakis et al. 2012). Red alder can improve growth of other conifer species, especially on nutrient-poor sites, such as after wildfires (Tarrant 1961). These effects can be especially dramatic after wildfire, including 40% increases in soil nitrogen and organic matter, and a tripling of total aboveground biomass—with this continuing 25 years after alders naturally died out (Bormann et al. 2023).

This LTEP study, in part, was to determine the potential effects of adding red alder in equal proportions to Douglas-fir and compare results to the pure Douglas-fir treatment. We found that at year 25 there were little differences in stand development, understory diversity, and seedling regeneration between these treatments. However, we did find site-specific differences with one of the blocks being significantly different than the others early in the study that demonstrates high variation at fine spatial scales of <150 acres. The early-seral treatments in one of the blocks had higher basal area, higher biomass, and lower mortality than the others. These trends faded over time, with very little difference in the two treatments by year 25. Future monitoring may uncover divergences in these treatments. In addition, other research could explore alternative methods of managing these young forests to increase our management toolbox going forward. A few new approaches are developed, implemented, and presented in chapter 3.

In chapter 3, I present a new small-scale ethnoforestry study established in 2020 on lands managed by WA DNR near La Push, WA. The coast range, spanning the Olympic Peninsula through northern coastal California, has experienced a decline in early-seral habitat for the last several decades (Phalan et al. 2019). Young forest stands provide benefits for wildlife who depend on the sun-dependent forbs and graminoids for forage and for communities who rely on these spaces for harvesting plant material, such as beargrass (*Xerophyllum tenax* (Pursh) Nutt.) (Shebitz et al. 2009, Cook et al. 2016b). In addition, on the westside of the Olympic Peninsula, copious amounts of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings grow far beyond that necessary to replace crop tree mortality, taking up space and nutrients from other understory species. This study tests alternative approaches to managing early-seral stands that could enhance ecosystem wellbeing, curtail western hemlock regeneration, and produce a timber crop in a 50-year rotation.

This ethnoforestry study includes a factorial design, with interacting vegetation and browse-control treatments. Two ethnoforestry prescriptions, an agroforestry and an early-seral management, are compared to a standard practice control. These vegetation treatments include planting understory species in rows at varying densities in the agroforestry and early-seral management and planting timber species in all treatments. Browse-control treatments include 1.) fencing; 2.) treating with a wildlife repellent; and 3.) no-action, open to browse. In addition, the blocks (replicates) were created based on levels of downed wood: low, medium, or high. Two years of monitoring has provided data for some initial results.

We found that planted understory and tree seedlings had significant mortality that was not driven by the treatments or observed across blocks. In addition, mortality of tree seedlings decreased as the amount of naturally regenerating understory increased, indicating that competition of neighboring vegetation did not contribute to this high mortality. Instead, unexpected high spring temperatures, low rainfall, and a record-breaking summer heat wave most likely played a role. In a changing climate, these events will most likely worsen, pointing to issues with mortality going forward.

The ethnoforestry study is a small five-acre experiment. In part, this was intended to inform the ethnoforestry-based experiments in the larger Type 3 (T3) Watershed Experiment (Bobsin et al. 2023). The study implementation coincided with stakeholder and tribal engagement, limiting the amount of input that could be directly applied. In addition, this unit is surround by private roads and a locked gate, making it very difficult to provide access to nearby communities. However, lessons learned from implementing this study helped with the decision making of the operational-scale T3 Watershed Experiment. This process also helped to inform and refine our work on ethnoforestry, our approach to collaboration, and how these elements can address ecosystem wellbeing. This is presented in chapter 4.

In chapter 4, I discuss the ways in which forestry has failed to adapt to changing conditions, address needs of diverse communities, or propose and enact novel approaches to forest management. I propose a new framework for ecosystem wellbeing, which has two key components that must be addressed simultaneously: community and environmental wellbeing. This approach places an emphasis on people as part of our ecosystems. The need for this distinction and emphasis is perhaps most evident in rural parts of the Pacific Northwest where communities and tribes rely on public lands management for their personal, economic, spiritual, and cultural wellbeing. In order to achieve ecosystem wellbeing, engaging with people is critical. We approach this through collaborative learning, which prioritizes bringing in a diverse range of collaborators (e.g., scientists, managers, and stakeholders) to produce work and learn from the outcome and the process itself (Daniels and Walker 1996, Walker and Daniels 2019a).

The collaborative process is necessary to ensure that research and management that are done can be useful, useable, and meet the needs of everyone that is affected by its outcome. Knowledge and input from this collaborative learning process can be directly fed into adaptive management studies that test alternative approaches. We see the field of ethnoforestry as the necessary context to achieve this. Ethnoforestry, or a people-centered forest management, seeks to use the input derived from engagement and apply it with a goal of achieving ecosystem wellbeing. Ethnoforestry is not a new field, having been applied in India and other parts of Asia (Pandey 1998, Prabakaran et al. 2013). In this paper, I detail how we have applied our variant of ethnoforestry to the new, operational-scale watershed experiment called the T3 Watershed Experiment (Bobsin et al. 2023).

This T3 Watershed Experiment applies the ecosystem wellbeing framework and includes extensive stakeholder and tribal participation to create a study that can addresses concerns of adjacent communities, attempts novel management strategies, enhances our adaptive capacity, and learns from the process. Through collaboration learning, a new form of engagement emerged that came to be known as learning groups and is the basis for chapter 5. This process applies social science concepts included under the umbrella of social learning and highlights the importance of addressing uncertainties and learning together (Lee 1993, Keen et al. 2005).

The learning groups bring together three key groups that appear critical for successful engagement: 1.) researchers; 2.) managers; and 3.) stakeholders and tribes. Each group works together on a given topic that could not be directly tackled in the study plan but has particular importance or interest to group members. So far, eight learning groups have formed including cedar browse, history, invasive species, carbon sequestration, tribal, aquatic responses, remote sensing, and economics and operations. Each group is unique and chooses to tackle projects that they are interested in. There have been varying levels of engagement and success between the groups. In chapter 5, I detail how we created the structure of these groups, initial typologies or categories that they have fallen into, and key insights in the first 10 months since they began. We hope that this type of structure could be helpful and provide some potential pitfalls to be aware of for others outside the Olympic Peninsula.

1.1 REFERENCES

Bobsin, C. R., B. T. Bormann, M. L. Miller, and B. D. Pelach. 2023. Perspectives: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest. *Forest Ecology and Management* 529:1–10.

Bormann, B., and R. Kiester. 2004. Options forestry: Acting on uncertainty. *J. For.* 102(4):22–27.

Bormann, B. T., C. R. Bobsin, R. J. McGaughey, J. C. Gordon, B. A. Morrissette, and A. Kruper. 2023. The Wind River alder strip revisited: Lessons for post-fire management on recent and future western Washington and Oregon fires. *Forest Ecology and Management* 537:120959.

Bormann, B. T., R. W. Haynes, and J. R. Martin. 2007. Adaptive Management of Forest Ecosystems: Did Some Rubber Hit the Road? *BioScience* 57(2):186–191.

Cook, J. G., R. C. Cook, R. W. Davis, and L. L. Irwin. 2016. Nutritional ecology of elk during summer and autumn in the pacific northwest. *Wildl. Monogr.* 195:1–81.

Daniels, S. E., and G. B. Walker. 1996. Collaborative Learning: improving public deliberation in ecosystem-based management. *Environ. Impact Asses. Rev.* 16:71–102.

Fernández-Giménez, M. E., D. J. Augustine, L. M. Porensky, H. Wilmer, J. D. Derner, D. D. Briske, and M. O. Stewart. 2019. Complexity fosters learning in collaborative adaptive management. *Ecology and Society* 24(2).

Hanley, T. A., R. L. Deal, and E. H. Orlikowska. 2006. Relations between red alder composition and understory vegetation in young mixed forests of southeast Alaska. *Can. J. For. Res.* 36(3):738–748.

Keen, M., V. A. Brown, and R. Dyball. 2005. Social learning: a new approach to environmental management. Pages 1–270 *Social Learning in Environmental Management: Towards a Sustainable Future*. Taylor & Francis Group.

Larson, A. J., R. T. Belote, M. A. Williamson, and G. H. Aplet. 2013. Making monitoring count: Project design for active adaptive management. *J. For.* 111(5):348–356.

Lee, K. N. 1993. *Compass and gyroscope: integrating science and politics for the environment*. Island Press.

Pandey, D. N. 1998. *Ethnoforestry: Local knowledge for sustainable forestry and livelihood security*. Himanshu Publications.

Perakis, S. S., J. J. Matkins, and D. E. Hibbs. 2012. N 2-Fixing Red Alder Indirectly Accelerates Ecosystem Nitrogen Cycling 15(7):1182–1193.

Phalan, B. T., J. M. Northrup, Z. Yang, R. L. Deal, J. S. Rousseau, T. A. Spies, and M. G. Betts. 2019. Impacts of the Northwest Forest Plan on forest composition and bird populations. *PNAS* 116(8):3322–3327.

Prabakaran, R., T. Senthil Kumar, and M. V. Rao. 2013. Ethnoforestry and ethnoagricultural knowledge of Malayali tribes of Chitteri hills, Tamil Nadu. *J. Bio. & Env. Sci* 12(5):12–19.

Rapp, V. 2008. *First-Decade Results of the Northwest Forest Plan*. Gen. Tech. Rep. PNW-GTR-720.

Shebitz, D. J., S. H. Reichard, and P. W. Dunwiddie. 2009. Ecological and Cultural Significance of Burning Beargrass Habitat on the Olympic. *Ecol. Restor.* 27(3):306–319.

Stankey, G. H., B. T. Bormann, C. Ryan, B. Shindler, V. Sturtevant, R. N. Clark, and C. Philpot. 2003. Adaptive Management and the Northwest Forest Plan: Rhetoric and Reality. *Journal of Forestry* 101(1):40–46.

Tarrant, R. F. 1961. Stand development and soil fertility in a Douglas-fir red alder plantation . *Forest Science* 7:238–246.

Tarrant, R. F., and R. E. Miller. 1963. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. *Soil Science of America* 27(2):231–234.

Walker, G. B., and S. E. Daniels. 2019. Collaboration in environmental conflict management and decision-making: Comparing best practices with insights from collaborative learning work. *Frontiers in Communication* 4.

Walters, C. 1986. *Adaptive Management of Renewable Resources*. MacMillan Publishing Company, New York.

Walters, C. J., and C. S. Holling. 1990. *Large-Scale Management Experiments and Learning*. Page *Source: Ecology*.

Williams, G. W. 2005. *The USDA Forest Service-The First Century*. Washington, DC.

Chapter 2: Relationships between overstory growth, understory regeneration, and red alder on a long-term ecosystem productivity study, Olympic Peninsula, WA

2.1 ABSTRACT

In the Pacific Northwest, short-rotations of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees is a common management prescription on public and private timberlands. Rarely, other species are planted alongside it, such as western hemlock or western red cedar. Historically, red alder has been seen as a weedy species and is most often removed from stands. Numerous research studies showcase the benefit of planting red alder along with conifers such as Douglas-fir. These include higher soil fertility due to red alder's ability to fix atmospheric N_2, increasing mineral-soil organic matter, and better nutrient cycling. Alder is also correlated with higher understory biodiversity and biomass, its leaf litter in streams provide food for insects, and it can be an important species for the timber industry. In a long-term ecosystem productivity study, an early-seral treatment with mixed red alder and Douglas-fir was compared to a pure Douglas-fir plantation treatment. This study evaluates the first twenty-five years of stand development, understory growth, seedling recruitment, and alder effects across vegetation treatments and site differences.

The first post-treatment measurement in year 7 showed little difference between treatments, with both having severe mortality of Douglas-fir and alder. However, site specific differences started to emerge across blocks (designated based on spatial proximity), with block four showing statistical differences between treatments. This block also had higher basal area, higher biomass, and lower mortality of Douglas-fir and red alder seedlings in the early-seral treatment compared to the Douglas-fir plantation. Additionally, block four also had higher soil C and N and lower rock content prior to treatment implementation in 1993. These differences,

which were statistically significant in year 7, disappeared by year 17 and continued in year 25. Aerial LiDAR, taken at year 20, showed the early-seral treatment with significantly taller (tallest 20%) trees in block four compared to those in the Douglas-fir plantation treatment. Future height changes are uncertain and will be revealed by continued monitoring.

Similar to the overstory, the understory and seedling analysis indicated site-specific differences with the early-seral treatments with block four having less understory cover, fewer seedlings, and less salal by year 21. An interesting negative relationship was discovered between red alder presence and salal cover. Salal, oftentimes a recalcitrant species, can quickly spread and dominate in this region. In the future, planting alder could assist in curtailing the growth and spread of salal. We have gained important insight into the changes of the overstory and understory over the first 25 years. Future monitoring will allow us to have a longer-term picture of changes, treatment impacts, and potential site-specific effects going forward.

2.2 INTRODUCTION

In most western Washington and Oregon forests, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) has been the predominant timber species. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is occasionally planted, but not nearly with the same frequently as Douglas-fir. These two species are most often planted one to two years post-harvest by land managers to create a new forest stand. Additions of other timber species, such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Western red cedar (*Thuja plicata* Donn ex D. Don), and red alder (*Alnus rubra* Bong.) are less common. Red alder has long been seen as a weedy species by foresters and managers, believing that it provides unnecessary competition to the other coniferous timber species even though it can achieve harvestable size sooner on many sites and often has a higher stumpage value than Douglas-fir.

Although often overlooked, red alder can provide several ecosystem and economic benefits in addition to wood production. This deciduous tree can support more understory biodiversity, biomass, and forage for wildlife (Hanley et al. 2006). It has a microbial endophytic symbiont (*Frankia*) that fixes atmospheric nitrogen (N_2) in root nodules that in turn improves soil fertility (especially compared to pure coniferous stands) and releases forms of nitrogen that can be accessed and used by nearby plants (Tarrant and Miller 1963, Teklehaimanot and Mmolotsi 2007, Perakis et al. 2012). Its deciduous leaves provide a pulse of nutrients—especially relative to dense, coniferous-dominated forests. Some studies have indicated that the growth of red alder does not negatively impact growth of Douglas-fir trees planted together, and it may even enhance total growth in nutrient depleted areas due to the ability of red alder to fix N_2 in soils (Fang et al. 2019). Climate projections suggest that the range of red alder will expand in the coming decades as the Pacific Northwest is projected to have warmer and wetter winters (Cortini et al. 2012), and could be planted in a wider range of sites.

Recently harvested stands often receive an herbicide application to eliminate any competition from understory species prior to planting coniferous seedlings on site. As in the case with red alder, understory is seen by and large to be a nuisance by land managers, with particular species, such as salmonberry (*Rubus spectabilis* Pursh), seen as negatively impacting conifer growth in the first several years after planting. Although, understory species that typically dominate these post-harvest early-seral stands (e.g. graminoids, forbs, and other disturbance-adapted species) are valuable for wildlife, such as pollinators, birds, and ungulates. Additionally, several early-seral-dependent plant species are culturally, personally, and economically valuable to rural communities, both tribal and non-tribal. A study by Yildiz et al. (2011) showed that up to 75% removal of understory positively impacted tree development, but beyond that amount there was no greater benefit, indicating that 25% of understory cover can be retained without negative impact to conifer growth.

Understory production and biodiversity, especially early-seral species, can provide an important food source for ungulates. In the Pacific Northwest, plants such as salmonberry, red elderberry (*Sambucus racemosa* L.), fireweed *(Chamerion angustifolium* Holub), and vine maple (*Acer circinatum* Pursh) provide key nutrients for Roosevelt elk (*Cervus canadensis roosevelti*) and black tailed deer (*Odocoileus hemionus columbianus*) populations (Thomas and Toweill 1982). These wildlife species are also important sources of protein for subsistence hunters, especially in rural places across the Pacific Northwest and beyond. The addition of understory species growing alongside conifer crops can be a win-win for both timber and ecosystem wellbeing. Although, certain recalcitrant understory species can dominate a forest ecosystem, limiting the ability for other species to thrive (Royo and Carson 2006).

On the Olympic Peninsula, salal (*Gaultheria shallon* Pursh) can quickly grow and spread through its rhizomes, shading out anything below it with its evergreen leaves. Even when aboveground stems are removed, it can easily regenerate from existing rhizomatic buds and limit the establishment of other shrubs and seedlings (Tappeiner et al. 2001). Belowground, it provides fierce competition with neighboring plants for nutrients and has been shown to limit the growth of western hemlock seedlings and saplings (Mallik and Prescott 2001). Although it does have value as a non-timber forest product that is used in the floral industry (Frey et al. 2021), its foliage does not provide adequate forage for grazers, including ungulates, who have difficulty digesting salal unless eaten alongside arboreal lichens (Bunnell 1990).

The objective of this research was to evaluate long-term 1.) changes in overstory development including effects red alder may have on tree composition and density; 2.) potential role red alder may play in understory growth, biomass, and biodiversity between two treatments; and 3.) differences in understory functional group cover and seedling regeneration (based on different height classifications) between silviculture and woody debris treatments over the first 25 years of a long-term ecosystem productivity study located on the northwestern side of the Olympic Peninsula, WA state.

2.3 METHODS

2.3.1 Study Area

The long-term ecosystem productivity (LTEP) study is a network of sites that includes replicates in the Rogue River - Siskiyou National Forest in SW Oregon, the Willamette National Forest in the Oregon Cascades, the Siuslaw National Forest in NW Oregon, and on the Olympic Peninsula on lands managed by WA Department of Natural Resources (WA DNR) within the Olympic Experimental State Forest. This paper focuses solely on the Olympic Peninsula site located in Sappho, WA. The Olympic Peninsula site has a mean annual rainfall of 294 cm (115.73 inches), with a mean rainfall of 48 cm (18.89 inches) in January and 4.5 cm (1.79 inches) in July ((NOAA 2023)). Mean temperatures in Sappho, WA range from 8° C (46.4° F) in January to 22.5° C (72.5° F) in July (NOAA 2023).

Before treatments were implemented, these approximately 70-year-old stands were primarily a mixture of Douglas-fir and western hemlock with a smaller quantity of Sitka spruce, western red cedar, and red alder. Pre-treatment stands had trees with a wide range of breast-height diameters (DBH) from 3.2 cm to 92.2 cm, averaging 23.8 cm. Understory cover was varied within these stands, ranging from 0% to 95%, with a mean of 4%. Evergreen woody shrubs was the predominant understory functional group type. There was a large quantity of small tree seedlings (under 30 cm) growing in these stands with a mean of 162,000 seedlings ha^{-1}, most of which were western hemlock. The spruce-hemlock zone is known for its abundant advanced regeneration of shade-tolerant species (Deal et al. 1991), especially western hemlock, as observed in this LTEP site prior to treatment implementation.

2.3.2 Experimental Design

This study evaluated two of the treatments that were implemented at the Olympic Peninsula LTEP site: 1.) a “mid-seral” Douglas-fir plantation representing standard practice; and 2.) an “early-seral” plantation with a 50:50 mixture of planted Douglas-fir and red alder. This site has four blocks (replicates), each with three Douglas-fir plantation and three mixed fir-alder treatments comprising 24 of the experimental units across the site. Each experimental unit is approximately 1 ha in size with an additional 25-50 m buffer surrounding it on all sides (Figure 2.1).

Pre-treatment measurements were completed in 1993 followed by treatment implementation in 1995. Both treatments were commercially clear-cut using ground-based operations followed by replanting with nursery stock. Douglas-fir plantation units were replanted with 100% Douglas-fir at even spacing while early-seral units were replanted with equal proportions of Douglas-fir and red alder with a total of 866 TPH (350 TPA) in both treatments.

Three levels of coarse woody debris were left on the soil surface during treatment implementation in 1995: low (all felled trees, branches, and tops were removed from the site), medium (7.5% of felled trees, branches, and tops were retained), and high (15% of felled trees, branches, and tops were retained). In each of the four blocks, the three Douglas-fir plantation and three early-seral units have one low, one medium, and one high woody debris treatment (Table 2.1). A standard practice pre-commercial thin occurred in 2013 (18 years after treatment implementation) to reduce the excess of small trees and saplings growing in both treatments, primarily naturally regenerated western hemlock. Western hemlocks and shrubs were left only when planted trees were missing.

Each unit has five tree plots, with a total of 120 tree plots for this analysis. Each is 18 m by 18 m in size with monumented corners to mark the boundaries of each plot where data are collected. In addition, each experimental unit has 15 or 16 (depending on the unit layout) understory subplots arranged in a 25 m grid, totaling 375 understory plots. These monumented plots are 3 m by 3 m in size and are used to collect data on understory species cover and abundance, seedlings, and biomass during each measurement year. Lastly, each experimental unit had 15 or 16 (depending on unit layout) soil sample locations where soil pits were dug and collected.

Table 2.1: Details on the early-seral and Douglas-fir plantation treatments including a description of prescription, years in which measurements took place, and total number of units

Operational Treatment	Treatment Description	Measurement Years	Total Units
Early-seral	Clear-cut and replanted with 50% Douglas-fir and 50% red alder at 433 TPH (175 TPA) for each species. High-wood: 4 units; medium-wood: 4 units; low-wood: 4 units	Tree Plots: pre-treatment, year 7, year 17, and year 25 Understory Plots: pre-treatment, year 1, year 7, and year 21	12
Douglas-fir plantation	Clear-cut and replanted 100% Douglas-fir at 866 TPH (350 TPA). High-wood: 4; medium-wood: 4 units; low-wood: 4 units	Tree Plots: pre-treatment, year 7, year 17, and year 25 Understory Plots: pre-treatment, year 1, year 7, and year 21	12

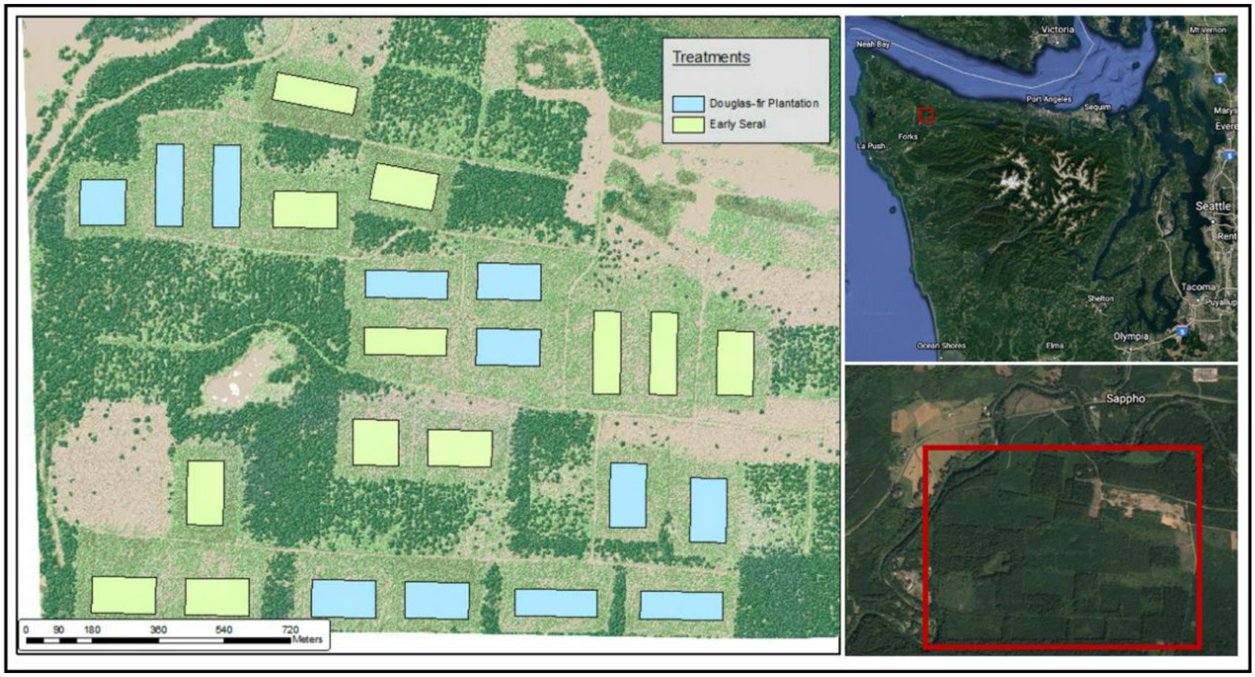


Figure 2.1: The location and spatial layout of Douglas-fir plantation and early-seral treatments within the Olympic Peninsula LTEP site located in Sappho, WA. The green and blue boxes indicate the experimental unit. Each is surrounded by a buffer on all sides, making up the experimental unit.

2.3.3 Measurements

Measurements were taken at monumented soil, tree, and understory plots in each experimental unit. Pre-treatment measurements were taken in 1993 followed by treatment implementation in 1995. In addition, tree plots were re-measured 7 years, 17 years, and 25 years after treatments were implemented. Understory plots were re-measured 1 year, 7 years, and 21 years after treatments were implemented.

Soil samples of the O, A, B1, and B2 horizons were collected within the experimental units at set soil sample locations tied to each grid point at a specified distance and azimuth. These samples were removed, bagged, and transported to a lab for processing and analysis (Homann et al. 2008). Soil samples were only completed in the 1993 pre-treatment measurement.

The nitrogen concentration, carbon concentration, rock content, and soil mass were analyzed for each of the horizons.

In tree plots, data were taken for each tree that fell within the boundaries of the plot, whether planted or naturally regenerated, and included 1.) mortality (alive or dead); 2.) species; 3.) DBH; and 4.) location within the tree plot for stem mapping and spatial analysis (only taken in year 25). In each understory plot, data were taken on 1.) understory species composition, 2.) total cover (%) by species; 3.) total understory biomass (measured only in year 2; and 4.) quantity of seedlings in three height classifications: a.) seedlings under 30 cm; b.) seedlings 30 to 136 cm; and c.) seedlings >136 cm with a DBH < 3.5 cm (tree class diameter minimum).

All understory plant species were categorized into six ‘functional groups’ based on their growth form. These include: 1.) graminoid; 2.) forb; 3.) evergreen fern; 4.) deciduous fern; 5.) evergreen woody shrub; 6.) deciduous woody shrub. In addition, salal, a particularly abundant and recalcitrant understory species on the Olympic Peninsula, was isolated to determine its relationship to the growth of red alder.

Understory biomass was estimated using a biomass photo-booklet, consisting of a series of images within a 3 by 3 m area delineated with posts and tarps covering the range of vegetation types and densities and their dried weight (Mg ha^{-1}) after complete harvest. This booklet was created by this team of researchers for stands in this and other LTEP sites. Field crews visually compared ground plots to the booklet, determined one or more photos that most closely aligned based on species present and cover, and used this to estimate total dry biomass for the plot.

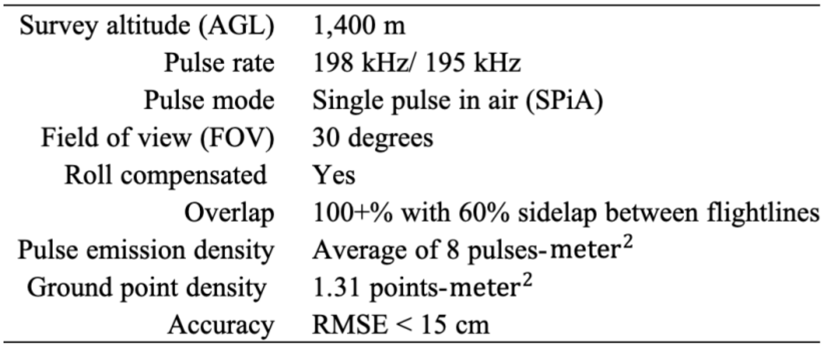
2.3.4 LiDAR data and spatial data analysis

Individual tree height in each experimental unit was determined using 2015 air-borne light detection and ranging (LiDAR) point cloud data. Tree heights were not collected in the field due to the difficultly of determining the tree top in dense stands from the ground and the greater accuracy of using remote sensing methods. Data acquisition occurred between October 17, 2014 and March 13, 2015 using a Leica ALS70 and ALS80 sensor. The survey was completed using opposing flight lines and side-lap of greater than 60%, with more than 100% overlap. Additional information on flight parameters is shown in Table 2.2. LiDAR data are accessible from the Washington LiDAR portal (https://lidarportal.dnr.wa.gov) under “Solduc 2015”.

The point cloud data was normalized relative to the ground surface. Then, a canopy surface model was created that was used to produce a canopy height model (CHM). Tree heights were then determined using this CHM. This analysis was completed using the LidR package in RStudio.

In addition, spatial data from the LiDAR point cloud (see details in Table 2.2) was used to map the location of individual trees, red alder in particular, based on its canopy. Approximate locations of red alder across LTEP were located using a model based on the airborne LiDAR with a 96% accuracy (Kruper et al. 2022). Once red alder locations were determined, a 5 m^2 buffers were drawn around each understory plot and the total alder cover (%) within each understory plot and buffer was calculated. This was used as a continuous variable within the analysis to determine the potential connection between red alder and understory growth (salal in particular), species richness, and biomass. The spatial analysis was completed using ArcGIS Pro and RStudio (version 1.4.1106).

Table 2.2: Flight parameters and sensor settings for the 2015 air-borne LiDAR flight



Survey altitude (AGL)	1,400 m
Pulse rate	198 kHz/ 195 kHz
Pulse mode	Single pulse in air (SPiA)
Field of view (FOV)	30 degrees
Roll compensated	Yes
Overlap	100+% with 60% sidelap between flightlines
Pulse emission density	Average of 8 pulses-meter^2
Ground point density	1.31 points-meter^2
Accuracy	RMSE < 15 cm

2.3.5 Overstory biomass calculations

Overstory biomass (Mg ha^{-1}) was calculated for each post-treatment measurement year and included all live aboveground trees. This was determined using biomass equations and methodologies described in Chojnacky et al. (2014).

3.3.6 Statistical analysis

Overstory

Changes in tree growth (DBH), basal area (BA), biomass, and trees per hectare (TPH) were calculated between the treatments and measurement years using linear regression in order to assess the ways in which stand composition has changed over the first 25 years since treatments were implemented. In addition, using the continuous and remotely sensed red alder data, we compared its abundance (percent cover within each understory plot and buffer) to overall understory cover, richness, biomass, and an isolated salal cover data to determine if a potential relationship existed. Lastly, a linear regression was completed to assess the relationship between the pre-treatment soils data and overstory BA, TPH, tree height, biomass, and mortality.

Understory and Seedling Growth

To evaluate the changes in understory cover, seedling growth, and their interaction over time between treatments, we used distance-based linear models using multivariate response matrices at the unit scale (Legendre and Anderson 1999). Data were separated into eight subsets for this analysis, four understory and four seedling subsets separated by measurement years (pre-treatment, year 1, year 7, and year 21). We ran permutational analysis of variance (PERMANOVA) tests separated using these eight subsets as response matrices. The understory response matrix included continuous mean cover data broken into six functional groups (graminoids, forbs, evergreen ferns, deciduous ferns, evergreen woody shrubs, and deciduous woody shrubs) using Bray-Curtis dissimilarity measures, while the seedling matrix used count data separated by the three height classifications and used Euclidean distance measures (McCune and Grace 2002). All response matrices were relativized by their maxima prior to the analysis due to their high coefficient of variation values (McCune and Grace 2002). All statistical analyses and visualizations were completed in R Studio Version 1.4.1106.

2.4 RESULTS

2.4.1 Overstory

2.4.1.1 Trees per Hectare

While these forest stands are still young, we can glean important information about stand development and treatment success over the first 25 years of a long-term study. Seven years after treatment implementation, the overstory measurement analysis showed that despite red alder and Douglas-fir being planted in equal proportions of approximately 433 TPH (175 TPA) each in the early-seral treatment in 1995, there was significant red alder mortality in the years that followed, resulting in far fewer red alder growing in this treatment than intended. By year 7, there were an average of 306 TPH of Douglas-fir and only 136 TPH of red alder growing in this treatment (both planted and natural regeneration; Figure 2.2; Table 2.3). A few red alder also naturally regenerated in the Douglas-fir plantation treatment, with a mean of 27 TPH, while planted and regenerating Douglas-fir trees had a mean of 363 TPH. Despite the Douglas-fir treatment having twice as many Douglas-fir trees planted, by year 7, there was not a significant difference in Douglas-fir TPH between the two treatments (p = 0.19).

Western hemlock, a species known to quickly regenerate in young Olympic Peninsula stands, were observed to have a mean of 500 TPH and 269 TPH in the early-seral and Douglas-fir plantation treatments respectively. Although, most western hemlocks were small in size with a mean DBH of 0.8 cm in the early-seral treatment and 0.9 cm in the Douglas-fir plantation treatment. There were also differences in hemlock TPH between blocks, with block 4 having significantly more TPH than the other blocks (r^2= 0.33; p = 0.05).

By year 17, red alder TPH had dropped to 120 TPH in the early-seral treatment and 8 TPH in the Douglas-fir plantation treatment. Alternatively, Douglas-fir TPH increased from the last measurement in year 7 to a mean of 450 TPH in the early-seral treatment and 408 TPH in the Douglas-fir treatment, presumably from naturally regenerated seedlings. Similar to the year 7 measurement, there was no difference in Douglas-fir TPH despite the early-seral treatment starting with half as many Douglas-fir trees planted (p=0.70). There was a substantial increase in quantities of western hemlock by year 17, with a mean of 1809 TPH in the early-seral treatment and 1270 TPH in the Douglas-fir treatment, but without statistical significance between the two treatments. However, there was a significant interaction effect between the treatment and block. Similar to the year 7 measurement, early-seral units in block four had greater numbers of western hemlock trees (r^2 = 0.53; p= 0.015).

One year after the year 17 measurement, a pre-commercial thin (PCT) was completed in these stands and removed many small trees and saplings, with a focus on reducing western hemlock. By year 25, the number of Douglas-fir trees growing in the two treatments had dropped to 292 TPH in the early-seral treatment and 384 TPH in the Douglas-fir plantation treatment (Figure 2.2). The number of red alders dropped in both treatments, continuing the trend of red alder mortality over time. In year 25, the Douglas-fir treatment had a mean of only 10 TPH of red alder, while the early-seral treatment, that started with densities equaling that of Douglas-fir, was down to 91 TPH. The red alder trees had a mean diameter of 18 cm in the Douglas-fir plantation treatment and 22 cm in the early-seral treatment, with more TPH (r^2= 0.41, p = 0.001) in the early-seral treatment.

Due to the PCT, the quantities of western hemlock trees decreased in both treatments by year 25. The majority of western hemlock trees were small with a mean diameter of 11 cm (Table 2.3). There were no significant differences in TPH (p = 0.43) of western hemlock between the treatments with a mean of 466 in the early-seral treatment and 412 in the Douglas-fir plantation treatment (Figure 2.2).

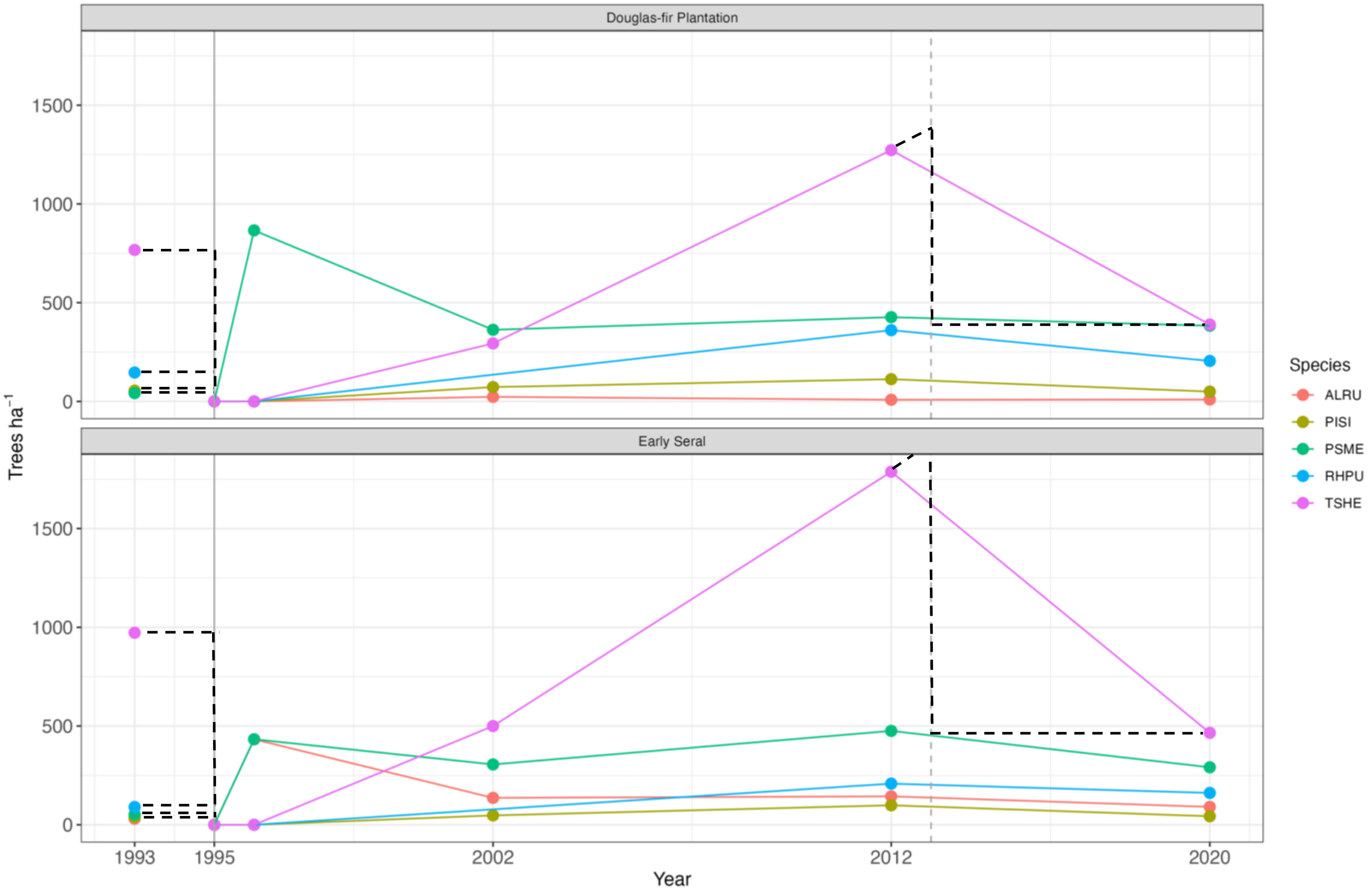


Figure 2.2: Changes in tree-sized indivudals (including smaller planted trees) per hectare (TPH) in Douglas-fir plantation and early-seral treatments at the four measurement years: pre-treatment (1993), year 7 (2002), year 17 (2012), year 25 and (2020). Sold gray line indicates the year treatments were implemented. Dashed gray line indicates when pre-commercial thinning occurred in these treatments. Dashed black lines indicate the projected trajectory based on harvesting and PCT knowledge. Some uncommon tree species were not included in this figure to help with visualization. This includes species such as crab apple (*Malus fusca* (Raf.) C.K. Schneid), vine maple (*Acer circinatum* Pursh), and Pacific silver fir (*Abies amabilis* (Dougl. Ex Loud.) Dougl.). Species labels are as follows: ALRU= red alder; PISI= Sitka spruce; PSME= Douglas-fir; RHPU= cascara; and TSHE= western hemlock.

2.4.1.2 Tree Mortality

Over the following two decades, significant mortality in both tree species occurred in each treatment following the initial planting densities of 433 TPH (175 TPA) of Douglas-fir and red alder in the early-seral treatment and 866 TPH (350 TPA) of Douglas-fir in the Douglas-fir plantation treatment. In the early-seral treatment, 136 TPH of red alder remained at year 7, which included all planted seedlings and any ingrowth meeting the tree criteria (>3.5 cm in DBH and >136 cm in height), suggesting a 69% or greater loss in red alder within the first 7 years post-planting. Additionally, in the early-seral treatment, Douglas-fir density dropped to a mean of 307 TPH (including both planted and any ingrowth trees meeting the criteria), indicating a 29% or greater mortality rate. In the Douglas-fir treatment in year 7, mortality of Douglas-fir trees (both planted and any ingrowth) had a mean of 58% or more (Table 2.3).

There was additional mortality of red alder between years 7 and 17. An average of 12% of the red alder trees growing in the early-seral treatment and 70% of the red alder growing in the Douglas-fir treatment had died between years 7 and 17. Douglas-fir quantities increased from the previous measurement, indicating additional ingrowth that had achieved tree size (>3.5 cm DBH) between years 7 and 17.

There was additional Douglas-fir mortality in both treatments by year 25 with a 6% reduction in the Douglas-fir plantation treatment and a 35% reduction in the early-seral treatment. Red alder mortality continued in the early-seral treatment with a 24% reduction in alder compared to year 17. By this time, the density of Douglas-fir and red alder was far lower than the initial prescription with the Douglas-fir plantation treatment having only 44% of the intended Douglas-fir trees and the early-seral management treatment having 21% of intended red alder and 67% of the intended Douglas-fir trees.

2.4.1.3 Basal Area

Before treatments were implemented, there were no significant differences in basal area (BA) between stands in future treatment units or between blocks. Mean BA was 59.5 $\mathrm{m^2ha^{-1}}$. Seven years after implementation, the early-seral treatment units had greater BA compared to the Douglas-fir treatment (r^2 = 0.37; p = 0.002), suggesting a small boost in total productivity presumably resulting from alder soil benefits. In addition, there were differences in BA between blocks with block 4 having greater BA than the other blocks ($r^2 = 0.33$; p = 0.04; Figure 2.3). Seventeen years after implementation however, the differences between treatments and blocks were gone. This lack of difference continued to year 25 where there were no differences in BA between treatments or blocks with a mean of 25.8 and 24 $\mathrm{m^2ha^{-1}}$ in the early-seral and Douglas-fir treatments respectively.

2.4.1.4 LiDAR-derived Tree Height

Although we do not have ground measurements between years 17 and 25, the aerial-LiDAR, taken at year 20 allowed us to determine tree height. From these tree heights, we subset the tallest 20% of trees from each unit to detect differences between treatments and found a height range from 12 m (40 ft) to 16 m (52 ft). These trees were most likely Douglas-fir and some alder based on DBHs. Using the subset data of the tallest 20% of trees, we found that there was a significant interaction effect with treatment and block with trees in the early-seral treatment of block four growing significantly taller than those in other blocks and treatments (r^2= 0.54; p= 0.05). This analysis is only suggestive of differences in site index since the tree height analysis was not species specific.

2.4.1.5 Aboveground Tree Biomass

Seven years after implementation, there were statistically significant differences in total biomass between the early-seral management and Douglas-fir plantation treatments with 1.8

Mg ha^{-1} and 0.4 Mg ha^{-1} respectively (r^2= 0.35; p= 0.002). In addition, there were differences between blocks with block four having the highest biomass (r^2= 0.31; p= 0.05). The interaction effect of treatment and block was also significant with early-seral units in block four having the highest levels of biomass in year 7 (r^2= 0.77; p= 0.0004; Figure 2.3). The results at year 7 suggest a possible alder effect, although other factors are involved such as significantly less Douglas-fir and red alder mortality in block four early-seral units that could have resulted in higher biomass compared to the other blocks. By year 17, those differences had disappeared and there was no difference between biomass of the two treatments. The early-seral management treatment had 50.6 Mg ha^{-1} and the Douglas-fir management treatment had 49.5 Mg ha^{-1}. This trend continued in year 25 with no detected differences. The early-seral management treatment had 130.6 Mg ha^{-1} while the Douglas-fir treatment had 131.8 Mg ha^{-1}.

2.4.1.6 Block Effect

There were significant differences between blocks that were evident in both the pre- and post-treatment conditions. In the 1993 pre-treatment measurement, soil carbon and nitrogen concentration in both the O and A horizons were significantly higher in block four compared to the other blocks. In addition, soil mass and rock content greater than 4mm were significantly lower in the O and A horizons in block four compared to the other blocks. When evaluating alder mortality in year 7, we found that the block variable was a significant predictor, with block four having significantly less mortality (r^2= 0.71; p= 0.01). Alder mortality in year 7 had a significant negative relationship with the 1993 soil carbon and nitrogen data, where areas of higher alder mortality had less soil carbon and nitrogen. Douglas-fir mortality was not significantly different between blocks. However, when evaluating the interaction effect of block and treatment on mortality, the early-seral treatment units in block four has significantly less Douglas-fir mortality

(r^2= 0.54; p= 0.003). Additionally, in year 7, basal area and tree biomass was greater in block four compared to the others. Even more significant was the interaction effect of block and treatment with early-seral units in block four having far higher basal area (r^2= 0.81; $p < 0.00001$; Figure 2.3).

By year 17, most of these block effects were no longer evident. This trend also continued through year 25, although this was affected strongly by the PCT. Alder and Douglas-fir mortality as well as alder, Douglas-fir, and hemlock TPH were not different between blocks. However, the interaction effect of the block and treatment was significant in Douglas-fir mortality, with early-seral units in block four having less mortality in year 25 (r^2= 0.54; p= 0.05). In addition, the lower alder mortality seen in block four in year 7 changed by year 25, with this block having higher mortality comparable to the other blocks making it not significantly different.

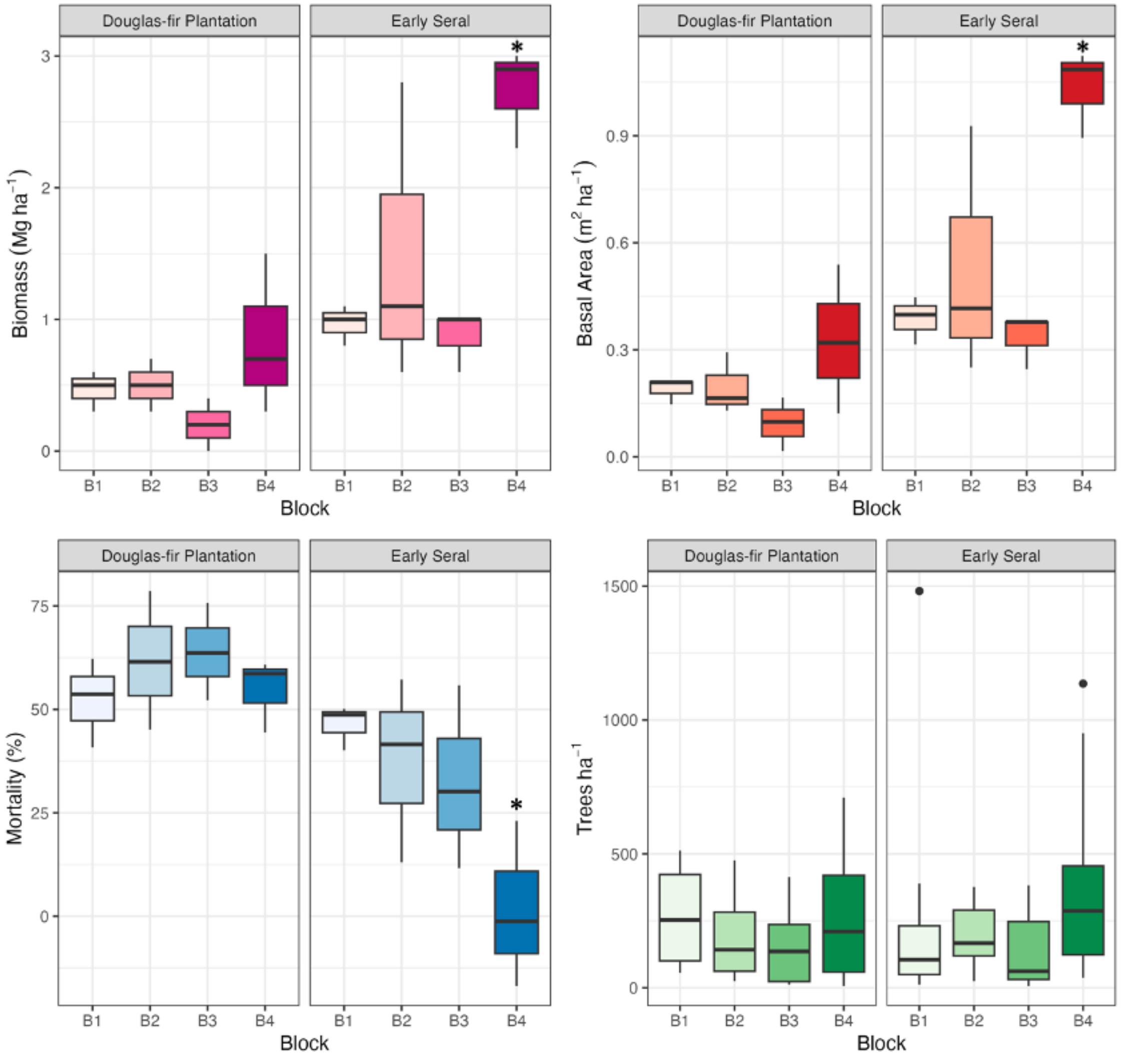


Figure 2.3: Results from seven years after treatments were implemented, including biomass (Mg ha^{-1}; top left), basal area ($m^2 ha^{-1}$; top right), mortality (%) of Douglas-fir trees (bottom left), and trees per hectare (bottom right) by block and silviculture treatment. * indicates a significant difference at $p < 0.05$.

Metric	Treatment	Species	7 years	17 years	25 years
TPH	Douglas-fir Plantation	PSME	363	408	384
		ALRU	27	8	10
		TSHE	269	1270	412
		Other hardwoods	N/A	262	264
		Other conifers	54	102	49
		Total/ha	713	2155	1157
	Early-seral	PSME	307	450	292
		ALRU	136	120	91
		TSHE	500	1809	466
		Other hardwoods	N/A	174	210
		Other conifers	36	41	32
		Total/ha	980	2604	1094
DBH (cm)	Douglas-fir Plantation	PSME	1.9	14.4	25.6
		ALRU	1.9	11.0	17.9
		TSHE	0.9	5.7	10.6
	Early-seral	PSME	2.3	12.9	26.4
		ALRU	5.4	14.2	22
		TSHE	0.8	5.7	11.0
Basal Area ($m^2 ha^{-1}$)	Douglas-fir Plantation	PSME	0.1	8.3	18.6
		ALRU	0	0.1	0.2
		TSHE	0.1	3.6	4.3
		Other hardwoods	0	0.5	0.5
		Other conifers	0	0.2	0.3
		Total/ha	0.2	13.3	24
	Early-seral	PSME	0.2	6.5	16.3
		ALRU	0.4	2.1	3.4
		TSHE	0	4.9	5.3
		Other hardwoods	0	0.4	0.4
		Other conifers	0	0.1	0.3
		Total/ha	0.6	14	25.8
Tree Biomass ($Mg\ ha^{-1}$)	Douglas-fir Plantation	Total (mg/ha)	0.4	49.5	131.8
	Early-seral	Total (mg/ha)	1.8	50.6	130.6
Initial Seedling Mortality (%)	Douglas-fir Plantation	PSME	58%		
		ALRU	N/A		
	Early-seral	PSME	29%		
		ALRU	69%		

Table 2.3: Mean TPH, DBH (cm), basal area ($m^2 ha^{-1}$), biomass (Mg ha^{-1}), and initial seedling mortality in the early-seral and Douglas-fir treatments at years 7, 17, and 25 and species codes are as follows: PSME (Douglas-fir), ALRU (red alder), and TSHE (western hemlock)

2.4.2 Seedling regeneration

One year following treatment implementation there were large quantities of small, under 30 cm seedlings growing in the both treatments with a mean of approximately 31,300 and 17,700 ha^{-1} growing in the early-seral and Douglas-fir plantation treatment respectively. By contrast, there were no saplings (136+ cm in height) at this time (Figure 2.4).

By year 7, there was a decrease in the number of seedlings under 30 cm in height in both treatments. However, some of these seedlings may have died and others likely grew larger and were part of the next height classification by this measurement year. There was an increase in the number of seedlings 30-136 cm in height by year 7 in both treatments. In addition, by this time there were a mean of 1850 and 1700 saplings ha^{-1} growing in the early-seral and Douglas-fir plantation treatment respectively. Overall, there were significant differences in quantities of seedlings and saplings between early-seral and Douglas-fir plantation treatments, with the early-seral treatment having a greater number by this time (Table 2.4).

A PCT was done in year 18, removing many of the smaller hemlock trees and possibly saplings. This wave of seedlings, saplings, and small hemlock trees growing at this time were knocked back, but were followed by another wave of mostly hemlock seedlings and saplings returning after the PCT. At the next measurement in year 21, numerous seedlings < 30 cm were growing with 24,500 and 25,000 individuals ha^{-1} growing in the early-seral and Douglas-fir plantation treatments respectively. However, there were fewer seedlings <30 cm and between 30-136 cm in block four compared to the other blocks, showing some site-specific differences.

Three years after the PCT, there were still 2,600 and 2,250 saplings ha^{-1} in the early-seral and Douglas-fir plantation treatments respectively (Figure 2.4).

Lastly, we analyzed the potential relationship between sapling density and tree mortality in year 7 to determine if the number of seedlings growing and competing for resources was related to tree mortality. The analysis showed that Douglas-fir and alder mortality were not connected to sapling growth ($p > 0.05$). In fact, there was a positive relationship between quantity saplings and hemlock TPH in year 7 (r^2=0.55; $p < 0.0001$).

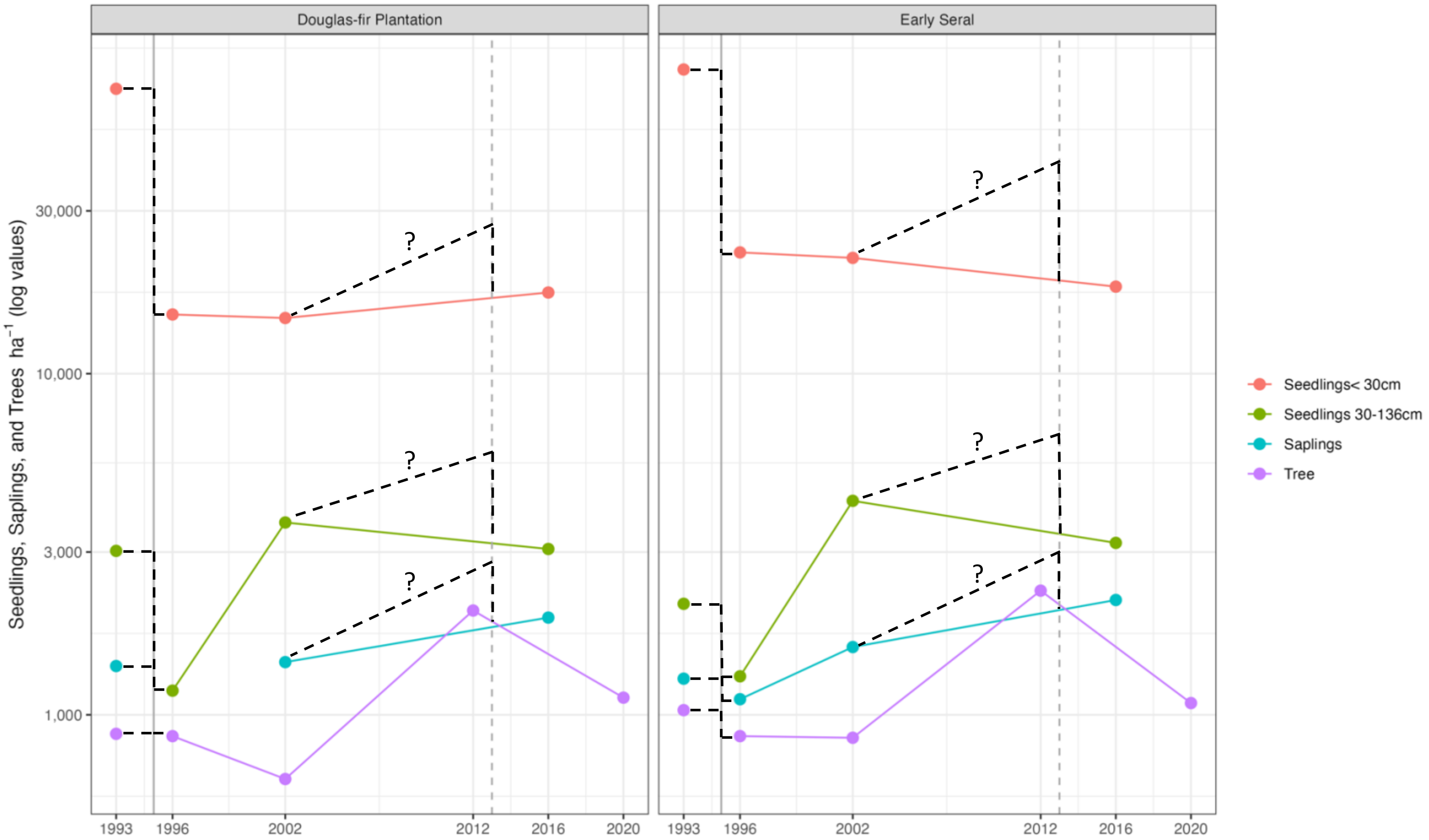


Figure 2.4: Changes in understory seedling and sapling regeneration and tree (must be >3.5 cm in diameter and greater than 136 cm in height) density across both treatments through time. Sold gray line indicates the year treatments were implemented. Dashed gray line indicates when pre-commercial thinning occurred in these treatments. Dashed black line were added to account for known changes from the initial harvest and leading up to a year 17 PCT. Due to the fact that no seedling and sapling measurements occurred right before PCT, these black dashed lines are intended to help visualize the projected totals. Planted Douglas-fir and red alder values are included in the tree classification and there may be some overlap with measured saplings in year 7 (2002). A logrithmic scale is used to observe all changes at the same time.

Table 2.4: Results from the PERMANOVA tests with relativized seedling matrices with a series of explanatory variables, including all understory functional group cover data, using 1000 permutations and Euclidean distance measures where pre-treatment data were collected in 1993 followed by post-treatment data in years 1, 7, and 21 Significance is noted as: * p < 0.05; ** p < 0.01; and *** p < 0.001

	Pre-treatment		Year 1		Year 7		Year 21	
	F-Statistic	R^2	F-Statistic	R^2	F-Statistic	R^2	F-Statistic	R^2
Silviculture treatment	1.42	0.05	2.56	0.08	7.05	0.15*	0.47	0.02
Woody debris treatment	1.73	0.06	0.93	0.03	1.26	0.03	0.88	0.04
Block	1.07	0.1	0.81	0.08	4.24	0.27**	2.55	0.34*
Silviculture x wood treatments	0.70	0.02	0.44	0.01	6.74	0.14*	0.41	0.02
Graminoid	3.42	0.11*	0.36	0.01	0.54	0.01	1.04	0.05
Forb	0.89	0.03	0.67	0.02	0.53	0.01	1.47	0.07
Evergreen fern	0.08	0.003	3.20	0.10*	0.56	0.01	0.76	0.03
Deciduous fern	0.7	0.02	1.95	0.06	5.06	0.11*	0.39	0.02
Evergreen shrub	2.23	0.07	1.16	0.04	1.90	0.04	1.31	0.06
Deciduous shrub	5.59	0.18***	6.59	0.21*	0.54	0.01	1.27	0.06

2.4.3 Understory regeneration

In each of the post-treatment measurement years, there was not a significant difference between understory cover (separated by functional group types) in either the Douglas-fir plantation or the early-seral treatments as well as the woody debris treatments (Figure 2.4). Although, there was a statistically significant difference in understory cover between blocks in each measurement year both pre- and post-treatment implementation. In year 7, evergreen fern and evergreen shrub cover was higher in block four compared to the other blocks. In year 21, evergreen shrub was highest in block three and forbs were significantly higher in block two. In addition, in year 21 there was an interaction effect between block and treatment with block four in the early-seral treatment having significantly less understory cover (r^2=0.04 , $p < 0.0001$). In addition, there were significant differences between salal cover in year 21, with blocks two and four having significantly less salal cover than the other two blocks (r^2=0.23; $p < 0.0001$).

In year 7, forb abundance was at its peak with a mean of 21% and 22% in the Douglas-fir plantation and early-seral treatments respectively. In year 21, ferns and shrubs had increased in abundance with deciduous ferns and evergreen shrubs, salal and bracken fern in particular, making up the majority of the understory. The growth of seedlings in any height classification was not a significant explanatory variable for understory growth in any year (Table 2.5).

Table 2.5: Results from the PERMANOVA tests with relativized understory cover matrices with a series of explanatory variables using 1000 permutations and Bray-Curtis dissimilarity measures where pre-treatment data were taken in 1993 followed by post-treatment data in years 1, 7, and 21. Significance is noted as: * p < 0.05; ** p < 0.01; and *** p < 0.001

	Pre-treatment		Year 1		Year 7		Year 21	
	F-Statistic	R^2	F-Statistic	R^2	F-Statistic	R^2	F-Statistic	R^2
Silviculture treatment	0.72	0.02	0.93	0.03	1.16	0.04	0.46	0.02
Woody debris treatment	3.99	0.11**	1.01	0.03	0.89	0.03	0.81	0.04
Block	4.44	0.35***	2.22	0.23*	4.03	0.37***	2.77	0.36*
Silviculture x wood treatments	0.76	0.02	3.35	0.11*	0.63	0.02	0.57	0.03
Seedlings < 30 cm	2.25	0.06	1.15	0.04	1.58	0.05	1.07	0.05
Seedlings 30-136 cm	1.56	0.04	1.84	0.06	0.99	0.03	0.60	0.03
Seedlings > 136 cm	1.11	0.03	0.64	0.02	1.80	0.05	1.09	0.05

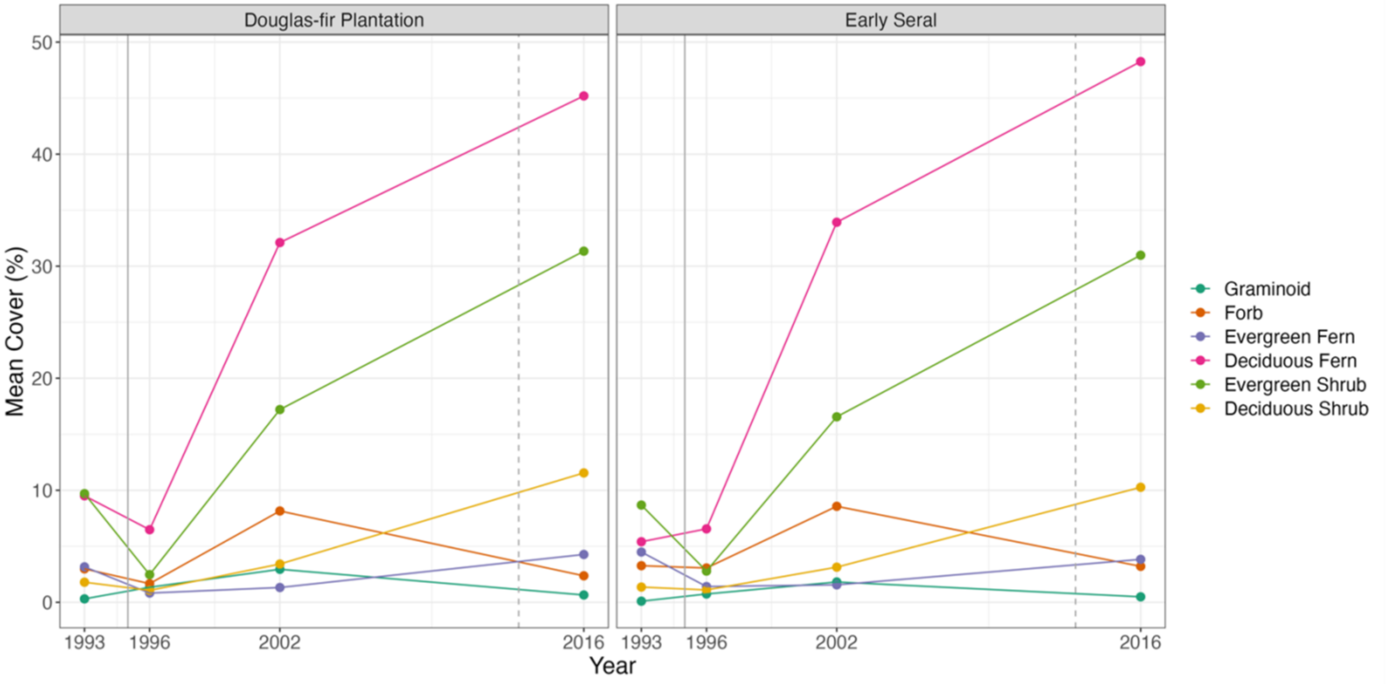


Figure 2.4: Changes in understory regeneration in Douglas-fir plantation and early-seral treatments from pre-treatment in 1993 to 2016 (year 21) separated by functional group type. Sold gray line indicates the year treatments were implemented. Dashed gray line indicates when pre-commercial thinning occurred in these treatments.

2.4.4 Relationship between red alder and salal

Though red alder was planted in the early-seral treatment, it also naturally regenerated in small quantities in the Douglas-fir plantation treatment. In year 20, the total alder cover (derived from aerial LiDAR) within understory plots and buffer ranged from 0% to 52% with a mean of 13% in the early-seral treatment and 0% to 31% with a mean of 3% in the Douglas-fir plantation treatment. Due to the presence of red alder in both silviculture treatments, we included all units in the red alder analysis. Salal had the highest abundance of any understory species in the study by year 21 with a mean of 50% in the early-seral treatment and 56% in the Douglas-fir plantation treatments.

A statistically significant and negative relationship between understory and red alder cover was found at year 20 and 21 (alder and understory cover respectively; $r^2= 0.05$, $p = 0.0003$). Although, upon further analysis, when all salal cover was removed from the understory dataset, this relationship dissapears ($p =0.90$), indicating that salal is influencing the negative relationship. Furthermore, when comparing salal and red alder directly through a linear regression, there was a negative correlation between the two ($r^2=0.098$, $p < 0.0001$), even more so than when evaluating all understory cover in relation to red alder. When evaluating the interaction effect of experimental unit and red alder to salal cover, results indicated a strong negative correlation ($r^2= 0.40$, $p < 0.0001$; Figure 2.5).

When evaluating the relationship between species richness and red alder cover, we found there was not a significant correlation ($p = 0.81$), unlike that observed by Hanley (et al. 2006) where their stands had much higher alder cover compared to the LTEP site. However, we observed differences in species richness within experimental units, indicating there is variation at a fine spatial scale. When evaluating understory biomass, we found red alder and variation within the experimental units were both significant predicators, but the interaction effect of these two resulted in the strongest correlation ($r^2 = 0.44$, $p < 0.0001$). Red alder cover and biomass had a negative relationship, most likely because salal is a substantial part of that biomass.

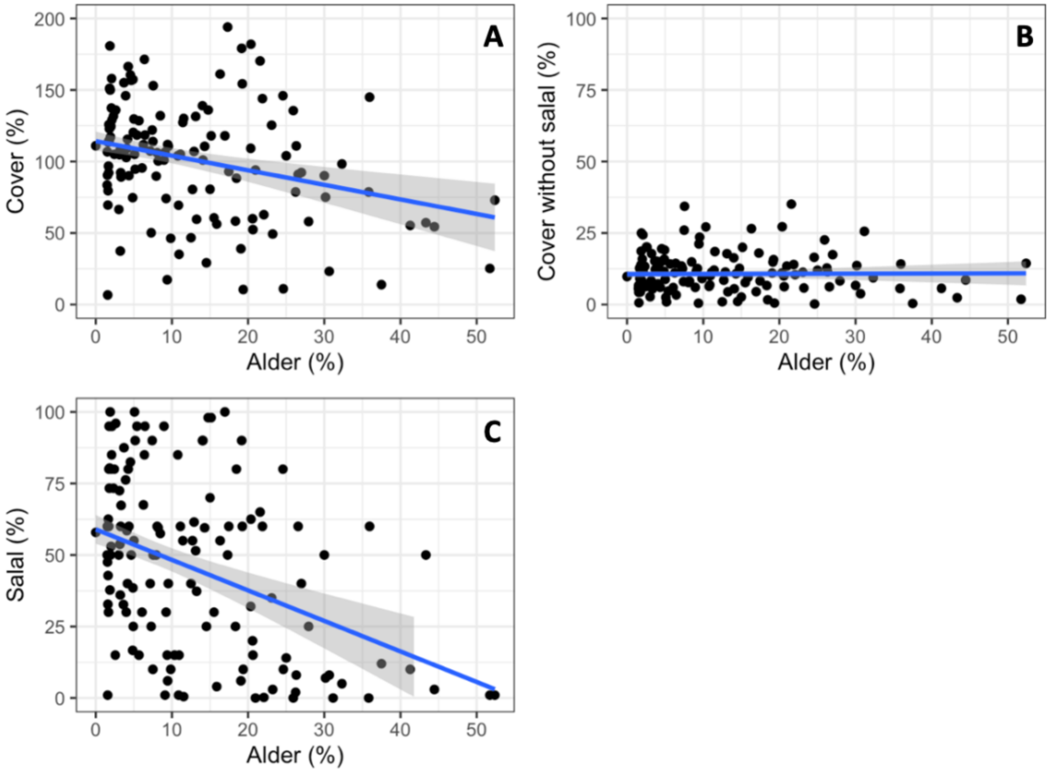


Figure 2.5: The relationship between all understory cover (A), understory cover excluding all salal cover (B), and only salal cover (C) in relation to the total cover of red alder using year 21 understory data and year 20 (2015) aerial LiDAR to derive alder cover.

2.5 DISCUSSION

In this study, we analyzed changes and interactions between the overstory, understory, and potential relationship between red alder and biomass, biodiversity, and understory species development over the first 25 years of a long-term ecosystem productivity experiment. Results indicate similarities between silviculture treatments over time, but differences in initial site conditions between blocks.

2.5.1 The first 25 years of overstory growth

Results of this study clearly show initial pre-treatment soil differences between blocks leading to significant differences in the overstory in early stand development. Blocks were selected based largely on proximity. Researchers noted that there did not appear to be any large differences between blocks prior to treatment implementation. However, based on soil analysis, we found that block four had significantly higher concentrations of nitrogen and carbon, lower rock content, and lower soil mass. In addition, significant differences emerged through this analysis with the early-seral block four units having higher tree biomass, higher basal area, and lower Douglas-fir and red alder mortality by year 7.

Although there were site differences in block four that likely contributed to these clear differences, the interaction effect of the early-seral treatment with this block suggests that the addition of red alder also contributed to these initial stand results. Many other studies have noted significant differences in productivity and growth of understory and/or overstory when red alder is growing with other crop conifer trees (Hanley et al. 2006, Deal et al. 2017). For example, a study by Fang et al. (2019) in coastal Southwest British Columbia indicated that up to 400 TPH of red alder in stands benefitted the growth of Douglas-fir.

Studies at the Wind River Experiment Forest have seen significantly higher stem biomass, tree height, and growth rates in stands with a mixture of red alder after stand-replacing fires have limited soil nutrients, which is evident even decades after alder die back (Tarrant 1961, Binkley 2003, Bormann et al. 2023). However, in stands where soils are productive for Douglas-fir, other studies have showed mixtures of red alder and Douglas-fir have not resulted in substantial differences in growth compared to monocultures (Binkley 2003, Moore et al. 2011).

In this study, the differences in the early-seral block four units that were clear in year 7 had disappeared by year 17 and continued through year 25. There were no significant differences in biomass, TPH, or basal area. This could be due to the initial and continued alder mortality that occurred over time, dramatically reducing the intended TPH of alder in the early seral treatment and limiting the benefits that alder can have on stand growth. When analyzing the tallest 20% of trees derived from the aerial LiDAR, most of which are likely Douglas-fir with some alder, we determined that early-seral units in block four had significantly taller trees. Although there are no significant differences in the other metrics, differences in tree height could signify that there may be a divergence in the future where the early-seral block four units may outperform others. Future monitoring and analysis will help to shed light on this. In addition, further studies could evaluate the influence of red alder on Douglas-fir growth on finer spatial scales to determine if localized available N under growing red alder may enhance nearby conifer growth.

2.5.2 Understory regeneration over time

Red alder can fix N_2 via its root nodules and provide localized N for nearby plants, contribute to nutrient cycling through its deciduous leaves, and contribute to increased soil microbial activity and soil organic matter (Tarrant and Miller 1963, Selmants et al. 2005). In addition, many studies have found correlations between red alder presence and increased understory biomass and richness (Hanley and Barnard 1998, Hanley et al. 2006). Our study did not confirm this pattern. We did see a negative relationship between red alder and understory biomass. Site differences between experimental units, more so than red alder, seemed to account for more of a difference in both understory biomass and richness.

The negative relationship seen between red alder and salal cover may not be due to direct competition between these two species. Salal grows well in nutrient poor environments with low soil nitrogen levels, where it can quickly spread via its rhizomes (Bennett et al. 2002). Alternatively, red alder will fix N_2 and create nutrient rich soils (Radwan et al. 1984), generating habitat that is not ideal for salal growth. Although salal can provide benefits for local community members who harvest its stems for the floral industry (Ballard and Huntsinger 2006), it does not provide many other ecosystem benefits. Its evergreen leaves do not provide quality nutrients for ungulates, it does not meaningfully contribute to soil nutrient cycling, and it can inhibit the growth of nearby plants, especially western hemlock, an important timber species that naturally regenerates in this region (Mallik and Prescott 2001, Tappeiner et al. 2001, Martin et al. 2010b). To prevent the spread of salal on site, as well as creating other benefits as described above, planting red alder as part of the timber crop rotation could be part of the solution. If the intended red alder densities were retained through the first 25 years, it is possible we could have seen a further suppression of salal in these stands.

The understory analysis provide insight on the changes in functional group cover over time. These changes follow typical successional patterns with the growth of sun-dependent graminoids and forbs following treatment implementation that declined over time as woody shrubs and ferns grew, shading out the forest floor (Franklin et al. 2002b). Similar to the overstory analysis, seedlings and understory composition varied based on block. Block four early-seral units showed significantly less salal cover, understory cover, and seedlings by year 21. This suggest that microclimate, soil, or other ecological factors may be creating differences in these units that are affecting understory cover and seedling regeneration (Hanley and Brady 1997).

On the west side of the Olympic Peninsula, copious amounts of western hemlock seedlings naturally regenerate following disturbance and timber harvest. In this study, we saw a first wave of 31,300 and 17,700 ha^{-1} seedlings under 30 cm growing in the early-seral and Douglas-fir plantation treatment respectively by year 7 followed by a second wave of 24,500 and 25,000 ha^{-1} growing in the early-seral and Douglas-fir plantation treatments respectively year 21, three years after PCT. Even with some expected mortality of planted crop seedlings following logging, this quantity of regenerating seedlings is far more than necessary, taking up space and nutrients that could be used by other understory species that has value to wildlife and local communities for personal, cultural, or commercial use. Considering alternative management strategies that promotes diverse understory composition and limits excess natural seedling and sapling regeneration through adaptive management studies could provide future insight and potentially reduce the need for a PCT.

These long-term studies spanning across ecosystems are uncommon and there is much information to be gleaned from regular remeasurement of these sites. Although changes are already occurring, it would be unwise to extrapolate that information too far into the future. Instead, future monitoring can continue to push the needle forward in our understanding of dynamic forest ecosystems and work to inform management.

2.6 CONCLUSIONS

The LTEP study was established as an adaptive management research site to test new and innovative approaches to forest management. When it was implemented, the goal was to have each site continue to be managed and monitored for 200 years, allowing for a long-term picture of how ecological processes change throughout decades and centuries. After 25 years, differences have already emerged that have implications for management.

A key conclusion from this study was the large differences in mortality, biomass, basal area, and understory between blocks. Despite initial conditions appearing similar, soil sampling showed one region to have higher concentrations of nitrogen and carbon, leading to more successful treatments. This, combined with the addition of red alder in this early-seral treatment, led to higher BA, taller trees, and greater biomass. Going forward, additional consideration could be made on initial site conditions and the impact it can have on stand development. In addition, the presence of red alder may be limiting the growth of salal, a dominating understory species that provides limited ecosystem values and can inhibit the growth of other understory species.

Continued monitoring of this site will only increase our understanding of successional patterns of overstory and understory in this region.

2.7 REFERENCES

Ballard, H. L., and L. Huntsinger. 2006. Salal harvester local ecological knowledge, harvest practices and understory management on the Olympic Peninsula, Washington. *Human Ecology* 34(4):529–547.

Bennett, J. N., B. Andrew, and C. E. Prescott. 2002. Vertical fine root distributions of western redcedar, western hemlock, and salal in old-growth cedar–hemlock forests on northern Vancouver Island. *Canadian Journal of Forest Research* 32(7):1208–1216.

Binkley, D. 2003. *Seven decades of stand development in mixed and pure stands of conifers and nitrogen-fixing red alder*. Page *Canadian Journal of Forest Research*.

Bormann, B. T., C. R. Bobsin, R. J. McGaughey, J. C. Gordon, B. A. Morrissette, and A. Kruper. 2023. The Wind River alder strip revisited: Lessons for post-fire management on recent and future western Washington and Oregon fires. *Forest Ecology and Management* 537:120959.

Bunnell, F. L. 1990. Ecology of black-tailed deer. Page *in* J. B. Nyberg and D. W. Janz, editors. B.C. Ministries of Forests and Environment, Victoria, B.C.

Chojnacky, D. C., L. S. Heath, and J. C. Jenkins. 2014. Updated generalized biomass equations for North American tree species. *Forestry* 87(1):129–151.

Cortini, F., P. G. Comeau, T. Wang, D. E. Hibbs, and A. Bluhm. 2012. Climate effects on red alder growth in the Pacific Northwest of North America. *Forest Ecology and Management* 277:98–106.

Deal, R. L., C. D. Oliver, and B. T. Bormann. 1991. Reconstruction of mixed hemlock-spruce stands in coastal southeast Alaska. *Canadian Journal of Forest Research* 21:643–654.

Deal, R. L., E. H. Orlikowska, D. v. D'Amore, and P. E. Hennon. 2017. Red alder-conifer stands in Alaska: An example of mixed species management to enhance structural and biological complexity. *Forests* 8(4).

Fang, C., P. G. Comeau, and G. J. Harper. 2019. Effects of red alder on growth of Douglas-fir and western redcedar in southwestern British Columbia. *Forest Ecology and Management* 434:244–254.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155:399–423.

Frey, G. E., J. L. Chamberlain, and M. G. Jacobson. 2021. Producers, production, marketing, and sales of non-timber forest products in the United States: a review and synthesis. Springer Science and Business Media B.V.

Hanley, T. A., and J. C. Barnard. 1998. Red Alder, Alnus rubra, as a potential mitigating factor for wildlife habitat following clearcut logging in southeastern Alaska. *Canadian Field-Naturalist* 112(4):647–652.

Hanley, T. A., and W. W. Brady. 1997. Understory species composition and production in old-growth western hemlock - Sitka spruce forests of southeastern Alaska. *Canadian Journal of Botany* 75(4):574–580.

Hanley, T. A., R. L. Deal, and E. H. Orlikowska. 2006. Relations between red alder composition and understory vegetation in young mixed forests of southeast Alaska. *Can. J. For. Res.* 36(3):738–748.

Homann, P. S., B. T. Bormann, J. R. Boyle, R. L. Darbyshire, and R. Bigley. 2008. Soil C and N minimum detectable changes and treatment differences in a multi-treatment forest experiment. *Forest Ecology and Management* 255(5–6):1724–1734.

Kruper, A., R. J. McGaughey, S. Crumrine, B. T. Bormann, K. Bennett, and C. R. Bobsin. 2022. Using Airborne LiDAR to Map Red Alder in the Sappho Long-Term Ecosystem Productivity Study. *Remote Sensing* 14(7):1591.

Legendre, P., and M. J. Anderson. 1999. Distance-Based Redundancy Analysis: Testing Multispecies Responses in Multifactorial Ecological Experiments. *Ecological Monographs* 69(1):1–24.

Mallik, A. U., and C. E. Prescott. 2001. Growth Inhibitory Effects of Salal on Western Hemlock and Western Red Cedar. *Agronomy Journal* 93:85–92.

Martin, J. L., S. A. Stockton, S. Allombert, and A. J. Gaston. 2010a. Top-down and bottom-up consequences of unchecked ungulate browsing on plant and animal diversity in temperate forests: Lessons from a deer introduction. *Biological Invasions* 12(2):353–371.

Martin, J. L., S. A. Stockton, S. Allombert, and A. J. Gaston. 2010b. Top-down and bottom-up consequences of unchecked ungulate browsing on plant and animal diversity in temperate forests: Lessons from a deer introduction. *Biological Invasions* 12(2):353–371.

McCune, B., and J. Grace. 2002. Analysis of ecological communities. MJM Software Design, Gleneden Beach, OR.

Moore, G. W., B. J. Bond, and J. A. Jones. 2011. A comparison of annual transpiration and productivity in monoculture and mixed-species Douglas-fir and red alder stands. *Forest Ecology and Management* 262(12):2263–2270.

NOAA. 2023. National Weather Service.

Perakis, S. S., J. J. Matkins, and D. E. Hibbs. 2012. N 2-Fixing Red Alder Indirectly Accelerates Ecosystem Nitrogen Cycling 15(7):1182–1193.

Radwan, M. A., C. A. Harrington, and J. M. Kraft. 1984. Litterfall and nutrient returns in red alder stands in western. *Plant and Soil* 79(3):343–351.

Royo, A. A., and W. P. Carson. 2006. On the formation of dense understory layers in forests worldwide: consequences and implications for forest dynamics, biodiversity, and succession. *Canadian Journal of Forest Research* 36:1345–1362.

Selmants, P. C., S. C. Hart, S. I. Boyle, and J. M. Stark. 2005. Red alder (Alnus rubra) alters community-level soil microbial function in conifer forests of the Pacific Northwest, USA. *Soil Biology and Biochemistry* 37(10):1860–1868.

Tappeiner, J. C., I. ; Zasada, J. C. Huffman, D. W. ; Ganio, and Lisa M. 2001. Salmonberry and salal annual aerial stem production: The maintenance of shrub cover in forest stands. *Canadian Journal of Forest Research* 31:1629.

Tarrant, R. F. 1961. Stand development and soil fertility in a Douglas-fir red alder plantation . *Forest Science* 7:238–246.

Tarrant, R. F., and R. E. Miller. 1963. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. *Soil Science of America* 27(2):231–234.

Teklehaimanot, Z., and R. M. Mmolotsi. 2007. Contribution of red alder to soil nitrogen input in a silvopastoral system. *Biology and Fertility of Soils* 43(6):843–848.

Thomas, J. W., and D. E. Toweill. 1982. *Elk of North America : Ecology and Management*. A Wildlife Management Institute Book.

Yildiz, O., K. Cromack, S. R. Radosevich, M. A. Martinez-Ghersa, and J. E. Baham. 2011. Comparison of 5th- and 14th-year Douglas-fir and understory vegetation responses to selective vegetation removal. *Forest Ecology and Management* 262(4):586–597.

Chapter 3: Ethnoforestry field trials: expanding adaptive management approaches to early-seral stands on the Olympic Peninsula, WA.

3.1 ABSTRACT

In the Pacific Northwest, forest stands managed for timber on private and public lands are typically planted with tightly spaced Douglas-fir seedlings with controls on competing vegetation to produce a timber crop in 40-50 years. This short rotation approach is designed to achieve crown closure quickly and by doing so truncates the early-seral stage, limiting the growth and abundance of sun-dependent understory plants. Wildlife adapted to these plants and conditions, especially ungulates and some birds and insects, are indirectly impacted. In addition, understory species that are valuable to nearby communities and tribes who harvest for cultural, semi-commercial, or personal needs are also less available. In an uncertain future with changing climate and societal needs, it is critical to explore alternative approaches to forest management that can expand our toolbox. This study uses ethnoforestry approaches, or people-focused forest management, to explore new methods of managing understory and timber seedlings together in recently harvested stands on the Olympic Peninsula, WA to benefit both environment and community wellbeing.

We used a randomized-block factorial design to study vegetation and browse-control treatments with blocks based on quantities of downed wood. Monitoring was completed one-year and two-years after planting and included tracking 1.) planted understory; 2.) planted Douglas-fir and red alder seedlings; 3.) natural regenerating understory; and 4.) natural regenerating tree seedlings. First- and second-year results showed significant mortality of planted understory, which varied based on species, and planted seedlings. Mortality of both planted understory and tree seedlings were not significantly different between treatments. In addition, tree seedling

mortality decreased as the amount of naturally regenerating understory increased, indicating that understory competition is not driving mortality in any way.

The feasibility of planting understory species is called into question by high mortality, however unusual extreme heat and drought following planting may have influenced these results. These types of events may become more frequent going forward and could inspire research on new approaches to early-seral management. Although we have some initial results, future monitoring will help provide a longer-term picture on stand development and treatment success.

3.2 INTRODUCTION

Across the Pacific Northwest, short rotation Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) monocultures have become the standard approach to forest management on most State and private timberlands because they grow fast and have high timber value. Other species and mixtures are planted less frequently, including western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), red alder (*Alnus rubra* Bong.), or western red cedar (*Thuja plicata* Donn ex D. Don). Oftentimes, alder and understory are controlled via broadcast herbicide applied to the site prior to planting a new conifer crop. Although chemical control helps achieve successful timber stands, it can negatively affect vegetation that wildlife and rural communities rely on (Mackinnon and Freedman 1993, Guynn et al. 2004). Forests and our understanding of how to manage them will have to adapt in the decades to come, in light of a warming climate, increased insect and pathogen outbreaks, wildfire, and extreme weather events.

In the last few decades, there has been a decline in early-seral habitat throughout the coastal Pacific Northwest forests (Phalan et al. 2019). This successional stage is used by a myriad of wildlife from pollinators to ungulates for forage, taking advantage of the fast-growing graminoids, forbs, and shrubs that grow and flower in this open and full sun environment (Ulappa et al. 2020). There are over 70 wildlife species that use early-seral, mainly deciduous, vegetation across the Pacific Northwest (Hagar 2007) and the early-seral stage promotes complex food webs that support plant life used by a wide array of species (Swanson et al. 2011), including over 50% of all endangered species in Washington and Oregon (Swanson et al. 2014).

As the tree canopy closes, understory plant composition changes to favor more shade tolerant species and eventually understory abundance becomes very limited (Franklin et al. 2002a). The diminishment of these open conditions and their subsequent available forage material has impacted Roosevelt elk (*Cervus canadensis roosevelti*) and black-tailed deer (*Odocoileus hemionus columbianus*) populations in the Pacific Northwest (Cook et al. 2016a). This has also impacted communities who rely on subsistence hunting and gathering for their personal or cultural wellbeing.

Public lands are important to rural communities across the Pacific Northwest in many ways. Some community members work in the non-timber forest products industry and regularly pick wild mushrooms to sell to restaurants, salal (*Gaultheria shallon* Pursh) and beargrass (*Xerophyllum tenax* (Pursh) Nutt.) foliage for the floral industry, and evergreen boughs during the winter holiday season (Alexander et al. 2011, Frey et al. 2021). In addition, tribal communities use ceded, usual and accustomed (U&A), or traditional hunting and gathering lands to fish, hunt, and harvest (Shebitz 2005, Johnson et al. 2021). Many of these areas are on lands currently managed by state or federal governments, and the ways in which they are managed impact tribal benefits. Tribal members have cited locked gates, difficulty navigating relationships with public lands managers, and low abundance of desired plant species as some of the current issues they face (Dobkins et al. 2016).

The Northwest Forest Plan (NWFP), created in the mid-1990s, focused on conserving late successional and old-growth habitat, and protecting species that relied on these forests, such as the endangered marbled murrelet (*Brachyramphus marmoratus*) and the northern spotted owl (*Strix occidentalis caurina*). Adaptive management (Walters 1986) was included in the NWFP as a way to identify uncertainties, test new approaches, and learn from the results. Its implementation was poorly realized, with very few experiments getting off the ground (Bormann et al. 2007a, Spies et al. 2018), and few policy changes evident over the subsequent 27 years. As we move forward into a future with changes in climate and societal needs, expanding our adaptive capacity by creating and testing innovative forest management approaches will be critical.

One adaptation in forest management is the field of ethnoforestry, or a people-centered forest management. This field has largely been used in India and other parts of Asia (Pandey 1998), but can easily be applied in the Pacific Northwest (Bobsin et al. 2023). This field incorporates the values, needs, opinions, and knowledge of people, especially those that impacted by management outcomes, into the forest management process (Bobsin et al. 2023). This approach uses an ecosystem wellbeing framework where both community and environmental wellbeing are prioritized simultaneously and with equal seriousness (Bobsin et al. 2023). In order to enact ethnoforestry practices that can meet ecosystem wellbeing goals, we can consider new methodologies to expand our management toolbox.

This study evaluates an application of ethnoforestry to manage young, recently harvested early-seral forest stands, with three vegetation and three browse-control treatments. The objective of this research is to compare treatments in terms of: 1.) growth, browse, and mortality of planted understory and tree seedlings; 2.) differences in understory cover (separated by their functional group type (e.g., graminoid, forb, shrub, etc.)) and understory and tree seedling natural regeneration; and 3.) potential interactions between natural regeneration and planting.

3.3 METHODS

3.3.1 Study Area

This ethnoforestry study is located on the northwest side of the Olympic Peninsula near La Push, WA on lands managed by the WA Department of Natural Resources (WA DNR) and surrounded by privately owned timberland (Figure 3.1). This WA DNR unit is approximately 40 hectares (100 acres) in total, with 2 hectares (5-acres) reserved for this study. Prior to treatment implementation, the unit was a 50-year stand. In 2018-2019, this unit received a variable-retention harvest with an average of 20 leave-trees left per hectare (8 per acre). In August 2020, WA DNR ground crews applied herbicide and pre-emergent, primarily made up of glyphosate and imazapyr, to reduce the amount of naturally regenerating understory that had grown since harvest. At that time, the most abundant understory species included foxglove (*Digitalis purpurea* L.), ground woodsel (*Senecio sylvaticus* L.), hairy cat’s ear (*Hypochaeris radicata* L.), sword fern (*Polystichum munitum* (Kaulf.) C. Presl) retained from the previous stand, and several others.

The site includes mainly south facing slopes with moderately steep terrain. Downed wood was scattered throughout the unit with some areas having dense amounts of woody debris (>2 ft. deep) and other areas having very little. In addition, there were several small riparian areas, seasonal wetlands, and channels running down many of the slopes with standing water and obligate wetlands plant species.

Figure 3.1: Location of the experimental site near La Push, WA on the northwest side of the Olympic Peninsula, WA (right) and the spatial distribution of the 27 experimental units across a 100-acre unit managed by the WA Department of Natural Resources (left).

3.3.2 Experimental Design

This study used a randomized-block, 3 by 3 vegetation x browse-control factorial design to evaluate post-harvest tree regeneration, wildlife habitat and browse, and vegetation important to local communities. The vegetation treatments included two ethnoforestry approaches and one control: 1.) agroforestry where understory species were planted in rows at 0.5m spacing and 445 trees her hectare (TPH; 180 trees per acre (TPA)) of Douglas-fir were planted in between understory rows; 2.) early-seral management where understory species were planted in rows at 2 m spacing and 445 TPH (180 TPA) of Douglas-fir and 123 TPH (50 TPA) of red alder were planted between understory rows; and 3.) a standard practice control with 890 TPH (360 TPA) of Douglas-fir planted with no understory added (Table 3.1). This was the prescription applied in the rest of the WA DNR unit.

Table 3.1: Understory and seedling planting densities in each vegetation treatment. Understory spacing is approximate and may be slightly less than total here due to stumps present in the understory rows from the previous harvest

Vegetation treatment	**Understory spacing (plants/hectare)**	**Douglas-fir spacing (TPH)**	**Red alder spacing (TPH)**	**Total tree spacing (TPH)**
Agroforestry	8,105	445	0	445
Early-seral management	2,470	445	123	568
Control	0	890	0	890

Both ethnoforestry treatments (agroforestry and early-seral management) included planting understory species in rows alongside timber species, with a goal of promoting understory growth while still maintaining a timber rotation of up to 50 years. The understory species planted included Nootka rose (*Rosa nutkana* C. Presl), whitebark raspberry (*Rubus leucodermis* Douglas ex Torr. & A. Gray), tall Oregon grape (*Mahonia aquifolium* (Pursh) Nutt.), roemer’s fescue (*Festuca roemeri* (Pavlick) Alexeev), and salmonberry (*Rubus spectabilis* Pursh). Ten rows total were planted in each unit, with two rows of each species. All understory plants were bare root with seeds harvested from zones 1, 2, or 77. All understory plants and red alder were purchased from Fourth Corner Nursery in Bellingham, WA. These species were selected because they had some value to nearby communities and/or value to wildlife, with a particular emphasis on ungulates. Species selection was also limited based on available nursery stock, with several species unavailable in higher quantities. Bear grass, for example, was an ideal species for this study, but availability was too limited and instead roemer’s fescue was chosen.

The browse-control treatments were: 1.) an 8-ft ungulate exclosure fence made from galvanized metal attached to fence posts; 2.) application of the liquid wildlife repellent

Plantskydd to planted understory and tree seedlings; and 3.) none, open to browse. Plantskydd was applied four times over an approximate 14-month period: once prior to planting in Winter 2021, just after bud break in spring 2021, fall 2021, and winter 2022.

Vegetation and browse-control treatments combined to create nine unique prescription treatments (Figure 3.2). In addition, due to uneven distribution of downed wood retained after harvest and the seasonal wetlands throughout the site, this study was blocked based on the levels of downed wood, with block one having low levels of downed wood (less than 1/3 of unit), block two having medium levels of downed wood (between 1/3 and 2/3 of unit), and block three having high downed wood (greater than 2/3 of unit). This resulted in a total of 27 experimental units.

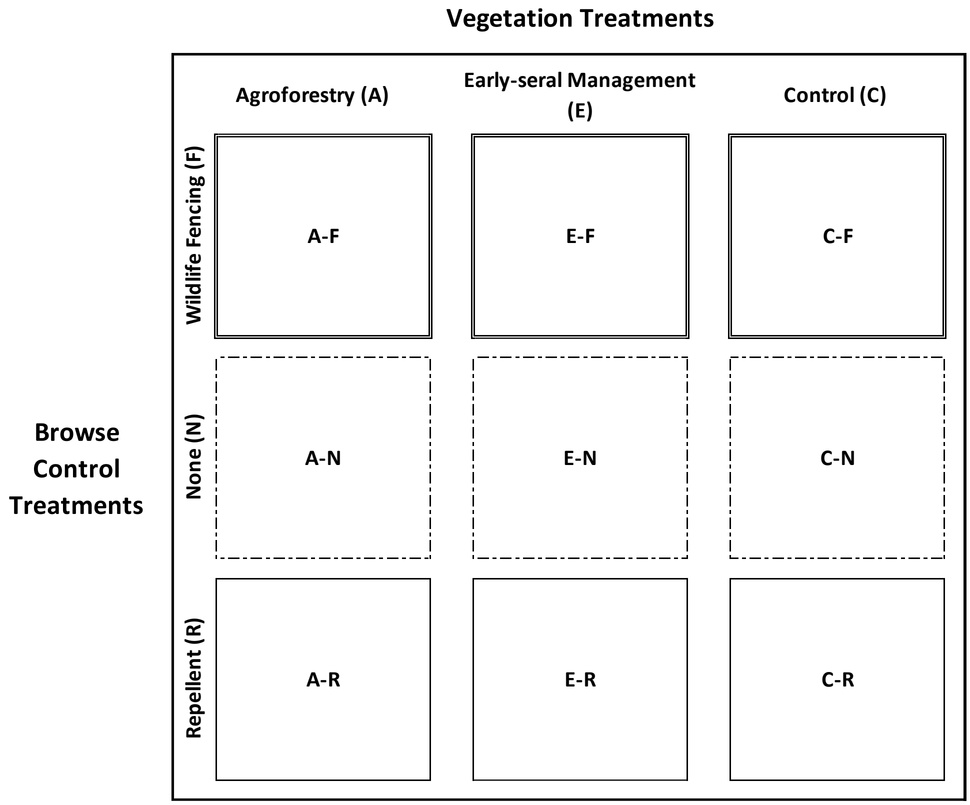


Figure 3.2: The 3x3 factorial design of the experiment showing vegetation treatments and browse-control treatments, and their interaction. These nine unique treatments were applied with three blocks, totaling 27 experimental units.

3.3.3 Measurements

Each unit was 20 x 20m (1/10 acre) and included ten understory rows (excluding control units which had no understory planting), intermediate rows in-between where seedlings were planted, and six monumented locations where natural regeneration was measured in 1.5 x 1.5m quadrats. Measurements were completed on each of these components. In the planted understory rows in the agroforestry and early-seral management treatments, a sub-set of each row was sampled. In each of the ten rows, five individuals were tagged in order to be re-measured in future years for mortality and browse.

Each planted seedling was tagged and measured. This included mortality and browse. In addition, measurements were completed at the natural regeneration quadrats. These measurements included: 1.) understory cover (%) of each individual species present; and 2.) count of naturally regenerating seedlings (excluding any planted seedlings that fell within the plot. Understory species were broken down into six functional group types based on their group form. These included: 1.) graminoid; 2.) forb; 3.) evergreen fern; 4.) deciduous fern; 5.) evergreen shrub; and 6.) deciduous shrub. These groupings were used to evaluate the change in particular types of understory cover.

All measurements, including natural regeneration of understory and seedlings, planted understory, and planted seedlings, were completed one-year post-planting in 2021 and two years post-planting in 2022. This provides us with an initial picture of the immediate stand response.

3.3.4 Statistical Analysis

3.3.4.1 Planted understory and seedlings

Planted understory and tree seedlings were evaluated throughout the first two years of stand development. Using binary browse data on both planted understory and tree seedlings, we determined a percent browse for each individual species per experimental unit. This was used as a continuous variable. Similarly, mortality was calculated and used in our analysis. Mortality and browse had a positive skew and therefore received a square root transformation. The vegetation and browse-control treatments and block (based on 3 levels of woody debris) were used as categorical explanatory variables. In addition, cover of natural regenerating understory and density of tree seedlings ha^{-1} were included as continuous explanatory variables to determine their potential significance in predicting mortality of planted understory and seedlings. This was done by using analysis of variance (ANOVA) and linear regression.

3.3.4.2 Natural regeneration of understory and tree seedlings

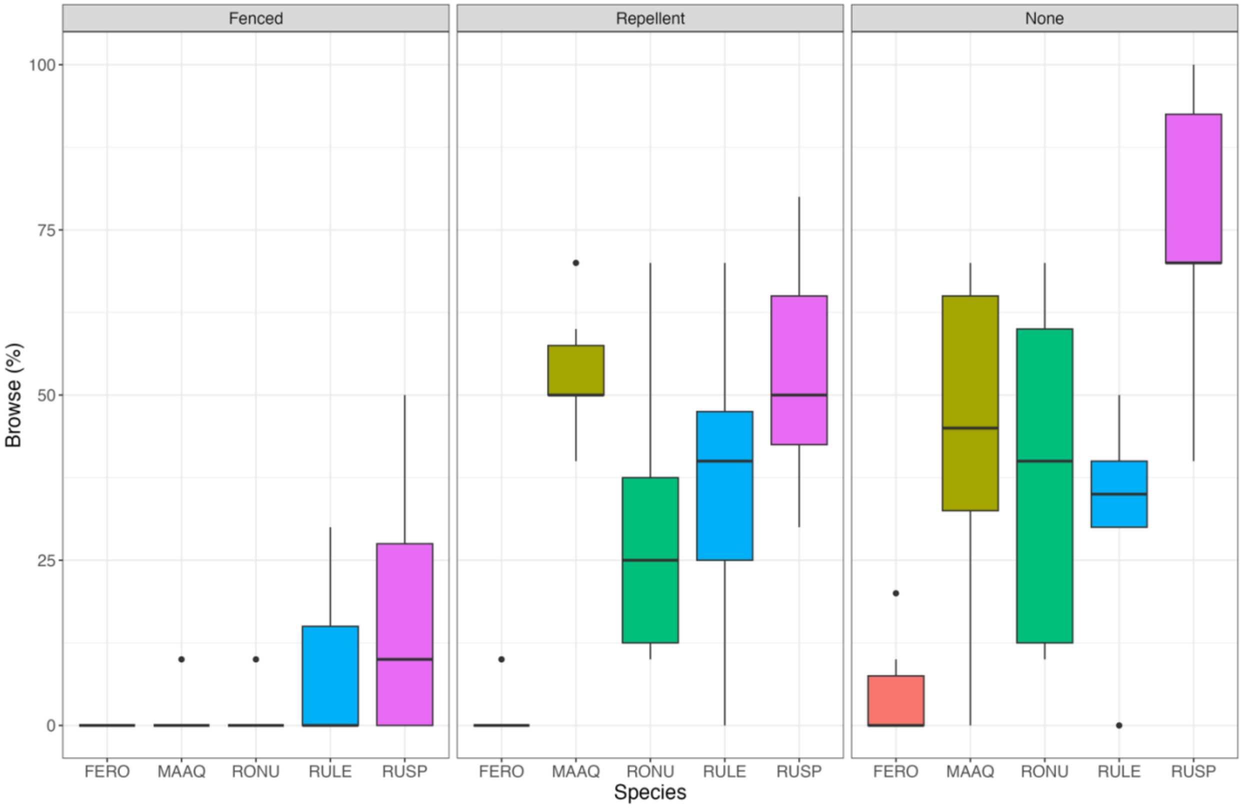
To evaluate differences in natural regeneration of understory cover and tree seedlings between treatments, we used distance-based linear models using multivariate response matrices (Legendre and Anderson 1999). Permutational analysis of variance (PERMANOVA) was performed using Bray-Curtis distance measures for understory cover and Euclidean distance measures for seedling counts. All response matrices were relativized by their maxima due to their high coefficient of variation values (McCune and Grace 2002). This was completed using the vegan package in R studio. In addition, individual species and functional group types (e.g., graminoids, forbs, evergreen shrubs, etc.) were evaluated to determine changes in cover between treatments and years through linear regression. The vegetation treatment, browse-control treatment, and block were used as explanatory variables in this analysis. All statistical analyses for this study were completed in R Studio Version 2023.03.0+386.

3.4 RESULTS

3.4.1 Planted understory

There was substantial variation in planted understory mortality among species. Two years after planting, tall Oregon grape had the largest mortality with an average of 61% and 56% dead in the agroforestry and early-seral management treatments respectively. In addition, an average of 36% whitebark raspberry, 17% Nootka rose, 37% salmonberry, and 8% Roemer's fescue died in the agroforestry treatment. An average of 40% whitebark raspberry, 19% Nookta rose, 42% salmonberry, and 10% Roemer's fescue died in the early-seral management treatment. The browse-control and vegetation treatments were not significant predictors of mortality in any of the planted species ($p > 0.05$).

Browsing also varied among species and between browse-control treatments (Figure 3.3). Fenced units often had less browsing than the other browse-control treatments. However, some browsing did occur with insects and potentially some small burrowing animals getting past the fences. In year 1, Roemer's fescue, tall Oregon grape, and Nootka rose had fewer than 2% of plants with signs of browse in fenced units. Applying repellent had little effect on browse in year 1, with even higher amounts of browsing on salmonberry (r^2 =0.61; p = 0.0009) and tall Oregon grape (r^2 = 0.72; p= 0.00007) compared to the other browse-control treatments. By year 2, browsing had increased for nearly all species in each browse-control treatment. However, only Roemer's fescue showed a difference in amount of browse based on treatment, with units treated with repellent showing significantly greater amounts of browse (r^2 = 0.33; p = 0.048).


Fenced
Repellent
None
Browse (%)
100
75
50
25
0
FERO
MAAQ
RONU
RULE
RUSP
Species

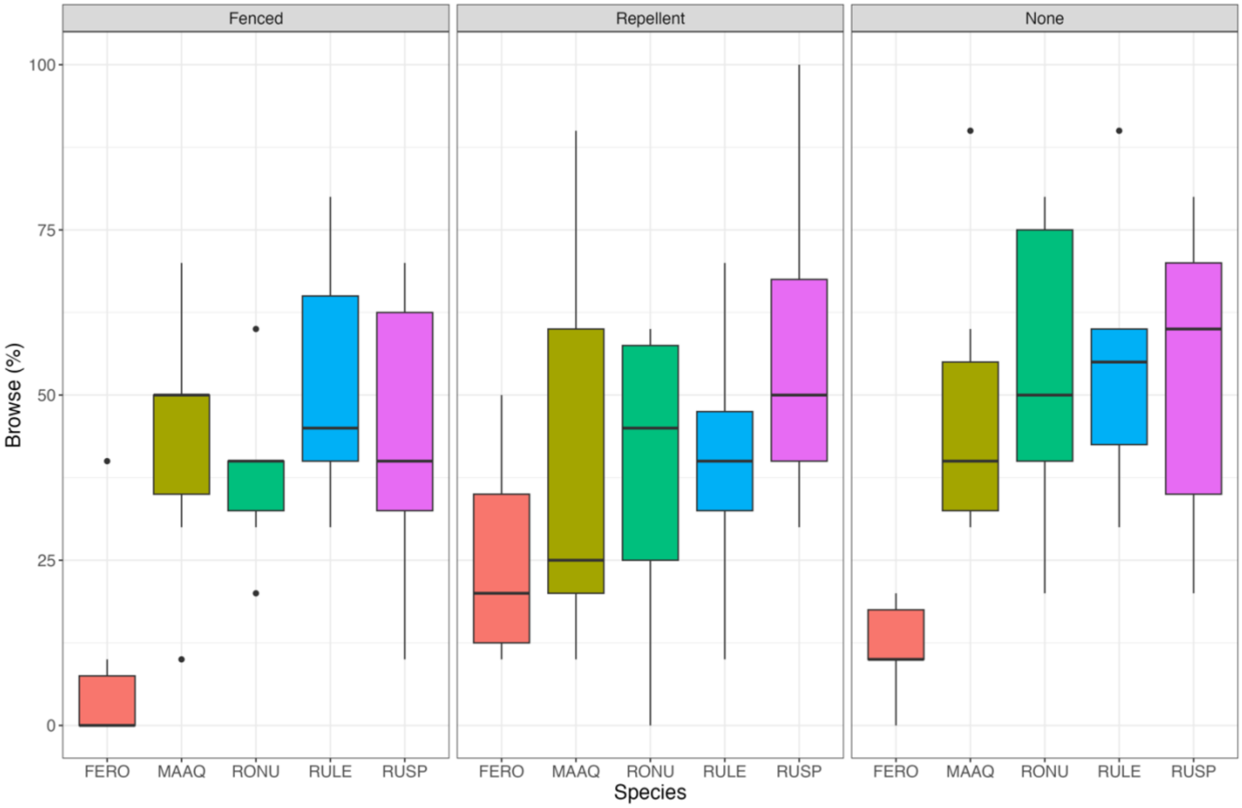

Fenced
Repellent
None
Browse (%)
100
75
50
25
0
FERO
MAAQ
RONU
RULE
RUSP
Species

Figure 3.3: Browsing (%) between each planted understory species in the three browse-control treatments: 1.) fenced; 2.) none, open to browse; and 3.) treated with wildlife repellent. Top boxplots represent one-year post-planting and the bottom boxplots represent two years post-planting. Species labels are as follows: FERO = Roemer's fescue; MAAQ = tall Oregon grape; RONU = Nookta rose; RULE = whitebark raspberry; and RUSP = salmonberry.

3.4.2 Planted tree seedlings

Planted tree seedling mortality was calculated and included all seedlings found dead and any seedlings that were not found during monitoring, which were presumed dead. For Douglas-fir seedlings in the early-seral management, agroforestry, and control units, mortality in year 1 had a mean of 4%, 1%, and 6% respectively. By the second year after planting, Douglas-fir mortality had risen in early-seral management units, agroforestry, and control units to a mean of 35%, 26%, and 40% respectively. There was no significant difference in mortality between the browse-control treatment, vegetation treatment, or block in the two measurement years ($p > 0.05$). Red alder seedlings (only planted in early-seral management treatment) had significant mortality with 35% dead one year after planting which increased to 73% two years after planting. The survival rate of alder seedlings was not significantly different across browse-control treatments and blocks with different levels of downed wood.

Browsing of planted Douglas-fir and alder occurred throughout the units, including fenced units. In both measurement years, Douglas-fir seedling browsing was significantly higher in units treated with repellent compared to the other browse-control treatments, with a mean of 20% in year 1 and 59% in year 2. Fenced units had the least amount of browsing of Douglas-fir seedlings in both years. Browsing damage on red alder was higher than that of Douglas-fir, but was not significantly different between the browse-control treatments. In year 1, the alder browsing ranged from 60-67% and in year 2 this was between 20-40%.

3.4.3 Natural regeneration of understory

One year after planting, understory composition as measured by cover (separated by its functional group type) was not significantly different between vegetation or browse-control treatments ($p > 0.05$). Understory cover was significantly higher in block 1 (low levels of downed wood) compared to the other blocks ($r^2 = 0.03$; $p = 0.011$; Figure 3.4). However, the r^2 was very low, indicating there are many other factors that are contributing to differences in understory cover at this time. Similarly, in year 2, vegetation and browse-control treatments were not significant predictors of understory cover ($p > 0.05$), but block was significant ($r^2 = 0.04$; $p=0.003$), again with a very low r^2 value similar to year 1. When evaluating individual functional group types through linear regression, we found that vegetation treatments, browse-control treatments, and block with varying levels of downed wood were not significant predictors of graminoid, deciduous fern, evergreen fern, deciduous shrub, or evergreen shrub cover in year 1 or year 2. In addition, none of these groups had significant increases in cover between the two measurement years. Although, there were differences present between forb cover.

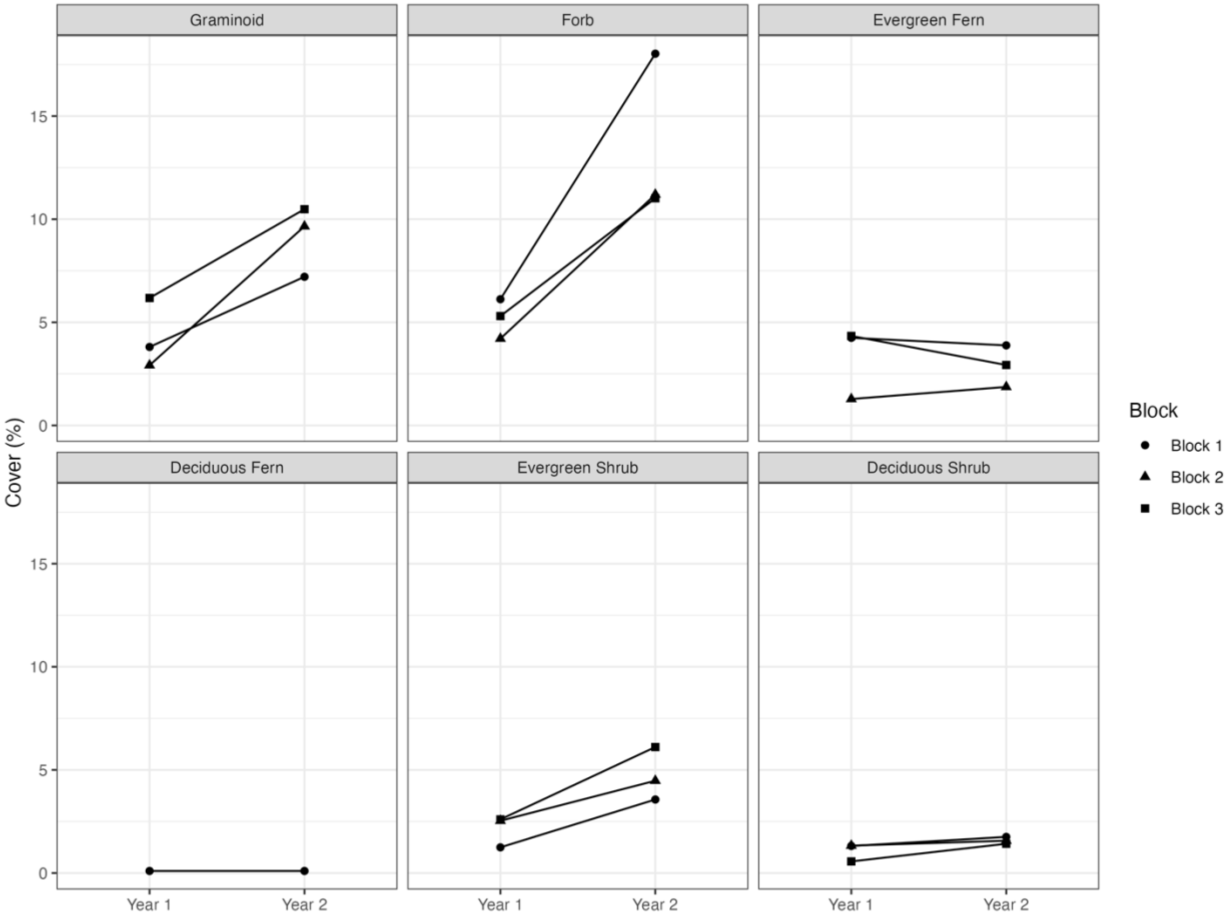


Figure 3.4: Understory cover (%) by functional group type in the first two years post-planting and showing variations among blocks with varying levels of downed wood levels (Block 1= low levels of wood; Block 2= medium levels of wood; and Block 3= high levels of wood). Functional group types include: 1.) graminoid; 2.) forb; 3.) evergreen fern; 4.) deciduous fern; 5.) evergreen shrub; and 6.) deciduous shrub.

When evaluating the interaction effect of the browse-control treatment and block on forb cover, we found a significant relationship (r^2= 0.56; p = 0.03). Fenced units in block 1 with low levels of wood had significantly greater forb cover (Figure 3.5), possibly due to the higher forage of forbs in non-fenced units. In addition, units treated with repellent had significantly less forb cover (r^2= 0.22; p = 0.05). By year 2 there was significant increase in forb cover in all treatments and blocks resulting in no statistical difference. In many treatments, forb cover nearly doubled in just one year of growth. For example, fenced units with low wood increased from a mean forb cover of 25% in year 1 to 49% in year 2. In addition, fenced units with high wood had mean forb cover of 16% in year 1 and increased to 32% by year 2.

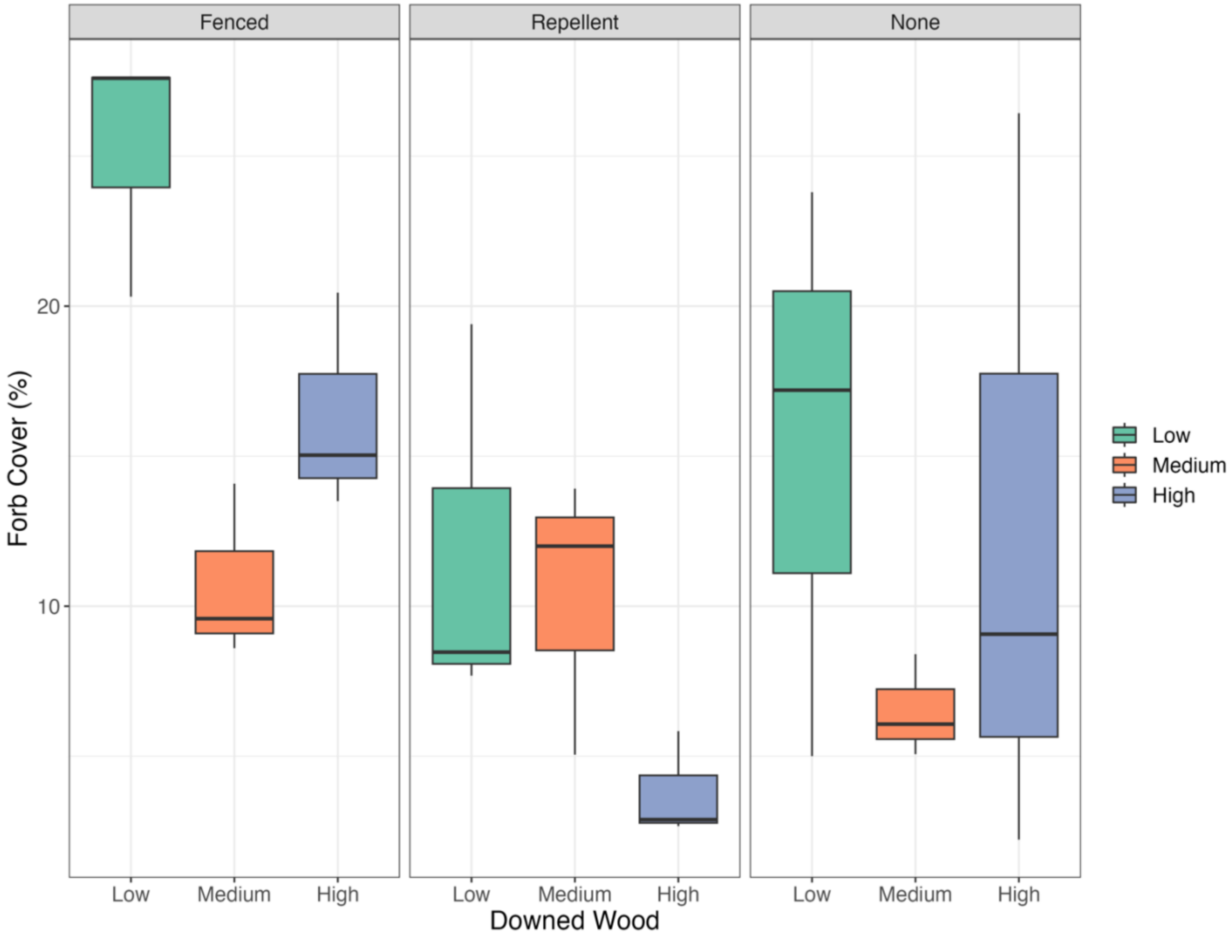


Figure 3.5: Forb cover (%) in each block with varying levels of downed wood including low (block 1), medium (block 2), and high (block 3) and browse-control treatments (fenced, treated with repellent, or none) one-year after planting (2021).

Two non-native forb species, ground woodsel and hairy cat's ear, were some of the most commons species found in units. In year 1, there was a significant interaction effect between browse-control treatments and block in wood groundsel cover ($r^2 = 0.15$; $p = 0.01$. By year 2, this trend had disappeared and there were no differences between treatments. There was no difference in hairy cat's ear cover between any treatment in year 1, but by year 2 there was a significant interaction effect between browse-control treatments and block with varying levels of downed wood. Fenced units with low wood had the highest cover of hairy cat's ear (r^2 = 0.26; $p < 0.000001$) with a mean of 13%.

3.4.4 Natural regeneration of tree seedlings

In both measurement years, the majority of naturally regenerating seedlings were small (under 30 cm in height) and there were no saplings (> 136 cm in height) present in either year. In year 1, there were no significant differences in quantities of seedlings between any of the treatments ($p > 0.05$). By year 2, some differences started to emerge between blocks, with high levels of downed wood having a significantly greater number of seedlings ha^{-1}compared to units with low levels of wood (r^2 = 0.04; $p = 0.018$) and units with medium levels of wood (r^2 = 0.04; $p = 0.017$). Similar to the natural regenerating understory, the r^2 was very low, indicating other factors are also driving seedling establishment. Low wood units had an average of 83 seedlings ha^{-1}, medium wood units had an average of 55 seedlings ha^{-1}, and high wood units had an average of 357 seedlings ha^{-1}.

3.4.5 Interaction of natural understory regeneration and planted tree seedlings

When evaluating the relationship between natural regeneration of understory and planted seedlings, we found that as the amount of understory cover increased in these units, seedling mortality decreased (Fig. 3.6). In addition, the interaction of understory cover and vegetation treatment was a significant predictor of seedling mortality in both years (Table 3.2).

Table 3.2: Results from linear regression models with seedling mortality as the response variable and several explanatory variables, including understory cover, vegetation, browse-control, and the interaction effect of understory cover and vegetation treatment. Results are from one year and two years after planting. Bolded values indicate a significant variable with α = 0.05

		Year 1			Year 2		
Response	Explanatory	F	P	R^2	F	P	R^2
Seedling Mortality	**Understory cover**	10.87	0.003	0.30	5.68	0.025	0.19
	Understory cover x vegetation treatment	6.00	0.001	0.59	4.75	0.005	0.53
	Vegetation treatment	3.43	0.05	0.22	3.80	0.037	0.24
	Browse-control treatment	0.66	0.52	0.05	0.13	0.882	0.01
	Block	0.96	0.40	0.07	2.31	0.121	0.16

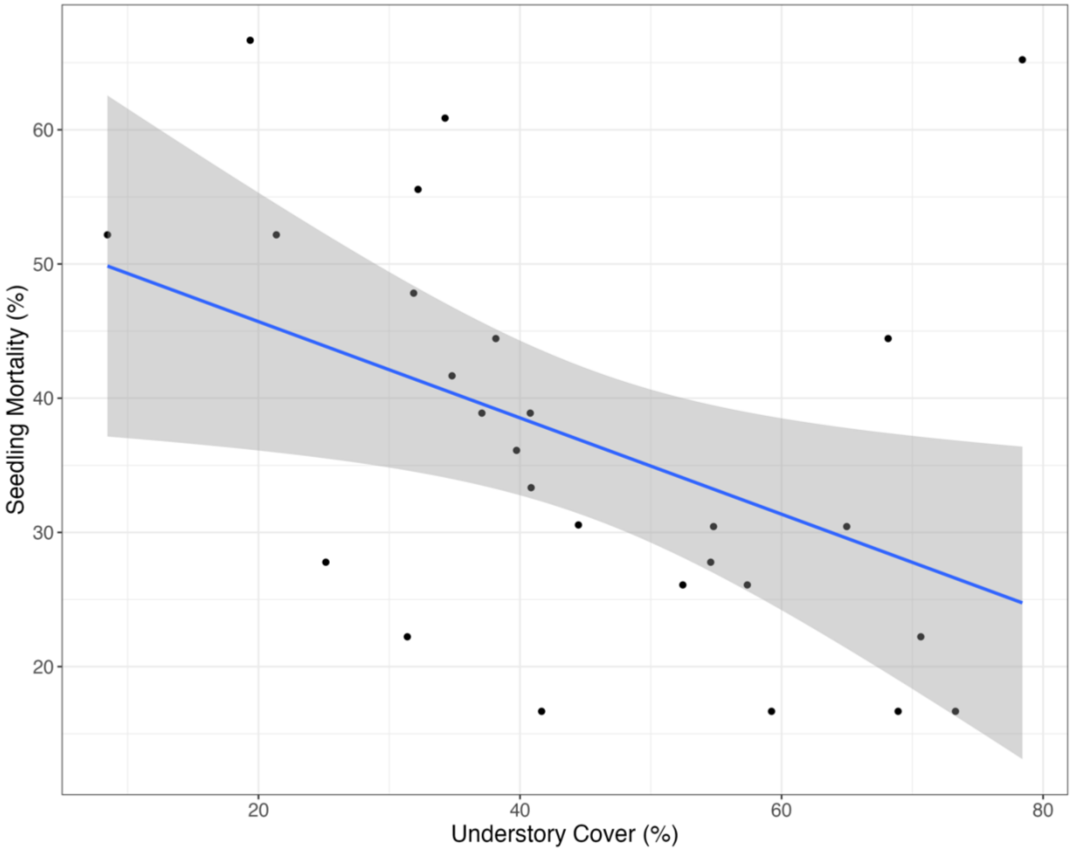


Figure 3.6: The relationship between seedling mortality (%) and understory cover (%) in the second measurement year (2022).

Lastly, we analyzed the potential relationship between naturally regenerating understory cover and the planted understory by species. For the majority of species, there was not a significant relationship, meaning that the growth of naturally regenerating understory is not driving the mortality of planted understory in these units.

3.5 DISCUSSION

Understory plants are rarely planted in forest stands managed for timber in Western Washington. Oftentimes, herbicide is applied to the site prior to planting conifer seedlings to inhibit the growth of competing vegetation and provide a head start for the next timber crop. Any additional planting and re-entries into the stands add extra costs early in the rotation, impacting net present value. However, as early-seral habitat decreases across the coastal Pacific Northwest (Phalan et al. 2019), impacting wildlife forage and plant access for nearby communities, we can re-envision and expand our approaches to managing young timber stands for additional benefits and to meet ecosystem wellbeing goals.

In this study, we planted five native plant species alongside Douglas-fir and red alder tree seedlings to promote growth of understory plants that have value to wildlife and local communities while still producing a timber crop in a typical 40 to 50-year rotation. Although we are only two years post-planting, there are some initial conclusions to the success of the treatments that we can learn from.

3.5.1 Initial mortality of planted understory and seedlings

The planted understory had significant mortality, with three of the five species having greater than 35% of individuals die two years after planting. The browse-control and vegetation treatments were not correlated with mortality of any species. In addition, there was no relationship between planted and naturally regenerating understory, indicating that any potential competition is not driving the death of planted understory species. Similarly, planted tree seedling mortality was not significantly different between any treatments. This indicates that there are other factors contributing to mortality of both planted understory and tree seedlings.

These plants were planted in the winter and spring of 2021, a time of unusually warm and dry weather for the west side of the Olympic Peninsula known for heavy spring rains. This was followed by the June 2021 ‘heat dome’ where temperatures in the nearby town of Forks, WA reached 110 degrees Fahrenheit, over 20 degrees above average for this time of year (NOAA 2023). It is likely that low precipitation, warm spring temperatures, and record-breaking summer heat within the first four months after planting could have contributed to or caused transplanting shock, leading to the ultimate mortality of many of these plants (Haase and Rose 1993, McDowell et al. 2008).

We found that as naturally regenerating understory cover increased, there was less mortality of planted tree seedlings. This stands in contrast to many managers perception that increased understory leads to unnecessary competition with crop tree seedlings that can result in their death. Our results show the opposite effect. We hypothesize that the increase in shade created by the understory could have helped mitigate for the high heat and result in less mortality of tree seedlings. However, future research at finer spatial scales could help to understand this relationship.

3.5.2 Browsing prevalent in planted understory and tree seedlings

Browsing is common in forest stands, especially in open conditions with desirable and digestible plant materials (Bunnell 1990, Lopez Perez 2006). A key goal was to develop an ethnoforestry-based approach that promotes habitat for wildlife, especially ungulates. Therefore, this study was not intending to minimize browsing, but rather quantify its prevalence and its effects on understory and seedlings. All planted understory species in this study experienced some degree of browse throughout the first two years. By the second year after planting, browsing had increased in all units, including in the fenced units where insects and small burrowing animals are able to enter to forage, most likely contributing to the browsing in this treatment.

The wildlife repellent Plantskydd was applied to limit browsing. However, for most species there was not a difference between units that had no browse-control and those treated with this repellent. In other instances, Plantskydd treated units had significantly more browse, including for Douglas-fir seedlings in both measurement years. Although repellent can be seen as a more economical alternative of preventing browse compared to other options such as exclosures, plant tubes, or slash piling, our results show it to be less effective in this case. This may be due, in part, to issues with applying the product only during a 24-hour rain-free window, which can be rare in the temperate rainforest of the Olympic Peninsula during the fall, winter, and spring. Some studies have seen success in this product, but in regions that do not receive as much annual rainfall or under more controlled settings (Wagner and Nolte 2001, Kimball and Nolte 2006). Future studies could explore alternative products that may be better suited to this climate or have less frequent re-application intervals.

3.5.3 Naturally regenerating understory and tree seedlings

In young stands with full sun, forbs and graminoids tend to grow and establish quickly. As the stand develops and saplings shade the forest floor, shade tolerant shrubs and ferns will often begin to grow (Franklin et al. 2002a). In this study, we saw an increase in forb cover between the two measurement years. In many of the treatments, the mean forb cover doubled as it capitalized on space and light in these stands. We expect that this trend will continue over the next 10-15 years until sunlight becomes limited and forbs are replaced by shade tolerant species.

Hairy cat’s ear and wood groundsel were two of the most common species found in the understory. These species are known to dominate and spread rapidly in open, full sun conditions. Although they are not invasive, this type of recalcitrant species can limit biodiversity and prevent the growth of other species (Royo and Carson 2006). Future monitoring can help track the spread of these species over time to determine if they are impacting biodiversity and the establishment of other understory species.

On the west side of the Olympic Peninsula, western hemlock seedlings are typically abundant and can grow in open, full sun to shaded conditions. In this region, it is not uncommon to have thousands of seedlings and saplings growing per hectare in managed stands (Bobsin et al.

2017). Oftentimes, foresters pre-commercially thin (PCT) around year 15 to avoid overly dense stands and concentrate growth on eventual crop trees. PCT increases light to the forest floor, soil moisture, and nutrient availability leading to better stand growth (Harrington and Reukema 1983, Chase et al. 2016). PCT can lead to a second wave of hemlock seedlings as well (Chapter 3). This study found limited number of seedlings growing two years after planting. Units in block 3 that had high levels of downed wood had a greater number of seedlings growing, but the very low r^2 value indicates that there were many things influencing this difference beyond downed wood levels. In the coming decade, future research could evaluate the growth of seedlings and the biomass of understory to determine if the understory planting and natural regeneration could limit the numerous hemlock seedlings from populating, perhaps preventing the need for a pre-commercial thin.

3.6 CONCLUSIONS

Managing understory, other than to eliminate it, is rare. Most managers see this as unnecessary cost and competition for crop trees that can reduce growth and yield and will herbicide all understory species prior to planting tree seedlings. However, promoting understory species and early-seral habitat can have benefits for wildlife, including birds, insects (especially pollinators), and ungulates that use these open conditions for foraging on sun-dependent understory such as graminoids and forbs. In addition, understory vegetation is harvested for personal or cultural reasons and by non-timber forest product pickers.

Future studies could explore other approaches that could result in additional understory growth of desirable species and biodiversity while also quantifying costs and benefits. This could include seeding in beneficial understory species, actively managing naturally regenerating understory for desirable species in the first decade after planting to extend early-seral characteristics, or studying the impact herbicides have on initial understory development.

As we move forward, climate change will continue to influence and impact our forests, whether that is through intensifying forest pathogens, increasing west side wildfires, or more extreme weather events and patterns (Chmura et al. 2011, Lee et al. 2017, Agne et al. 2018). These types of studies, although small-scale, can help contribute to our understanding of new approaches to manage our forests. These initial results can help to address uncertainties, but continued monitoring and evaluation of conditions will be beneficial to have a better, longer-term picture of treatment success and stand development going forward.

3.7 REFERENCES

Agne, M. C., P. A. Beedlow, D. C. Shaw, D. R. Woodruff, E. H. Lee, S. P. Cline, and R. L. Comeleo. 2018. Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, U.S.A. *For. Ecol. Manag.* 409:317–332.

Alexander, S. J., S. N. Oswalt, and M. R. Emery. 2011. *Nontimber Forest Products in the United States: Montreal Process Indicators as Measures of Current Conditions and Sustainability*.

Bobsin, C. R., B. T. Bormann, M. L. Miller, and B. D. Pelach. 2023. Perspectives: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest. *Forest Ecology and Management* 529:1–10.

Bobsin, C. R., B. T. Bormann, T. Minkova, and K. Ewing. 2017. Understory development in thinned stands as part of a long-term ecosystem productivity study. University of Washington, Seattle.

Bormann, B. T., R. Haynes, and J. Martin. 2007. Adaptive management of forest ecosystems: Did some rubber hit the road? *BioScience* 57(2):186–191.

Bunnell, F. L. 1990. Ecology of black-tailed deer. Page *in* J. B. Nyberg and D. W. Janz, editors. B.C. Ministries of Forests and Environment, Victoria, B.C.

Chase, C. W., M. J. Kimsey, T. M. Shaw, and M. D. Coleman. 2016. The response of light, water, and nutrient availability to pre-commercial thinning in dry inland Douglas-fir forests. *Forest Ecology and Management* 363:98–109.

Chmura, D. J., P. D. Anderson, G. T. Howe, C. A. Harrington, J. E. Halofsky, D. L. Peterson, D. C. Shaw, and J. Brad St.Clair. 2011. Forest responses to climate change in the northwestern United States: Ecophysiological foundations for adaptive management. *Forest Ecology and Management* 261(7):1121–1142.

Cook, J., R. Cook, R. Davis, and L. Irwin. 2016. Nutritional ecology of elk during summer and autumn in the pacific northwest. *Wildlife Monographs* 195:1–81.

Dobkins, R., C. Lewis, S. Hummel, and E. Dickey. 2016. *Cultural Plant Harvests On Federal Lands: Perspectives From Members of the Northwest Native American Basketweavers Association*.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155:399–423.

Frey, G. E., J. L. Chamberlain, and M. G. Jacobson. 2021. Producers, production, marketing, and sales of non-timber forest products in the United States: a review and synthesis. Springer Science and Business Media B.V.

Guynn, D. C., S. T. Guynn, T. B. Wigley, and D. A. Miller. 2004. Herbicides and forest biodiversity—what do we know and where do we go from here? *Wildlife Society Bulletin* 32(4):1085–1092.

Haase, D. L., and R. Rose. 1993. Soil moisture stress induces transplant shock in stored and unstored 2 + 0 Douglas-fir seedlings of varying root volumes. *Forest Science* 39(2):275–294.

Hagar, J. C. 2007. Wildlife species associated with non-coniferous vegetation in Pacific Northwest conifer forests: A review. *For. Ecol. Manag.* 246:108–122.

Harrington, C. A., and D. L. Reukema. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. *Forest Science* 29(1):33–46.

Johnson, A., A. E. Clavijo, G. Hamar, D. A. Head, A. Thoms, W. Price, A. Lapke, J. Crotteau, L. K. Cerveny, H. Wilmer, L. Petershoare, A. Cook, and S. Reid. 2021. Wood products for cultural uses: Sustaining native resilience and vital lifeways in southeast Alaska, USA. *Forests* 12(1):1–26.

Kimball, B. A., and D. L. Nolte. 2006. Development of a New Deer Repellent for the Protection of Forest Resources. *Western Journal of Applied Forestry* 21(2).

Lee, E. H., P. A. Beedlow, R. S. Waschmann, D. T. Tingey, S. Cline, M. Bollman, C. Wickham, and C. Carlile. 2017. Regional patterns of increasing Swiss needle cast impacts on Douglas-fir growth with warming temperatures. *Ecology and Evolution*.

Legendre, P., and M. J. Anderson. 1999. Distance-Based Redundancy Analysis: Testing Multispecies Responses in Multifactorial Ecological Experiments. *Ecological Monographs* 69(1):1–24.

Lopez Perez, E. 2006. Natural selenium and planted forages: effects on mule deer and elk in Washington. Washington State University.

Mackinnon, D. S., and B. Freedman. 1993. Effects of Silvicultural Use of the Herbicide Glyphosate on Breeding Birds of Regenerating Clearcuts in Nova Scotia, Canada. *Journal of Applied Ecology* 30(3):395–406.

McCune, B., and J. Grace. 2002. Analysis of ecological communities. MJM Software Design, Gleneden Beach, OR.

McDowell, N., W. T. Pockman, C. D. Allen, D. D. Breshears, N. Cobb, T. Kolb, J. Plaut, J. Sperry, A. West, D. G. Williams, and E. A. Yepez. 2008, June. Mechanisms of plant survival and mortality during drought: Why do some plants survive while others succumb to drought?

NOAA. 2023. National Weather Service.

Pandey, D. N. 1998. *Ethnoforestry: Local knowledge for sustainable forestry and livelihood security*. Himanshu Publications.

Phalan, B. T., J. M. Northrup, Z. Yang, R. L. Deal, J. S. Rousseau, T. A. Spies, and M. G. Betts. 2019. Impacts of the Northwest Forest Plan on forest composition and bird populations. *PNAS* 116(8):3322–3327.

Royo, A. A., and W. P. Carson. 2006. On the formation of dense understory layers in forests worldwide: consequences and implications for forest dynamics, biodiversity, and succession. *Canadian Journal of Forest Research* 36:1345–1362.

Shebitz, D. 2005. Weaving Traditional Ecological Knowledge into the Restoration of Basketry Plants. *J. Ecol. Anthropol.* 9(1):51–68.

Spies, T. A., P. A. Stine, R. Gravenmier, J. W. Long, M. J. Reilly, and R. Mazza. 2018. *Synthesis of Science to Inform Land Management Within the Northwest Forest Plan Area*. Portland, Oregon. Gen. Tech. Rep. PNW-GTR-970.

Swanson, M. E., J. F. Franklin, R. L. Beschta, C. M. Crisafulli, D. A. Dellasala, R. L. Hutto, D. B. Lindenmaver, and F. J. Swanson. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Front. Ecol. Environ* 9(2):117–125.

Swanson, M. E., N. M. Studevant, J. L. Campbell, and D. C. Donato. 2014. Biological associates of early-seral pre-forest in the Pacific Northwest. *For. Ecol. Manag.* 324:160–171.

Ulappa, A. C., L. A. Shipley, R. C. Cook, J. G. Cook, and M. E. Swanson. 2020. Silvicultural herbicides and forest succession influence understory vegetation and nutritional ecology of black-tailed deer in managed forests. *For. Ecol. Manag.* 470–471:1–16.

Wagner, K. K., and D. L. Nolte. 2001. Comparison of Active Ingredients and Delivery Systems in Deer Repellents. *Wildlife Society Bulletin* 29(1):322–330.

Walters, C. 1986. *Adaptive Management of Renewable Resources*. MacMillan Publishing Company, New York.

Chapter 4: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest

Originally published in Forest Ecology and Management in 2023 under a CC-BY license.

4.1 ABSTRACT

The field of forestry has changed substantially in the last 100 years as scientists and managers have grappled with ways to best manage forests and adapt to changing knowledge, needs, and climates. We offer a new path forward using an ecosystem wellbeing framework where both community and environment wellbeing must be achieved to meet ecosystem wellbeing goals. To achieve this, we propose a learning-based collaboration (LBC) process where managers, researchers, tribes, stakeholders, and collaborators engage with one another to ask and answer questions about options and effects of management choices through scientifically valid comparisons. We also propose the use of the field of ethnoforestry, or a people-focused forest management, as the necessary context for LBC. We offer two examples of ways ethnoforestry is being tested on the Olympic Peninsula through an operational-scale experiment that seeks to meet the needs of communities and the environment, while producing revenue for trust land beneficiaries and meeting late-seral habitat requirements.

4.2 INTRODUCTION

Forest management over the last 100 years has seen significant changes, from operational equipment to philosophy. In the last few decades, there have been many meaningful attempts to change and update practices, such as the steady development of new milling, harvesting, and other technologies. Furthermore, some additional set-aside reserves have been added to public lands, and agencies have continued with projects to respond to widespread and intense wildfires in dry forests. However, what has been lacking are important changes in operational-scale prescriptions across ownership types. On public lands, from standard National Environmental Policy Act (NEPA) reviews to stakeholder engagement, societal involvement has been changing rapidly to include different forms of adaptive management (Walters 1986) and collaborative learning (Daniels and Walker 2001).

As forestry is thrust into the global limelight around climate adaptation, and with major climate and social changes afoot, increasing collective capacity to adapt forestry to meet these challenges is necessary. Therefore, creating frameworks focused on building and applying adaptive capacity quickly is imperative.

In this paper, we explore an ecosystem wellbeing framework that considers both community and environmental wellbeing as integrated and integral to the wellbeing of the forest ecosystem. To understand what contributes to the livelihood and wellbeing of communities, we are using a form of collaborative learning where managers, researchers, tribes, and stakeholders are all involved in the development and implementation of management as described by Daniels and Walker (1996, 2001).

Finally, we explore how the emerging concept of ethnoforestry might be applied to smooth forestry's evolution going forward. Specifically, we focus on the intersection of the ongoing revolution of stakeholder engagement connected to needed innovation in land management practices. We apply our variant of ethnoforestry by seeking to integrate and apply concepts of sustainable development, adaptive management, and collaborative learning to the Washington Department of Natural Resources (DNR) trust lands on the Olympic Peninsula, WA through an operational-scale study called the Type 3 Watershed Experiment. This ownership and its legal, environmental, and social setting provide a new perspective that allowed us to develop an innovative approach that we believe may have value especially for other state and federal lands.

4.3 BACKGROUND

4.3.1 Forest Management in the Pacific Northwest

In the Pacific Northwest, the ways in which federal and state lands are managed and operated changed significantly about 30 years ago with the listing of the northern spotted owl (*Strix occidentalis caurina*) and marbled murrelet (*Brachyramphus marmoratus*) as endangered species. The listing contributed to an injunction on federal lands in the early 1990s and the path forward emerged as the Northwest Forest Plan (the Plan), impacting management of nearly 25 million acres of federal lands. Other forest management plans were generated for state lands, with the similar goal to protect threatened and endangered species and their associated old-growth or late-seral and riparian species and habitat, with variably reduced timber production. Additionally, other resource management plans have been created for tribal lands held in trust by the federal government and evaluated by the Indian Forest Management Assessment Team (Gordon et al. 2013b).

During this period, there has been a continued unfolding of more extreme weather events, greater intensity of disturbance, diseases, and wildfire, and changes in our understanding of how forests and rural communities work—all calling out for policy changes. Adaptive management has often been seen as a way to overcome these uncertainties, where new and innovative prescriptions can be created, implemented, and studied, and where learning is a main objective, and the outcomes address key uncertainties (Walters 1986).

Adaptive management was a key tenet of the Plan and was envisioned as a way for policies and practices to evolve to changing conditions through structured learning (USDA Forest Service 1994, Spies et al. 2018). Few applications, however, ended up testing major policy alternatives (Bormann et al. 2007a) due to: 1.) limited resources or inclination to implement these types of experiments (Stankey et al. 2003b); 2.) limited capacity to create an organizational learning culture (Brown and Squirrell 2010); and 3.) a lack of adoption of the study results into management policies and prescriptions. Although several refinements and alternatives to adaptive management have been proposed to address these issues, including active adaptative management (Larson et al. 2013), options forestry (Bormann and Kiester 2004), and collaborative adaptive management (Colfer 2010, Barrett et al. 2021), there is still limited operational-scale research that addresses uncertainty. In 24 years under the Plan, Spies et al. (2018, 2019), concluded that adaptive management has been slow to respond to specific challenges, including climate change (and its effects on wildfire regimes), loss of habitat diversity, degradation of habitat quality for vulnerable species, and greater recognition of diverse public values. A decline in early-seral habitat is a notable example.

There have been difficulties addressing the sharp declines in early-seral habitat on both public and private lands in the Pacific Northwest (Phalan et al. 2019). The Plan's focus on late-seral reserves and the forest industry's effectiveness in limiting competing vegetation in short-rotation conifer stands led to a decline in early-seral vegetation, a stage that is typically dominated by sun-tolerant graminoids, forbs, shrubs, and hardwoods, critical for the health and population growth of ungulates and other wildlife (Cook et al. 2013, Ulappa et al. 2020). Declines in the early-seral stage has had ripple effects for all aspects of ecosystem wellbeing, limiting the amount of available forage and plant material for wildlife, and tribal and rural communities.

4.3.2 Collaboration

Throughout this time period, there has been an explosion of ideas, frameworks, and practical applications surrounding improving forest management in the United States and elsewhere through collaboration. While this paper is not intended to present an exhaustive list, we would like to highlight some notable examples.

First, the concept of social learning emerged several decades ago and had been used in a myriad of fields, including natural resource management. As with many widely used terms, there are multiple definitions applied, but some commonality between these includes stakeholder participation where learning is occurring (Reed et al. 2010). Social learning has been used in the collaboration and natural resource context, intersecting with collaborative management, adaptive management, adaptive co-management, and others (Cundill and Rodela 2012). Starting in the early to mid 1990s, collaborative learning provided an innovative framework for collaboration in natural resource management that built off principles within social learning. It emphasizes systems thinking, conflict resolution, and learning from one another (Daniels and Walker 1996, Walker and Daniels 2019b). Collaborative learning has been used extensively as a framework to guide collaboration efforts (e.g., Blatner et al. 2001).

One example of the principles of collaboration being applied to natural resources would be the creation of the Collaborative Forest Landscape Restoration Program (CFLRP) in 2009. The CFLRP funds landscape-scale collaborative projects that work on a broad range of sustainability and restoration goals (Schultz et al. 2012). Oftentimes, this is centered around wildfire mitigation, a topic that has united collaborative groups due to the pressing and tangible nature of the issue. An assessment of the 2020 fiscal year projects showed high demand to participate in this program, with many proposals in regions that had never applied for this funding before (Kooistra et al. 2022). These projects are restoration focused and do not typically include formal research projects.

In addition to CFLRP, there have been numerous other examples of formal and informal collaboration occurring on a range of spatial and temporal scales that address natural resource issues through the participation of engaged stakeholders (Margerum 2007). Examples include public agencies engaging in collaboration including between tribes (Charnley et al. 2007, Donoghue et al. 2010) and through collaborative groups that advise and build consensus around management in National Forests (Davis et al. 2017). Most often, stakeholders are not the final decision makers, but rather give input (Butler 2013). The Forest Service planning rule of 2012 opened the door to trying more collaborative approaches that includes additional public involvement (Ryan et al. 2018). Participants in National Forest collaboratives are convinced that this has reduced lawsuits, but some wonder if their de facto consensus model gives individuals within the collaboratives veto rights over significant changes, forcing everyone to fully agree on each part before anything can be initiated (Flitcroft et al. 2017, Urgenson et al. 2017).

Though there has been collaboration, lawsuits against state and federal agencies that manage forests are still common (Keele et al. 2006). Inconsistencies between environmental laws, precedents based on limited perspectives, and disillusionment with public input has seemingly led to lawsuits as the main change mechanism (e.g., the Plan). Courts, however, are not well suited, nor have much capacity, to manage forests. In some cases, litigants can reduce economic viability of management by slowing decisions, and on federal lands can even collect large legal fees by winning narrow lawsuits that sustain their staff. By design or accident, this often appears to intimidate decisionmakers. With increased collaboration and buy-in from the beginning of a project, there is a potential to reduce the number of lawsuits and satisfy a diverse array of stakeholders.

4.3.3 Ethnoforestry

The concept of ethnoforestry is largely one that has been used in research in India and other parts of Asia, and often centered around agroforestry. Limited work has been published in North America. However, this concept certainly has implications and usefulness in Pacific Northwest forestry. Ethnoforestry has previously been defined as “the creation, conservation, management, and use of forest resources, through continued practice of customary ways by local communities” by Dr. Deep Pandey, one of the first scholars to write and publish on this topic in the late 1990s (Pandey 1998). Many other researchers have applied ethnoforestry to their research and work, focusing on using input and knowledge from local communities in forests and resources management (Silva et al. 2011, Prabakaran et al. 2013). In our context in the Pacific Northwest, we see ethnoforestry as not exclusively using ‘customary ways’ but also new and innovative approaches that have not been attempted.

The application of a people-oriented forestry is not new. Indigenous communities have been actively managing land since time immemorial to produce food, plant material for crafts such as basket weaving, for timber production, and for a wide range of cultural values using their expert and traditional ecological knowledge, for example using fire to maintain early-seral and open conditions to promote culturally important species such as camas (*Camassia quamash* (Pursh) Greene) or beargrass (*Xerophyllum tenax* (Pursh) Nutt.) (Turner et al. 2000, 2009, Shebitz 2005, Charnley et al. 2008, Gordon et al. 2013b). Many indigenous communities use a holistic approach to management that avoids creating conservation or cultural area preserves. Instead, their prescriptions actively manage their lands for cultural resources and other values (Gordon et al. 2013a). Gifford Pinchot’s vision for the U.S. National Forests of “the greatest good for the greatest number, in the long run” is another reflection of a strong people-oriented goal.

4.4 LOOKING FORWARD TO THE FUTURE OF FOREST MANAGEMENT

In this paper we ask, what if increased collaboration, engagement, and structured learning could be applied to forestry to enhance our adaptive capacity into the future? As we consider a future for forestry that is more collaborative, inclusive, and adaptive, we believe one solution lies in implementing the following framework and process, that serve as a foundation for a field that reorients collaboration and learning to be central to sustainable forest management.

4.4.1 Ecosystem Wellbeing Framework

There are many different social-ecological models and frameworks that have been used to address natural resource and forestry issues that this research builds upon. The two that most inspired our work are: 1.) the human-forest ecosystem model by Olson et al. (2017) that advocates for management prescriptions incorporating both scientific insight and social and economic viewpoints; and 2.) the human-ecosystem model by Burch et al. (2017) that highlights specific critical resources necessary to support a social system. Although we find great value in these frameworks and understand that there are numerous other published models and frameworks that address wellbeing in some capacity (e.g., Millennium Ecosystem Assessment 2005, Villamagna and Giesecke 2014, Breslow et al. 2016), we propose a simple ecosystem wellbeing framework that is holistic yet easy to visualize and apply (Figure 4.1).

Our ecosystem wellbeing framework gives equal consideration to both community and environment wellbeing, understanding that they are inherently linked and interact with one another. Similar to the other foundational models, people are a part of the ecosystem. In order to truly achieve ecosystem wellbeing, both community and environmental wellbeing need to be considered simultaneously and with equal seriousness. This stands in contrast with some other frameworks that consider an ecosystem detached from nearby people and communities, or that demand environmental wellbeing be achieved before community wellbeing can be fully addressed (or vice versa). When the components of this model are interactive, a focus on formal, structured learning becomes the key to success. Achieving community wellbeing, and by extension ecosystem wellbeing, starts with a process of engaging people.

Figure 4.1: The ecosystem wellbeing framework that gives equal consideration to both community and environment wellbeing, focusing on the inherent interactions between these two elements where learning occurs.

4.4.2 Harnessing Collaborative Learning

There are certainly numerous approaches to collaboration in areas of the Pacific Northwest and beyond. However, we are focused on the west side of the Olympic Peninsula where formal collaboration has not been done on state lands. This area differs from the rest of the state in many ways, both ecologically and socially. The west side of the Olympic Peninsula is situated in a temperate rainforest, where the region receives well over 100 inches of rain per year and the main disturbance agent is windthrow. Additionally, rural communities in this area suffered tremendously with the rise and fall of the timber industry in the 1990s and are still recovering. Many tribal communities have reservation lands in this region that are remote and have different needs from public lands management than tribes near urban areas. These factors led us to use a form of collaborative learning to engage managers, researchers, stakeholders, and tribes (Daniels and Walker 1996, 2001).

We believe that a collaborative learning process is well suited to successfully achieve ecosystem wellbeing in our setting. This term has been defined many ways by researchers in the last 30 years. In our context we see collaborative learning as an iterative process in which (a) natural resource managers including tribal and other leaders; (b) natural, social, and policy researchers; and (c) other collaborators engage with one another, focusing on asking and answering questions about options and effects of management choices through scientifically valid comparisons. Through participatory research design and co-production of research questions, monitoring, and study objectives from the outset of a project, studies can better incorporate the values and needs of stakeholders (Fernandez-Gimenez et al. 2008, Ballard and Belsky 2010). This emphasizes that learning should be focused on the key questions as well as on the learning process itself to inform future work.

This collaborative process is focused on putting structured learning first ahead of negotiating, seeking to create an environment of trust, respect, and curiosity, where people can raise or consider novel and innovative approaches that are currently missing, creating a safe space for nurturing creative solutions. We believe this increases the likelihood of different perspectives coalescing around new ideas and out-of-the-box thinking that can be adopted into new and emerging practices. This approach to collaboration, which situates learning as central to its success and brings diverse, often opposing viewpoints together to test their range of ideas and feedback, can bring success and can further our adaptive capacity. This can ensure the process to produce work is more equitable by facilitating stakeholder engagement from the beginning of a given project including research development, design, and monitoring. The input gained from this bottom-up approach can be directly fed into management prescriptions that meet the needs of the entire ecosystem, people and the environment. We propose the field of ethnoforestry as the necessary context for implementing ideas and knowledge generated from the collaborative learning process.

4.4.3 Ethnoforestry: Our Variant

We believe ethnoforestry can be used to better meet forest management goals. We build off the previous work and, in our context, define the field of ethnoforestry as people-focused forest management. *Ethno* comes from the Ancient Greek *εθnυs* meaning ‘nation’ or ‘folk’. In the forest management context, ethnoforestry requires the study of all constituencies (managers, tribal peoples and nations, and stakeholders) who shape, are affected by, and inform forest policy. This entails people’s affect, behavior, knowledge, feelings, preferences, and values, in so far as it is associated with a forest ecosystem. This differs from forestry, which inherently includes certain groups of people such as managers, operators, loggers, and more. Ethnoforestry also requires the inclusion of those that are affected (economically, culturally, socially, etc.) by forest management but that often do not get a seat at the decision-making table. In many cases this includes rural community members and tribes.

The science of ethnoforestry draws from diverse and interconnected disciplines including cultural anthropology, human geography, forestry, ecology, history, and public policy and governance. Similar to ethnobotany, ethnozoology, or ethnoecology, ethnoforestry can also be situated as under the umbrella of ethnoscience (Sturtevant 1964).

Although ethnoforestry certainly advocates for the involvement of all local communities, including tribal communities, it should not be thought of as exclusively indigenous. Ethnoforestry seeks to ensure that people, especially those who are invested (socially, culturally, economically, spiritually, etc.) in the outcome of public lands management, be included in forest management. We advocate for the consideration of expert, local, scientific, and traditional ecological knowledge into this process to ensure it is meeting the needs of all constituencies (Grant and Miller 2004).

4.4.4 Interactions

A key tenet of ethnoforestry is that people are central to the process. As such, ethnoforestry can only be successfully achieved through the lens of the ecosystem wellbeing framework that requires both communities and the environment to be considered simultaneously. Ethnoforestry also requires collaborative learning for its success, where three distinct groups must be engaged including 1.) forest managers; 2.) researchers; and 3.) tribes and stakeholders. These groups must all be part of the research design and implementation as they each bring important perspectives and expertise to the table (e.g., researchers bringing study design or statistical frameworks; tribes and stakeholders bringing their unique needs and knowledge). Through this, results may have a better chance of connecting back to management due to the involvement and buy-in from key players from the outset, the development of tangible and specific ecological and/or forest management problems being addressed, and a clear emphasis on learning (Bormann et al. 2007a, Greig et al. 2013). We believe that this framework, process, and field presented (Figure 4.2) was central to the success of our work. This large-operational scale research provides an example of how these elements can come together.

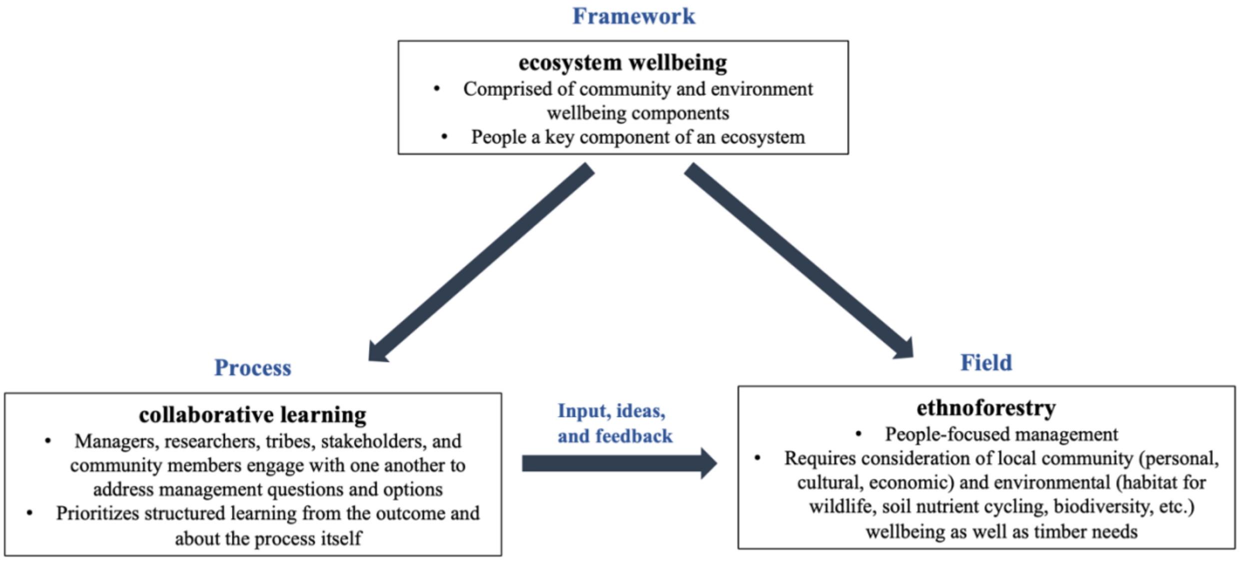


Figure 4.2: The interaction of the ecosystem wellbeing framework, collaborative learning, and ethnoforestry.

4.5 ETHNOFORESTRY IN PRACTICE: CASE STUDY FROM THE OLYMPIC PENINSULA, WA

4.5.1 Study Background

A 20,000-acre adaptive management project called the Type 3 (T3) Watershed Experiment (Chauvin et al. 2021) provides a case study on state trust lands in the Olympic Experimental State Forest (OESF) managed by Washington Department of Natural Resources (DNR). This forest lies on the outer Olympic Peninsula, known for fast-growing forests, very infrequent wildfire, and occasional windstorms. This project seeks to build institutional and societal capacity to learn and adapt at a fast enough pace to address critical needs of forests and communities on the Olympic Peninsula in the face of climate and other changes. The scarcity of new solutions in Pacific Northwest forestry over the last 30 years suggested limited capacity and motivated this strategic application of ethnoforestry.

Through its policy for sustainable forests, DNR manages 850,000 ha (2.1 million acres) of state forested trust lands "…to produce long-term, sustainable trust income and environmental and other benefits for the people of Washington" (Washington Department of Natural Resources 2006). The fiduciary responsibility has pushed DNR to maximize net present value through 40- to 50-year conifer rotations on operable areas not included in reserves. Driven by available funding, administrative efficiencies, and legal strategies by stakeholders on different sides, DNR's array of management options (its toolbox) became very limited. The T3 Watershed Experiment was designed to explore whether the DNR management toolbox could be expanded by applying ethnoforestry. The ecosystem wellbeing framework helped broaden the potential goals beyond standard conifer rotations and late-seral habitat to include emerging environmental concerns, and more specific social and economic concerns associated with community wellbeing. The collaborative learning process was applied to bring in knowledge and ideas from participating researchers, managers, tribes, and stakeholders, and several possible innovations and solution spaces emerged, some that appear to better reflect what people want without reducing net present value[1]. This approach has real potential to build the social and scientific mandates behind active management on state forest lands.

The people focus of ethnoforestry led to increased attention on both tribal and non-tribal forest users. The Olympic Peninsula tribes have rights to hunt, fish, and harvest plant material on reservation, ceded, and Usual and Accustomed lands, many of which are now managed by DNR and the USDA Forest Service. Species such as beargrass, cedar bark (*Thuja plicata* Donn ex D.

---

[1] Project scientists are exploring large uncertainties in existing growth and yield models for projecting future revenue of ethnoforestry prescriptions and how this might change broad-scale planning. Projections will form hypotheses to be evaluated through time.

Don), and red huckleberry (*Vaccinium parvifolium* Sm) are frequently harvested to make anything from baskets to teas (Arnett and Crawford 2007, Shebitz et al. 2009, Hummel et al. 2012, Hummel and Lake 2015). Additionally, some residents on the Olympic Peninsula work in an informal market harvesting non-timber forest products (NTFP) from public lands such as salal (*Gaultheria shallon* Pursh), Oregon grape (*Mahonia nervosa* (Pursh) Nutt.), and evergreen boughs (Hansis 1998, Lynch and McLain 2003). The number of jobs and profits from NTFP industry is difficult to quantify, but certainly contributes to local, state, tribal, and federal economies (Vaughan et al. 2013, Frey et al. 2019).

4.5.2 Community Engagement

To successfully create new ethnoforestry prescriptions, we engaged managers, tribes, stakeholders, and local communities through collaborative learning. This provided the necessary information and input to create ethnoforestry prescriptions, and by extension contribute to community wellbeing. In order to understand the ways in which current management could change to have a positive impact on their wellbeing, we used mixed qualitative methods to conduct semi-structured interviews with local people on the westside of the Olympic Peninsula (Dexter 1970, Terkel 1974). Through these interviews, key themes emerged around the changes and reduction in abundance of particular plant species (with beargrass and cedar being a common response) and a decline in the population of ungulates over the last several decades, with a lack of appropriate forage material cited as a contributing factor (Shebitz 2005, Cook et al. 2013, Ulappa et al. 2020). These changes to the local environment have direct personal, cultural, economic, and social impacts on the livelihoods of both tribal and non-tribal residents.

Through the collaborative learning process, our research team also hosted numerous engagement meetings where principal investigators presented the T3 Watershed Experiment novel treatments. This included two 8-hour conferences, three 2-hour sessions focused on individual prescriptions, presentations at various meetings, and countless one-on-one or small group meetings with stakeholders to gain additional insight. These engagement efforts were opportunities for anyone to engage, listen, comment, or offer feedback. In addition, the team hosted a field tour that brought together nearly 40 people representing researchers, managers, tribes, forest industry, business development, environmental groups, and engaged community members. The feedback from all of these outreach events was critical to ensuring the study met the needs of local people. The input and conclusions drawn from the community interviews and outreach efforts were used to directly inform the experimental study plan and generate ethnoforestry prescriptions. Eight different learning groups made up of researchers, managers, tribes, and stakeholders have been formed around particular topics (e.g., invasive species, tribal needs, remote sensing, cedar browse, economics, and history) that will continue to inform research questions, implementation, and monitoring efforts into the future (Bliss et al. 2001). These groups allow anyone who has interest or expertise in a particular topic to be engaged. This allows for continued relationship building, collaboration, and learning. While some groups are focused on staying informed about particular aspects of the study, others are putting together sub-studies to inform future management (e.g. cedar browse learning group).

4.5.3 Expanding the Management Toolbox

Possible solution spaces in the T3 Watershed Experiment have taken the form of new management tools to be tried out for possible broader use in the future. New directions include increasing ways to diversify stands and landscapes that build resilience to climate and other uncertainties, speed late-seral development, support wildlife (e.g., insects, birds, elk), diversify forest products (e.g., red alder (*Alnus rubra* Bong.), cedar, culturally important species), and build back early-seral habitat actively and passively. Key to our approach to adaptation is trying new forest management ideas at an operational-scale where true costs and benefits are easier for all to see. The T3 Watershed Experiment is comparing 7 upland and 5 riparian operational-scale (>30 acre) prescriptions (4 novel upland and 3 novel riparian) placed on 16 watersheds (Figure 4.3). Prescriptions, initially totaling about 2000 acres, were developed to be applied as part of 4 landscape-scale strategies:

> **Control (no-action):** The only possible strategy for the Control watersheds is to maximize carbon sequestration, but this is not possible on a widespread basis given the Trust mandate. The Control serves to provide evidence of background changes critical to interpreting the other strategies. DNR has committed to one decade of no-action at this point.
>
> **Standard Practice:** Continue the current best practice and plan as set forth in the OESF forest land plan (Washington Department of Natural Resources 2016) including harvesting for revenue and management for various upland and stream habitats.
>
> **Alternative-1 Integration:** Seeks greater integration of additional ecological concerns (early-seral habitat, riparian function, and fish populations mainly) with continued revenue generation and habitat mandates—by applying the latest environmental science knowledge.

Alternative-2 Integration: Seeks greater integration of community wellbeing concerns by applying perspectives and knowledge from diverse collaborators, along with social and environmental science developments, including increasing cultural understory species, ungulates, red alder, cedar, fish populations, and stakeholder and tribal engagement. This is accomplished through ethnoforestry prescriptions.

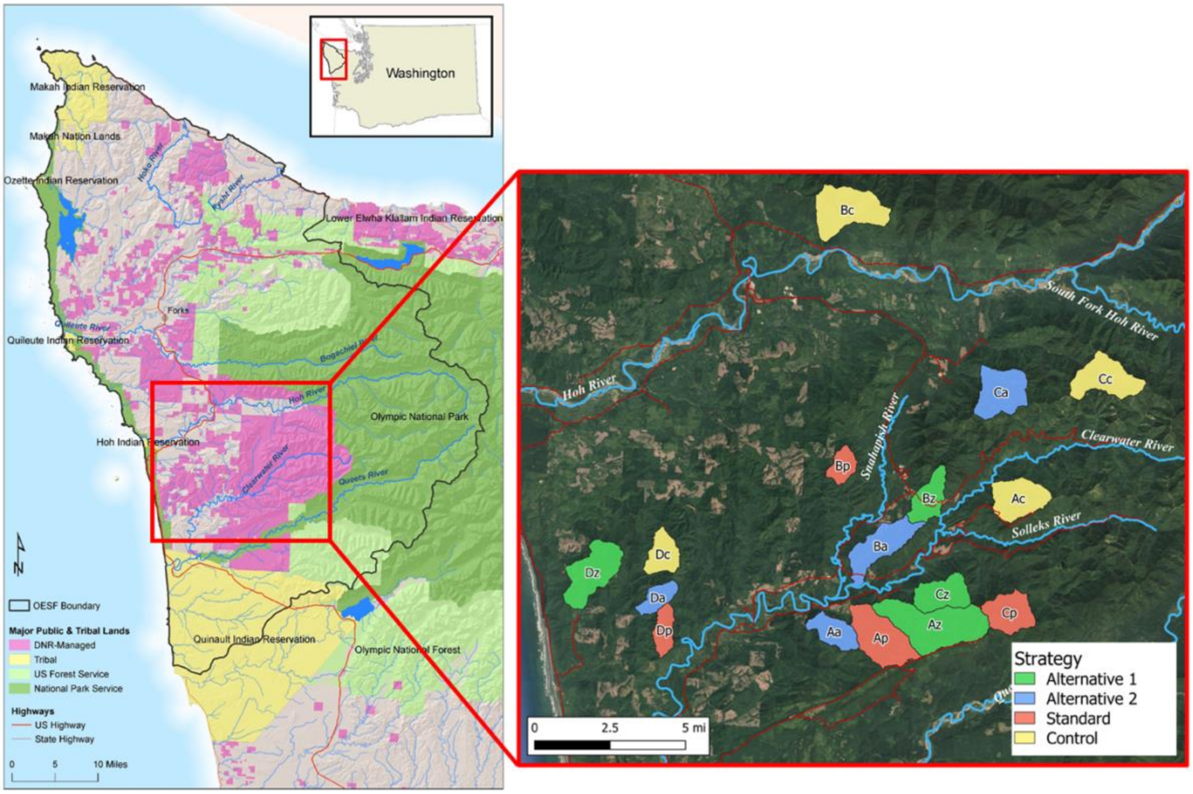


Figure 4.3: The location of the T3 Watershed Experiment, taking place on the westside of the Olympic Peninsula within the Washington DNR's Olympic Experimental State Forest.

Here, we describe the two upland ethnoforestry prescriptions developed with community outreach being applied in the four replicate Alternative-2 Integration watersheds.

Ethnoforestry with variable-density planting

In a typical westside Olympic Peninsula forest, the first two decades following a timber harvest or major disturbance results in a pulse of available nutrients, space, and sunlight reaching the forest floor. This can result in a reestablishment of sun-tolerant graminoids, forbs, and fast-growing shrubs and hardwood trees (e.g., red alder) and add structural complexity (Swanson et al. 2011). Most often, broadcast herbicide mixtures are used prior to planting to control species that compete with the evenly spaced, planted Douglas-fir. Typically, competition from naturally regenerating and overly abundant species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is not controlled and is instead reduced during precommercial thinning around age 15, but usually not before shading out most understory plants. This herbicide and evenly distributed planting approach truncates the time and space for early-seral species that would have persisted much longer under natural succession (Donato et al. 2012, Bormann et al. 2015).

Many managers see all competing understory species as “brush”, which stands in contrast to the view of many community members and some researchers who find ecological and social value in these species. Through the collaborative learning process, we learned that stakeholders and tribes are clearly interested in ungulates that use and depend on understory as forage and in plant harvesting for their cultural, economic, or personal use. Researchers were interested in the regional diminishment of species and ecological processes associated with declining early-seral forest, especially in the coastal Pacific Northwest (Phalan et al. 2019).

Instead of viewing this as a simple choice or trade-off, we sought innovative solutions to better integrate conifer production and early-seral habitat by applying an ethnoforestry prescription based on the feedback and outcomes of the collaborative learning process. To achieve this, the variable-density planting prescription will include planting conifers in varying sized clumps (ranging from 4-tree to 36-tree clumps), leaving interstitial space between clumps to actively promote understory species that are valuable for ecosystem wellbeing and exclude excessive ingrowth of seedlings and non-favorable understory species. Growth of evenly distributed conifers versus clumps is poorly understood and generally not accounted for in standard growth and yield models. Means of controlling species in the interstitial area to economically favor ungulates, insects, or cultural species is also poorly known. Due to the remote location and steep slopes in treatment areas, it is an undesirable location for personal harvesting. Instead of focusing on plant material for people, we will instead promote development of desirable understory plants that are beneficial to ungulates, a key concern of local communities and tribes. This will be accomplished through one or more re-entries after planting to manually remove dominant or recalcitrant understory species and seedlings (e.g., scotch broom (*Cytisus scoparius* (L.) Link), salal, or western hemlock seedlings).

These uncertainties were used to build this prescription that includes a sub-study to examine relative effectiveness of different clumping patterns (Figure 4.4). The prescription increases heterogeneity at multiple scales and focuses on learning why variable-density planting might be successful. If this approach works, doors could open to a myriad of planting arrangements and understory management that could be tailored for varying ecosystems and community needs (Halpern and Spies 1995).

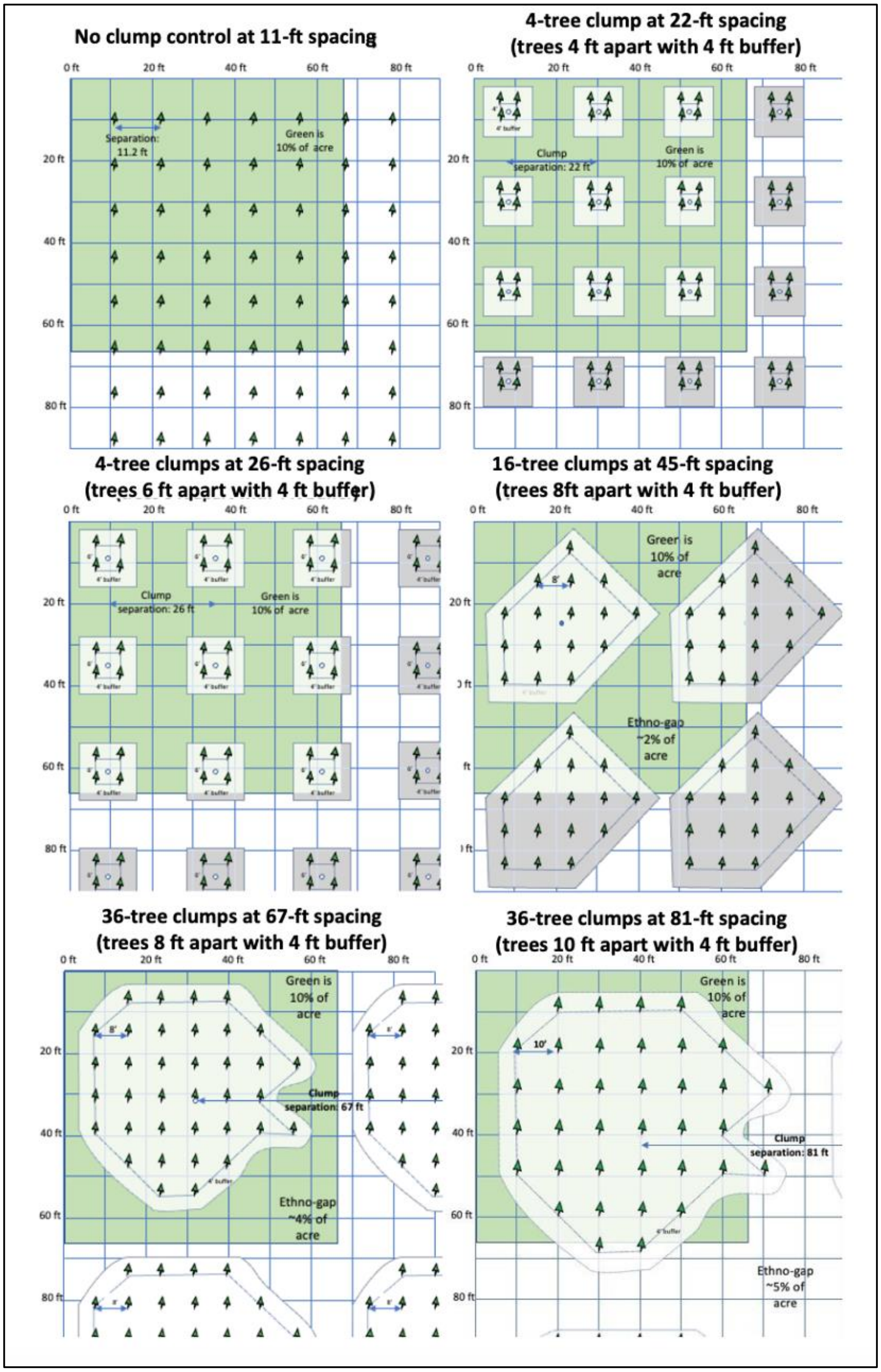

No clump control at 11-ft spacing
Separation: 11.2 ft
Green is 10% of acre
4-tree clump at 22-ft spacing (trees 4 ft apart with 4 ft buffer)
Clump separation: 22 ft
Green is 10% of acre
4' buffer
4-tree clumps at 26-ft spacing (trees 6 ft apart with 4 ft buffer)
Clump separation: 26 ft
Green is 10% of acre
4' buffer
16-tree clumps at 45-ft spacing (trees 8ft apart with 4 ft buffer)
Green is 10% of acre
8'
Ethno-gap ~2% of acre
36-tree clumps at 67-ft spacing (trees 8 ft apart with 4 ft buffer)
Green is 10% of acre
8'
Clump separation: 67 ft
4' buffer
Ethno-gap ~4% of acre
36-tree clumps at 81-ft spacing (trees 10 ft apart with 4 ft buffer)
Green is 10% of acre
10'
Clump separation: 81 ft
4' buffer
Ethno-gap ~5% of acre
0 ft
20 ft
40 ft
60 ft
80 ft

Figure 4.4: Conifer clumping and interstitial arrangements in the variable density planting treatment. Options include no-clump controls, 4, 16, and 36 tree clumps with varying spacing, and interstitial space open in between for recruitment of valuable understory species.

Ethnoforestry with variable-ratio polyculture

On the Olympic Peninsula, Douglas-fir is predominately planted after harvest, with other conifers planted historically less than 10% of the time; just recently this jumped to 40% (M. Perry Pers. Comm.). Combined with natural regeneration of hemlock, these two species are favored because they are well-suited for short-rotation, dimensional-lumber production. Benefits from increasing the diversity of tree species, mainly cedar and alder, and concerns over reduced heterogeneity were raised by tribes, stakeholders, and researchers in the collaborative learning process.

The abundance of western red cedar has declined substantially in the last 75 years, resulting from demand, difficulty in re-establishment, and lower compatibility with short-rotation culture. Cedar manufacturing has also plummeted from its heyday in the mid-late 1900s. Cedar’s cultural and ecological value cannot be overstated. Uses for housing, basketry, clothing, canoes, and totems are well known (Johnson et al. 2021). Many indigenous peoples have historically and currently strip cedar bark annually (Zahn et al. 2018) and have noted the difficulty in finding cedar trees in accessible locations for these ceremonies. Cedar is also one of the longest living and largest trees of special importance to late-seral conditions, such as nesting and roosting for Northern spotted owls and marbled murrelets.

Abundance of harvestable red alder on the Peninsula has also declined to the point that local alder mills are importing logs from Canada to remain in business (Sweitzer Pers. Comm.).

Much effort has been given in effectively controlling alder in young stands, with almost no effort given to learning to plant and grow alder for profit, even though it often has higher stumpage value than Douglas-fir. Alder's ecological value is well established as the predominant N_2 fixing species in the Pacific Northwest that can also build available nutrients and organic matter in the mineral soil and speed weathering release of nutrients from minerals (Binkley et al. 1992, Bormann et al. 1994, Edmonds and Tuttle 2010). Other benefits include higher understory biodiversity (Deal 2007) and greater understory biomass (Hanley et al. 2006). Rapid early growth has the potential to capture carbon more effectively than conifers, at least for the first 20 to 30 years (Binns et al. 2021).

Concern over declining heterogeneity on the "vast tree-farm landscape" was a concern of some stakeholders and researchers who preferred more natural looking stands. Others worried about future, more extreme pest and pathogen outbreaks on landscapes lacking heterogeneity. An example of the latter is planting of Douglas-fir near the Pacific Ocean, where its pathogen, Swiss needle cast, has already been increasing (Ritóková et al. 2016). Other diseases and their interactions under a changing climate are of concern as well (Agne et al. 2018).

The collaborative learning process allowed for potential innovations to flourish in this prescription as well. The idea of growing alder and cedar together emerged as a way to connect to community wellbeing and at the same time address ecological concerns. This operational-scale, ethnoforestry prescription allows for 2 alder rotations at 30-35 years with a single cedar rotation of 60-70 years allowing it to achieve much higher value. How to grow alder and cedar intentionally and together is uncertain so a variable-ratio approach will be used to explore options and, like variable-density planting, includes a sub-study to explore how well individual ratios work. In the variable-ratio polyculture prescription, 5 stands will be planted with red alder and western red cedar at varying ratios, (100:0, 50:50, 0:100, 25:75, and 75:25; Figure 4.5). These mixes will be planted in 5- to 10-acre patches within operational-sized units of 30+ acres. The primary purposes are to produce net revenue from rotations of high-value western red cedar and red alder, while also producing additional benefits such as increased local jobs through value-added manufacturing, adding heterogeneity, increasing soil productivity, and generating future options for late-seral habitat or tribal uses associated with larger trees.

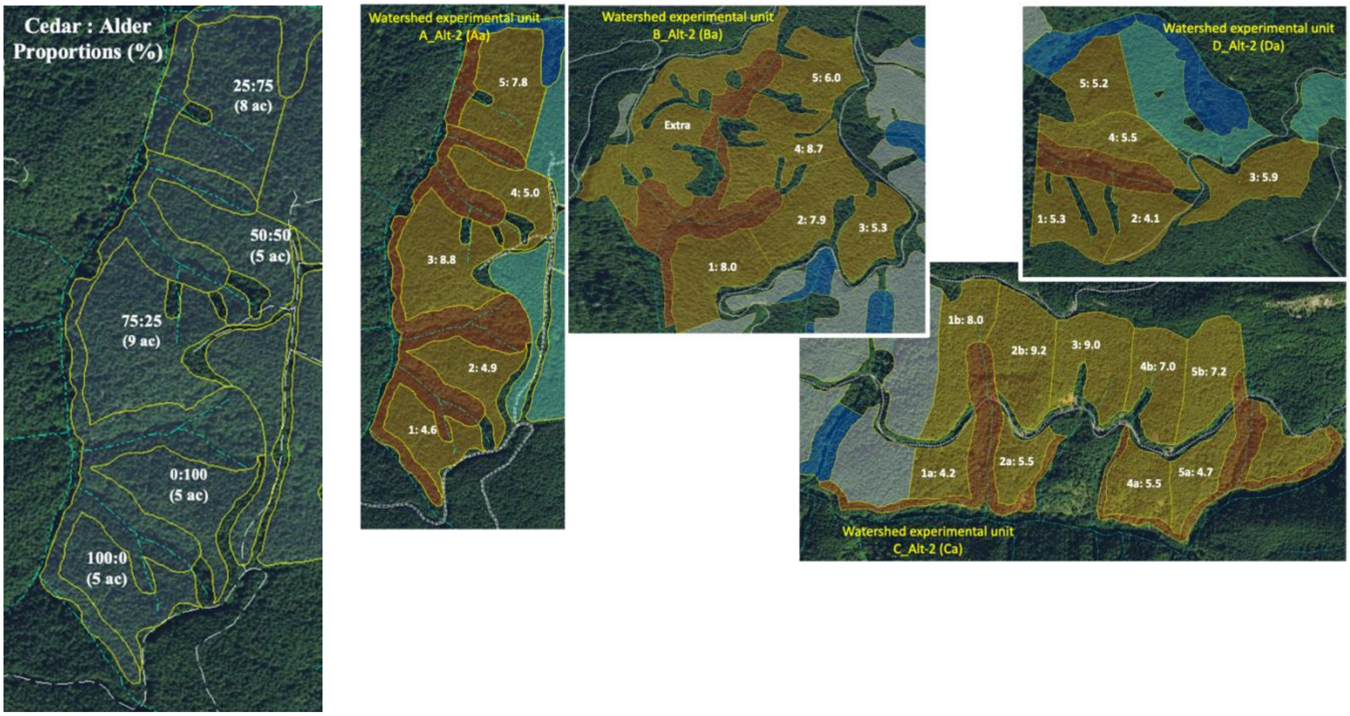


Figure 4.5: The variable-ratio polyculture treatment arrangement with varying proportions of western red cedar and red alder planted in subunits across the four watersheds (Aa, Ba, Ca, and Da) with associated riparian prescriptions (dark orange). Subunits range from approximately five to ten acres (right). The proportions of western red cedar and red alder include 0:100, 25:75, 50:50, 75:25, and 100:0 respectively (left).

4.5.4 Learning about Wellbeing and Collaborative Learning

Through the development and implementation of this experiment, collaborative learning was used to generate the input, knowledge, and feedback that made the ethnoforestry prescriptions possible. This allowed the study plans, research questions, and treatments themselves to be shaped by the communities who will be most affected by this research and its outcomes. By creating space for ideas and questions from managers, researchers, tribes, stakeholders, and local people, we hoped to generate research with widespread buy-in that could be directly connected to future management decision making. The wellbeing framework eased tribal and stakeholder engagement and facilitated new prescriptions that reflect their ideas and needs, which in turn helped gain support from researchers and managers.

Our experience suggests that this case would have failed if it had not been designed and applied at the operational scale. Research, historically done at small scales, rarely translates easily to management. We suggest that an operational-scale, along with research participation, has also helped tribes and stakeholders perceive manager's commitment to learning and trying new ideas with more seriousness. Study of the economics and application issues will provide for a more informed debate about prescription preferences. Finally, we postulate that the extent and speed of adaptation depends on a working collaboration of researchers, managers, and tribes and stakeholders—all are necessary.

4.6 CONCLUSIONS

The three elements described in this paper--the ecosystem wellbeing framework, collaborative learning, and the field of ethnoforestry--are intended to expand the forestry toolbox by bringing in new perspectives and innovations when developing management strategies and prescriptions. This facilitates adaptation by embracing collaborative learning and having a greater consideration of new and emerging needs of local people. Experimental studies will allow managers to make informed decisions on potential changes to forest management in the future. As we look ahead to the next phase on forest management in the Pacific Northwest, we think innovation, collaboration, and structured learning will allow us to adapt to the changing needs of our climate, communities, and the environment that we all cherish and depend on.

4.7 REFERENCES

Agne, M. C., P. A. Beedlow, D. C. Shaw, D. R. Woodruff, E. H. Lee, S. P. Cline, and R. L. Comeleo. 2018. Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, U.S.A. *For. Ecol. Manag.* 409:317–332.

Arnett, J., and R. Crawford. 2007. *The Status of Huckleberries in Washington State prepared for The Status of Huckleberries in Washington State*. Natural Heritage Report. WA Department of Natural Resources.

Ballard, H. L., and J. M. Belsky. 2010. Participatory action research and environmental learning: Implications for resilient forests and communities. *Environ. Educ. Res.* 16(5–6):611–627.

Barrett, K. J., J. B. Cannon, A. M. Schuetter, and A. S. Cheng. 2021. Effects of collaborative monitoring and adaptive management on restoration outcomes in dry conifer forests. *For. Ecol. Manag.* 488:1–9.

Binkley, D., P. Sollins, R. Bell, and D. Myrold. 1992. Biogeochemistry of Adjacent Conifer and Alder-Conifer Stands. *Ecol.* 73(6):2022–2033.

Binns, D., G. Dalan, I. Ganguly, and M. Maki. 2021. Red alder: A natural climate solution for the Northwest? *The Learning Forest*:6–8.

Blatner, K. A., M. S. Carroll, S. E. Daniels, and G. B. Walker. 2001. Evaluating the application of collaborative learning to the Wenatchee fire recovery planning effort. *Environ. Impact Assess. Rev.* 21(3):241–270.

Bliss, J., G. Aplet, C. Hartzell, P. Harwood, P. Jahnige, D. Kittredge, S. Lewandowski, and M. lou Soscia. 2001. Community-based ecosystem monitoring. *J. Sustain. For.* 12(3–4):143–167.

Bormann, B., K. Cromack Jr, and W. O. Russell III. 1994. *Influences of red alder on soils and long-term ecosystem productivity*. Corvallis, OR.

Bormann, B., and R. Kiester. 2004. Options forestry: Acting on uncertainty. *J. For.* 102(4):22–27.

Bormann, B. T., R. L. Darbyshire, P. S. Homann, B. A. Morrissette, and S. N. Little. 2015. Managing early succession for biodiversity and long-term productivity of conifer forests in southwestern Oregon. *For. Ecol. Manag.* 340:114–125.

Bormann, B. T., R. Haynes, and J. Martin. 2007. Adaptive management of forest ecosystems: Did some rubber hit the road? *BioScience* 57(2):186–191.

Breslow, S. J., B. Sojka, R. Barnea, X. Basurto, C. Carothers, S. Charnley, S. Coulthard, N. Dolšak, J. Donatuto, C. García-Quijano, C. C. Hicks, A. Levine, M. B. Mascia, K. Norman, M. Poe, T. Satterfield, K. St Martin, and P. S. Levin. 2016. Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management. *Environ. Sci. Policy* 66:250–259.

Brown, G. G., and T. Squirrell. 2010. Organizational Learning and the Fate of Adaptive Management in the US Forest Service. *J. For.* 108(8):379–388.

Burch, W. R., G. E. Machlis, and J. E. Force. 2017. *The Structure and Dynamics of Human Ecosystems Toward a Model for Understanding and Ethics*. Yale University Press.

Butler, W. H. 2013. Collaboration at arm's length: Navigating agency engagement in landscape-scale ecological restoration collaboratives. *J. For.* 111(6):395–403.

Charnley, S., A. P. Fischer, and E. T. Jones. 2007. Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *For. Ecol. Manag.* 246:14–28.

Charnley, S., A. P. Fischer, and E. T. Jones. 2008. *Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest*. Portland, Oregon. Gen. Tech. Rep. PNW-GTR-751.

Chauvin, C., T. Minkova, and B. Bormann. 2021. Expanding the tool box: The type 3 watershed experiment. *The Learning Forest* :2–5.

Colfer, C. 2010. *The Complex Forest: Communities, Uncertainty, and Adaptive Collaborative Management*. Page (C. Colfer, editor). 1st edition. Routledge.

Cook, R. C., J. G. Cook, D. J. Vales, B. K. Johnson, S. M. Mccorquodale, L. A. Shipley, R. A. Riggs, L. L. Irwin, S. L. Murphie, B. L. Murphie, K. A. Schoenecker, F. Geyer, P. B. Hall, R. D. Spencer, D. A. Immell, D. H. Jackson, B. L. Tiller, P. J. Miller, and L. Schmitz. 2013. Regional and seasonal patterns of nutritional condition and reproduction in elk. *Wildl. Monogr.* 184:1–45.

Cundill, G., and R. Rodela. 2012. A review of assertions about the processes and outcomes of social learning in natural resource management. *J. Environ. Manag.* 113:7–14.

Daniels, S. E., and G. B. Walker. 1996. Collaborative Learning: improving public deliberation in ecosystem-based management. *Environ. Impact Asses. Rev.* 16:71–102.

Daniels, S. E., and G. B. Walker. 2001. *Working Through Environmental Conflict: The Collaborative Learning Approach*. Praeger.

Davis, E. J., E. M. White, L. K. Cerveny, D. Seesholtz, M. L. Nuss, and D. R. Ulrich. 2017. Comparison of USDA Forest Service and stakeholder motivations and experiences in collaborative federal forest governance in the western United States. *Environ. Manag.* 60(5):908–921.

Deal, R. L. 2007. Management strategies to increase stand structural diversity and enhance biodiversity in coastal rainforests of Alaska. *Biol. Conserv.* 137(4):520–532.

Dexter, L. A. 1970. *Elite and Specialized Interviewing* . Northwestern University Press .

Donato, D. C., J. L. Campbell, and J. F. Franklin. 2012. Multiple successional pathways and precocity in forest development: Can some forests be born complex? *J. Veg. Sci.* 23(3):576–584.

Donoghue, E. M., S. A. Thompson, and J. C. Bliss. 2010. Tribal-federal collaboration in resource management. *J. Ecol. Anthropol.* 14(1):22–38.

Edmonds, R. L., and K. M. Tuttle. 2010. Red alder leaf decomposition and nutrient release in alder and conifer riparian patches in western Washington, USA. *For. Ecol. Manag.* 259(12):2375–2381.

Fernandez-Gimenez, M. E., H. L. Ballard, and V. E. Sturtevant. 2008. Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring: a Study of Five Community-Based Forestry Organizations in the western USA. *Ecol. Soc.* 13(2).

Flitcroft, R. L., L. K. Cerveny, B. T. Bormann, J. E. Smith, S. T. Asah, and A. P. Fischer. 2017. The Emergence of Watershed and Forest Collaboratives. Pages 116–130 *People, Forests, and Change*. Island Press, Washington, DC.

Frey, G. E., S. J. Alexander, J. L. Chamberlain, K. A. Blatner, A. W. Coffin, and R. J. Barlow. 2019. Markets and Market Values of Nontimber Forest Products in the United States: A Review, Synthesis, and Identification of Future Research Needs. *J. For.* 117(6):613–631.

Gordon, J. C., J. Sessions, J. Bailey, D. Cleaves, V. Corrao, A. Leighton, L. Mason, M. Rasmussen, H. Salwasser, and M. Sterner. 2013a. *Assessment of Indian forests and forest management in the United States: Volume 2*.

Gordon, J., J. Sessions, J. Bailey, D. Cleaves, V. Corrao, A. Leighton, L. Mason, M. Rasmussen, H. Salwasser, and M. Sterner. 2013b. *An assessment of Indian forests and forest management in the United States: Executive summary*.

Grant, K. L., and M. L. Miller. 2004. A cultural consensus analysis of marine ecological knowledge in the Solomon Islands. *SPC Tradit. Mar. Resour. Manag. Knowl. Inf. Bull.* 17.

Greig, L. A., D. R. Marmorek, C. Murray, and D. C. E. Robinson. 2013. Insight into enabling adaptive management. *Ecol. Soc.* 18(3).

Halpern, C. B., and T. A. Spies. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecol. Appl.* 5(4):913–934.

Hanley, T. A., R. L. Deal, and E. H. Orlikowska. 2006. Relations between red alder composition and understory vegetation in young mixed forests of southeast Alaska. *Can. J. For. Res.* 36(3):738–748.

Hansis, R. 1998. A political ecology of picking: Non-timber forest products in the Pacific Northwest. *Hum. Ecol.* 26(1):67–86.

Hummel, S., S. Foltz-Jordan, and S. Polasky. 2012. *Natural and Cultural History of Beargrass (Xerophyllum tenax)*. Portland, Oregon. Gen. Tech. Rep. PNW-GTR-864.

Hummel, S., and F. K. Lake. 2015. Forest site classification for cultural plant harvest by tribal weavers can inform management. *J. For.* 113(1):30–39.

Johnson, A., A. E. Clavijo, G. Hamar, D. A. Head, A. Thoms, W. Price, A. Lapke, J. Crotteau, L. K. Cerveny, H. Wilmer, L. Petershoare, A. Cook, and S. Reid. 2021. Wood products for cultural uses: Sustaining native resilience and vital lifeways in southeast Alaska, USA. *Forests* 12(1):1–26.

Keele, D. M., R. W. Malmsheimer, D. W. Floyd, and J. E. Perez. 2006. Forest Service Land Management Litigation 1989-2002. *J. For.* 104(4):196–202.

Kooistra, C., E. Sinkular, and C. Schultz. 2022. Characterizing the Context and Demand for the US Forest Service’s Collaborative Forest Landscape Restoration Program in 2020. *J. For.* 120(1):64–85.

Larson, A. J., R. T. Belote, M. A. Williamson, and G. H. Aplet. 2013. Making monitoring count: Project design for active adaptive management. *J. For.* 111(5):348–356.

Lynch, K. A., and R. J. McLain. 2003. *Access, labor, and wild floral greens management in western Washington’s forests*. Portland, Oregon. Gen. Tech. Rp. PNW-GTR-585.

Margerum, R. D. 2007. Overcoming locally based collaboration constraints. *Soc. Nat. Resour.* 20:135–152.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: synthesis*. Island Press.

Olson, D. H., B. van Horne, B. T. Bormann, P. D. Anderson, and R. W. Haynes. 2017. Introduction: The Human-Forest Ecosystem. Pages 3–15 *People, Forests, and Change*. Island Press, Washington, DC.

Pandey, D. N. 1998. *Ethnoforestry: Local knowledge for sustainable forestry and livelihood security*. Himanshu Publications.

Phalan, B. T., J. M. Northrup, Z. Yang, R. L. Deal, J. S. Rousseau, T. A. Spies, and M. G. Betts. 2019. Impacts of the Northwest Forest Plan on forest composition and bird populations. *PNAS* 116(8):3322–3327.

Prabakaran, R., T. Senthil Kumar, and M. V. Rao. 2013. Ethnoforestry and ethnoagricultural knowledge of Malayali tribes of Chitteri hills, Tamil Nadu. *J. Bio. & Env. Sci* 12(5):12–19.

Reed, M. S., A. C. Evely, G. Cundill, I. Fazey, J. Glass, A. Laing, J. Newig, B. Parrish, C. Prell, C. Raymond, and L. C. Stringer. 2010. What is Social Learning? *Ecology and Society* 15(4).

Ritóková, G., D. C. Shaw, G. Filip, A. Kanaskie, J. Browning, and D. Norlander. 2016. Swiss needle cast in western oregon douglas-fir plantations: 20-Year monitoring results. *Forests*.

Ryan, C. M., L. K. Cerveny, T. L. Robinson, and D. J. Blahna. 2018. Implementing the 2012 forest planning rule: Best available scientific information in forest planning assessments. *For. Sci.* 64(2):159–169.

Schultz, C. A., T. Jedd, and R. D. Beam. 2012. The Collaborative Forest Landscape Restoration program: A history and overview of the first projects. *Journal of Forestry* 110(7):381–391.

Shebitz, D. 2005. Weaving Traditional Ecological Knowledge into the Restoration of Basketry Plants. *J. Ecol. Anthropol.* 9(1):51–68.

Shebitz, D. J., S. H. Reichard, and P. W. Dunwiddie. 2009. Ecological and Cultural Significance of Burning Beargrass Habitat on the Olympic. *Ecol. Restor.* 27(3):306–319.

Silva, R. R. V. da, L. C. Marangon, and A. G. C. Alves. 2011. Between ethnoecology and forestry: the role of local informants and scientists in forest research. *Interciencia* 36(7):485–492.

Spies, T. A., J. W. Long, S. Charnley, P. F. Hessburg, B. G. Marcot, G. H. Reeves, D. B. Lesmeister, M. J. Reilly, L. K. Cerveny, P. A. Stine, and M. G. Raphael. 2019. Twenty-five years of the Northwest Forest Plan: what have we learned? *Front. Ecol. Environ.* 17(9):511–520.

Spies, T. A., P. A. Stine, R. Gravenmier, J. W. Long, M. J. Reilly, and R. Mazza. 2018. *Synthesis of Science to Inform Land Management Within the Northwest Forest Plan Area*. Portland, Oregon. Gen. Tech. Rep. PNW-GTR-970.

Stankey, G. H., B. T. Bormann, C. Ryan, B. Shindler, V. Sturtevant, R. N. Clark, and C. Philpot. 2003. Adaptive management and the Northwest Forest Plan: Rhetoric and reality. *J. For.* 101(1):40–46.

Sturtevant, W. C. 1964. Studies in Ethnoscience. *Am. Anthropol.* 66(3):99–131.

Swanson, M. E., J. F. Franklin, R. L. Beschta, C. M. Crisafulli, D. A. Dellasala, R. L. Hutto, D. B. Lindenmaver, and F. J. Swanson. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Front. Ecol. Environ* 9(2):117–125.

Terkel, S. 1974. Working: people talk about what they do all day and how they feel about what they do:589.

Turner, N. J., Y. Ari, F. Berkes, I. Davidson-Hunt, Z. F. Ertug, and A. Miller. 2009. Cultural management of living trees: An international perspective. *J. Ethnobiol.* 29(2):237–270.

Turner, N. J., M. B. Ignace, and R. Ignace. 2000. Traditional Ecological Knowledge and Wisdom of aboriginal peoples in British Columbia. *Ecol. Appl.* 10(5):1275–1287.

Ulappa, A. C., L. A. Shipley, R. C. Cook, J. G. Cook, and M. E. Swanson. 2020. Silvicultural herbicides and forest succession influence understory vegetation and nutritional ecology of black-tailed deer in managed forests. *For. Ecol. Manag.* 470–471:1–16.

Urgenson, L. S., C. M. Ryan, C. B. Halpern, J. D. Bakker, R. T. Belote, J. F. Franklin, R. D. Haugo, C. R. Nelson, and A. E. M. Waltz. 2017. Visions of Restoration in Fire-Adapted Forest Landscapes: Lessons from the Collaborative Forest Landscape Restoration Program. *Environ. Manag.* 59(2):338–353.

USDA Forest Service. 1994. *Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl.*

Vaughan, R. C., J. F. Munsell, and J. L. Chamberlain. 2013. Opportunities for Enhancing Nontimber Forest Products Management in the United States. *J. For.* 111(1):26–33.

Villamagna, A., and C. Giesecke. 2014. Adapting human well-being frameworks for ecosystem service assessments across diverse landscapes. *Ecol. Soc.* 19(1).

Walker, G. B., and S. E. Daniels. 2019. Collaboration in environmental conflict management and decision-making: Comparing best practices with insights from collaborative learning work. *Front. Commun.* 4:1–12.

Walters, C. 1986. *Adaptive Management of Renewable Resources*. MacMillan Publishing Company, New York.

Washington Department of Natural Resources. 2006. *Policy for Sustainable Forests*. Olympia, Washington.

Washington Department of Natural Resources. 2016. *Olympic Experimental State Forest Habitat Conservation Plan (HCP) Planning Unit Forest Land Plan*. Olympia.

Zahn, M. J., M. I. Palmer, and N. J. Turner. 2018. "Everything We Do, It's Cedar": First Nation and Ecologically-Based Forester Land Management Philosophies in Coastal British Columbia. *J. Ethnobiol.* 38(3):314–332.

Chapter 5: Learning groups in natural resource management: collaboration on the Olympic Peninsula, WA

5.1 ABSTRACT

On the Olympic Experimental State Forest in Washington State, a new Type 3 (T3) Watershed Experiment has been established that brings together researchers, managers, stakeholders, and scientists to create novel prescriptions that seeks to expand the forest management toolbox. Throughout the study design process, the T3 team engaged with stakeholders and tribes to include their input and knowledge into the experiment to ensure the study was addressing their needs and wellbeing. While this was an effective engagement strategy, moving into the implementation phase meant re-envisioning the engagement process, leading to the natural emergence of learning groups.

These learning groups, seen as a form of social learning, brought together people of different backgrounds and interests to address specific portions of the study that they were interested in personally or professionally. These groups prioritize learning through the outcome of the work and about the learning process itself. In the first year, eight groups have formed (e.g., cedar browse, invasive species, history, carbon sequestration, etc.), and many have made significant progress toward their goals. In this paper, we discuss how the groups fell into three broad categories based on their type and level of engagement, including 1.) updates and review; 2.) information exchange; and 3.) research and monitoring. We also offer key insights on the reasons we have seen some success and offer methodologies to consider if implementing learning groups elsewhere. Lastly, we provide constraints and potential barriers for other researchers interested in creating learning groups elsewhere.

5.2 INTRODUCTION

Collaborative efforts have been increasing in natural resource management over the last three decades. Federal agencies have been working with stakeholders through collaborative groups such as the National Forest collaboratives to tackle local issues. Collaborative watershed partnerships have formed in states across the country to focus on issues around water resources and management (Bidwell and Ryan 2006). In addition, the federal government has allocated millions of dollars through the Collaborative Forest Landscape Restoration Project (CFLRP) that has funded large-scale interdisciplinary restoration work across the United States (Schultz et al. 2012). These collaborative groups follow different frameworks, typologies, and approaches. And although they may work to achieve common goals together, many collaboratives do not have a primary focus on learning, nor do they emphasize learning together.

The process of learning is cyclical, where direct experiences lead to observations and reflections that then develop into abstract concepts. These concepts can lead to testing or experimentation that can then form more direct experiences, repeating the cycle (Kolb 1984, Keen and Mahanty 2006). Pahl-Wostl (2009) defines learning in the context of natural resource management as "…an explanatory, stepwise search process where actors experiment with innovation until they meet constraints and new boundaries." In organizational learning theory, single-, double-, and triple-loop learning have been used to describe and understand how learning is being applied and potentially changes a governance structure and values (Argyris 2002, Tosey et al. 2012). Single-loop learning refers to learning in order to improve current conditions while double-loop learning refers to learning that is challenging the assumptions of the existing conditions to explore different approaches (Fabricius and Cundill 2014). Triple-loop learning has been defined broadly (Tosey et al. 2012), but refers to the assessment and subsequent change in the overarching context of these conditions (Pahl-Wostl 2009) and is sometimes described as ‘learning about learning’.

We adopt the broad umbrella of social learning for our natural resource application, where social learning is an iterative process that addresses uncertainty and can use collaboration and public participation to tackle issues (Lee 1993, Keen et al. 2005). A key aspect to ensuring successful social learning is to understand the context, location, and culture in which the work is being done (Keen and Mahanty 2006). As used by others, social learning can take many forms and have different definitions (Muro and Jeffrey 2008, Reed et al. 2010, Rodela 2011). For example, it has been applied to co-management (Schusler et al. 2003), adaptive management (Cundill et al. 2012, Jordan et al. 2016), and collaborative adaptive management (Fernández-Giménez et al. 2019). Adaptive management was originally developed to identify uncertainties, test new management approaches, and learn through the process (Walters 1986), although many attempts to enact adaptive management projects have failed to fully live up to this (Bormann et al. 2007a). Rarely is there a clear understanding of how learning should occur, including what people are learning and how they are doing it (Fabricius and Cundill 2014). We explore a social learning-based approach used to develop and run a new large-scale adaptive management study on the Olympic Peninsula.

This paper details 1.) a new application of social learning, we refer to as learning groups, being applied to a large-scale adaptive management experiment on the Olympic Peninsula; 2.) methodologies to enact these learning groups; 3.) assessment of learning group categories; 4.) key insights and themes from the first year after implementation; and 5.) constraints to this work.

5.3 THE TYPE 3 WATERSHED EXPERIMENT

A new Type 3 (T3) Watershed Experiment (Chauvin et al. 2021) has been created on lands managed by Washington Department of Natural Resources (WA DNR) within the Olympic

Experimental State Forest (OESF) in collaboration between WA DNR and the University of Washington's Olympic Natural Resources Center (ONRC; Figure 5.1). This study, set on the west side of the Olympic Peninsula, aims to expand the management toolbox by developing and studying innovative approaches to lands management and comparing them to several standard practice approaches. This 20k acre watershed experiment has an overarching goal of achieving ecosystem wellbeing, defined as having two key components that must be achieved simultaneously: community and environment wellbeing (Bobsin et al. 2023). These two elements are inherently interconnected and interact. This framework highlights that people are part of our ecosystem and their wellbeing must be considered alongside that of the environment.

A key process to achieve ecosystem wellbeing and create a large, operational-scale study that informs management must include the participation and consistent engagement of three key groups: 1.) researchers, who provide expertise in the scientific literature, study design, statistics, and research question development; 2.) forest managers who have expertise on effects of past management, treatment feasibility, harvesting operations, and logistics; and 3.) stakeholders and tribes who have their own values, needs, and knowledge of how public lands management impact individual and community wellbeing. All of these groups must collaborate together to successfully create this type of study.

The very early stages of the T3 Watershed Experiment development had occasional but limited stakeholder participation by design. There were concerns that if the study was not officially approved, it could be a waste of stakeholder's time to engage on a project that may never be implemented. As the study made progress and was accepted by the University of Washington and WA DNR, active engagement started by listening closely to a wider array of stakeholders and tribes on various components of the study.

Researchers completed semi-structured interviews with tribal and non-tribal community members, three 2-hour focus groups, two conferences, two field tours, and countless discussions, to listen to stakeholders, tribes, and community members throughout the design of the study. Research and management principal investigators used what they heard to combine with their understanding of forest ecology and managerial feasibility to better frame questions, design innovative prescriptions for experiment, and propose monitoring priorities. This led to the creation of a study that addressed what principal investigators, stakeholders, and tribes perceived to both meet community needs, concerns, and preferences and address scientific uncertainties and ecological questions simultaneously.

This initial engagement was important to ensure the study design could meet the needs of stakeholders and tribes. However, continued engagement and collaboration throughout the life of the study was always a priority. As the study design process progressed and the plan was finalized it became clear that many of those involved were interested in continued participation but had more narrow interests than the study plan as a whole. For those whose professional interests aligned with a part of the study, they were more interested in digging deeper into specific elements, for example cedar growth and establishment or invasive species. This led to a change in the typical collaboration and engagement methodologies and allowed us to rethink the structure altogether to better meet the needs of those involved. This was a joint effort between the T3 team and other engaged participants.

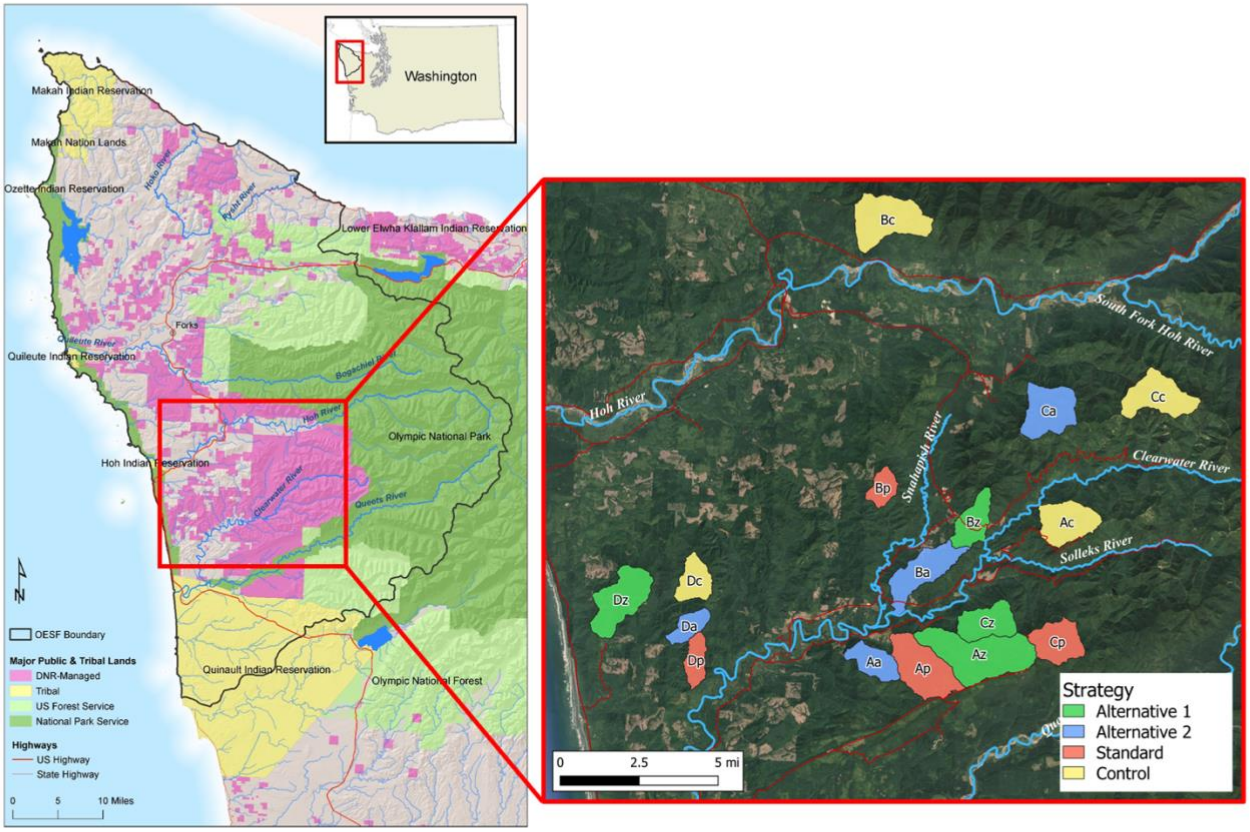


Figure 5.1: Spatial layout of the Type 3 Watershed Experiment on the west side of the Olympic Peninsula within the WA DNR's Olympic Experimental State Forest.

5.4 LEARNING GROUPS

As the T3 Watershed Experiment study plan was finalized, involved stakeholders and tribes were interested in continued participation around focused topics that they had a personal or professional interest in. Learning groups (LGs) became an obvious way to harness this interest and enthusiasm to continue collaboration, work towards study goals, and learn together. Learning groups could be considered a form of social learning, where T3 managers, researchers, stakeholders, and tribes are collaborating around a particular topic and shared goals while learning together (Reed et al. 2010). In addition, the T3 team was embarking on a new engagement structure altogether in response to the needs of those involved in order to answer key questions, address uncertainties, and learn from and about the process, leading to triple-loop learning (Pahl-Wostl 2009).

5.4.1 Learning group format

Before launching these LGs, a framework was created to lay out the goals, format, leadership, membership, and tasks. Although each LG would be different, a set of guiding principles could unite them and ensure consistency. The goal of each group was to bring together managers, researchers, stakeholders, and tribes into specific portions of the T3 study that the participants had expertise or interest in. The groups could create their own projects and goals that aligned with those of the participants and study, and assume leadership if possible.

Anyone interested in a topic could participate in any group. The researchers and managers were not gatekeepers of membership. However, the tribal LG was the exception where current members could restrict membership if a participant who wanted to be involved was not part of or working for a local tribe. This LG was focused on creating space for input, discussion, and collaboration on topics relevant to the tribes and therefore current members could decide if they wanted non-tribal members involved. In all the LGs, learning was a key component, not only about the outcome of the work, but about the learning process itself. The T3 team hired two professional facilitators familiar with the study and the region who could schedule meetings, create Zoom links, set agendas, compile notes, facilitate each meeting, and help with communication and synthesis. This was done to take the burden off other participants, allow for a neutral party to guide the group forward, and foster additional trust (Leach and Pelkey 2001, Folke et al. 2005). Each LG included the participation of the key groups including T3 researchers and mangers, a facilitator, stakeholders, and/or tribes.

5.4.2 Emergent learning group topics

Throughout the process of creating the T3 study, stakeholders and tribes would often express interest in additional topics that they wanted to see included in the study. For example, one treatment being implemented is a western red cedar (*Thuja plicata* Donn ex D. Don) and red alder (*Alnus rubra* Bong.) polyculture where these two species will be grown together in varying proportions as a replacement series. Several stakeholders expressed their concern over ungulates browsing the cedar and ultimately killing too many seedlings. This could be monitored in the T3 study but could also be further studied through a LG where browsing prevention could be tested as part of a smaller scale sub-study. T3 researchers did not have the capacity to create this sub-study but understood its importance to the community and the learning opportunity it presented. As a result, this became one of the LGs that formed naturally.

Some LGs were centered around very specific topics and others were more general. In total, eight LGs were formed that covered a broad array of topics. These included: 1.) cedar browse; 2.) invasive species; 3.) aquatic responses; 4.) carbon sequestration; 5.) economics and harvest operations; 6.) tribal; 7.) remote sensing; and 8.) history.

5.4.3 Initiating learning groups

In order to kickstart these groups, the T3 team needed to recruit members. One of the first and widely announced ways was through the May 2022 WA DNR OESF science conference, which was dedicated in its entirety to the T3 LGs. A presentation on the framework, concept, and goals kicked off the conference, followed by presentations on six potential LG topics including economics, operations, remote sensing, carbon sequestration, invasive species, and aquatic responses. These were given either by T3 researchers or stakeholders involved in the given topic. Presenters described an overview of the topic, the current status of the topic in the T3 study, and potential projects the LG could work on. Each presentation was followed by a 30–40-minute discussion where participants could voice their thoughts and opinions about these topics. This was used to determine if there was enough interest to start a LG. At the end of each session, participants could sign-up for one or more LG. Information presented in the conference was also sent out to a listserv of over 100 people who have been connected to the T3 Watershed Experiment in some way, generating additional sign-ups.

After this conference, the LG facilitators reached out to those who volunteered to participate. In the following 8 weeks, each of the groups had an initial kick-off meeting where they could meet one another and define priorities for the group. In the first year, groups started to diverge in priorities, participation, and topics of interest, leading to initial findings on the LGs success.

5.5 CATEGORIES OF LEARNING GROUPS

There have been several different classifications and typologies developed to categorize different forms of collaboration that can help understand how groups operate and function (Margerum 2008). For example, researchers have developed typologies based on key participant types in the collaborative (Moore and Koontz 2003) or the governance structure (Hill et al. 2012, Diaz-Kope and Miller-Stevens 2015). In our case, we found that because the various LGs focused on a wide range of topics and were made up of participants from many different organizational types (e.g. government agency, universities, non-profits, etc.), they did not fit well in one particular existing typology. Instead, we observed that the LGs fell into three different categories that distinguished between their type and level of engagement. These categories included 1.) updates and review; 2.) information exchange; and 3.) research and monitoring.

1.) **Updates and review**: members have limited capacity to work on additional projects but would like to stay updated and informed about any relevant T3 information. Members may review relevant documents and provide feedback throughout the year. These groups tend me meet less frequently (3 to 4 times per year).

2.) **Information exchange**: members may work in the LG topic professionally, oftentimes having expertise in the subject matter. The T3 team and participating stakeholders share information between their organizations and work towards the co-development of projects, including data sharing, future monitoring work, or running new analyses.

3.) **Research and monitoring**: members are interested in putting together sub-studies to investigate a particular topic within the T3 study area, often topics that were not possible to include in the main study. These groups are largely made up of the most active stakeholders, participants with expertise within the focal topic, and have a clear leader(s) who pushes them forward (other than the facilitator). These groups are the most active and have accomplished the most in the first year of LG creation.

The three categories have their own types of priorities, involvement, and goals (Table 5.1). Each of these allow T3 researchers and managers to continue to build partnerships and relationships with these stakeholders and tribes. Several overarching themes have begun emerging through this process.

Table 5.1: An overview of the three LG categories: 1.) updates and review; 2.) information exchange; and 3.) research and monitoring

	Updates and review	Information exchange	Research and monitoring
Organization structure	Periodic meetings to provide updates and information between stakeholders and tribes and the T3 team, allowing space for feedback and learning between groups.	T3 researchers and managers, stakeholders, and tribes share information (e.g., updates, data, protocols, etc.) from their respective organizations. There is an exchange of information and learning between members and organizations.	T3 researchers and mangers work alongside LG members to create a sub-study that is focused on a specific element of the T3 study. Members often meet once a month and are asked to give input and review documents, literature, and plans outside of meeting times.
Overarching goals	Updating key groups on any progress or new information in the T3 study. Review of necessary and relevant documents.	Exchanging information between T3 team and stakeholders who have professional experience in the given topic. Work on co-development of projects that benefit both groups (e.g., data sharing, new analyses, etc.).	Create a sub-study not covered in the T3 study plan that can be implemented near or in the study watersheds.
Time commitment	1-2 hours every 3-4 months	1-2 hours every other month	2-5 hours per month
Key participants	Stakeholders and/or tribes that are affected by the outcome of the T3 study.	Stakeholders who work for organizations that have interest or are doing work similar to T3. These stakeholders often have expertise in their LG subject matter.	External researchers with expertise, community members with time and interest, others in organizations that can provide time, resources, materials, etc.
Previous T3 study engagement	Many members have working knowledge of the T3 study and have kept in the loop about changes. Many have attended field tours, focus groups, conferences, or other events focused on the study.	Many members have working knowledge of the T3 study before joining but may not have participated in the review of study plans, field tours, or focus groups.	Many of these members have participated throughout the development of the T3 study.
Types of projects	Review documents, provide feedback, and	Exchanging ideas between T3 and other	Creation of new sub-study associated with the T3

	hear updates that they will take back to their organizations.	organizations; collaborate on data sharing and monitoring efforts.	study within the watersheds.
Learning groups	Tribal and economics and operations	Aquatic responses, remote sensing, and carbon sequestration	Cedar browse, invasive species, and history

5.6 KEY INSIGHTS EMERGING FROM LEARNING GROUP DEVELOPMENT

In the first year, there are key insights that have emerged through this LG process. Though there is certainly work left to be done in all the groups, the following insights represent our initial findings on the reasons we have seen some success. We also offer methodologies to consider and other shortfalls to be aware of if implementing LGs elsewhere. We offer the following attributes that contributed to the LG success:

1.) Connection to an existing operational-scale watershed experiment

Each of the LGs are closely connected to the T3 Watershed Experiment. The study allows scientific questions to be addressed at an operational scale. Having the LGs connected to this type of work has allowed for additional resources and support by the T3 team, space within or adjacent to study stands, and endless project options for the groups to work on. This provided critical infrastructure for the groups to use, which ultimately allowed them to hit the ground running. We believe that the connection to a place-based study nearby allowed for increased buy-in and trust that the T3 team was taking the work generated from the LGs seriously (Cheng and Mattor 2010). In addition, there were several topics and questions that stakeholders and tribes were interested in exploring that could not be included in the study plan due to experimental space, budget, researcher capacity, or other constraints. The LGs offered a space to explore additional ideas that could be connected to this larger effort.

2.) Building trust and rapport

Prior to the LGs starting, T3 researchers and managers had been working with nearby tribes and stakeholders from a wide array of fields from small business to private timber to environmental. Past engagements were not always easy or satisfactory to participants, and trust needed to be built and earned. In order to get to know local communities and facilitate this trust building, stakeholders, tribes, and community members were invited to participate in interviews, workshops, focus groups, field tours, and conferences to hear their perspectives, input, and knowledge about the study as it was developing. Through this engagement, T3 researchers observed that rapport and trust were being built, a process that took several years. As the LGs were beginning, this trust and rapport gained from continued engagement led to greater participation and dedication to the project (Spradley 1979).

In addition, stakeholders often represented organizations that opposed one other. They each had varied interests and perspectives on how forest management should be done and the way it may affect them and their community. Through the development of the T3 study, all groups could have their voices heard and each diverse perspective was considered. Over time, we observed opposing groups understanding the merits in testing many novel approaches through the T3 study. We believe that trust and rapport were built through this process, ultimately allowing many diverse groups to work together.

3.) Participation of key stakeholders

The groups that have achieved the most within the first year have largely included key stakeholders who have expertise in the LG topic, including a number of retired scientists and managers. While anyone can join the groups, recruiting participants whose professional experience aligns with group goals has brought important perspectives that ultimately have made those LGs more successful. These groups have been able to quickly and easily identify where additional studies would be useful and can help push the group forward.

For example, in the cedar browse LG, two researchers who had extensive experience studying cedar and browse mitigation joined the group to provide their knowledge and expertise. These members were critical to narrowing down the options of studying cedar browse to realistic but innovative choices that had not been studied together in this region before. Other LG members who did not have as much research experience could learn from their expertise and provided other strengths to the group. This led to the group working and learning together while quickly moving forward towards establishing a sub-study to test these proposed cedar browse mitigation alternatives.

4.) Enthusiastic leader

The cedar browse and invasive species groups were two notable examples of LGs who made significant progress towards their goals in the first year. Their progress can be traced back to each having a dedicated group of participants with expertise in their given topic and also saw a person provide enthusiastic leadership within the group. In the cedar browse LG, a University of Washington graduate student was using this LG as the basis for her master's capstone project. She was passionate about the work, had dedicated time in her schedule to commit to this project, a clear deadline to complete her portion, and brought enthusiasm that was contagious to the rest of the group. She invited members to help her achieve her capstone and then, through her leadership, enthusiasm, and personality, provided energy to other participants to achieve rapid progress. Her leadership drove the group forward while the other experts could give her consistent feedback that she incorporated into the sub-study plan.

In addition, the invasive species group has also been striving to develop a research study and monitoring proposal for the T3 study and west side Olympic Peninsula region. They have brought in members who have expertise in remote sensing and invasive species monitoring. One member has taken on more of a leadership role in this group, as her professional experience is focused on invasive species identification and removal for tribes and state and federal agencies, including getting state funding to run a local crew of underemployed youth. Her enthusiasm and dedication to the topic has kept this group moving forward with tangible and realistic plans. Having a committed leader with resources, experience, and available crews has driven the group forward.

5.) Dynamic purpose and goals

The T3 team provided a broad framework that could be used in each of the LGs. However, each group could pick their format, purpose, and goals through discussion or creation of a charter. This was a key element to creating a successful learning and collaborative process (Schuett et al. 2001, Keen and Mahanty 2006). Although the groups included T3 researchers and managers, the LGs were not intended to be driven or led by members of the T3 team. Instead, the stakeholders and tribes could define their own path forward. In some cases, their purpose was clear and targeted. For example, the history LG was focused on learning more about the disturbance and logging history of the stands within the T3 Watershed Experiment. Other groups were more abstract, such as the aquatic responses group that could focus on several different topics within that category. Some of the groups shifted their purpose and goals as they evolved. We believe having the ability to make these shifts allowed for greater flexibility and ultimately more participation.

The LGs that have specific goals from the beginning were able to make progress quickly. Their purpose was narrow in scope, resulting in the group focusing and coalescing around a few ideas quickly. Groups that were broader in scope, such as the carbon sequestration, had too wide a range of possibilities resulting in slower progress. In the future, narrowing the groups further may help with this effort.

6.) Formatting

The formatting of the LGs typically includes a monthly or bi-monthly meeting during the daytime over Zoom. This can be an advantageous format for those who have flexibility in their schedule or whose work overlaps with the LG topic. However, for others this type of format is atypical and have resulted in more limited participation. In the harvest operations and economics groups, the T3 team had hoped to engage purchasers and logging companies to work together and learn from the process of executing the novel prescriptions. Although, there has been more limited participation, most likely due to the format of the LG (e.g., employees of companies operate more in-person and are often in the field rather than at a desk). Rather than having the LG structured in this way, we could consider a different type of format for groups or industries that would prefer to engage in other ways.

5.7 CONSTRAINTS

The LG approach naturally emerged as a way to continue engagement, build and maintain relationships with stakeholders and tribes, make progress on topics relevant to the T3 study, and learn together. We saw this approach as the best way to meet these goals. However, there are a few constraints to the LG process that may prevent its success in other contexts. Although, the format can be adjusted and tailored to a different study and setting.

This work took place on the west side of the Olympic Peninsula, WA, where communities are small, and this rural setting means most people know one another outside of this collaborative context. Although many groups disagree (e.g., environmental community and private timber industry), over time we found that there was collaboration and interest in working together. There can be deep divisions, but the ecosystem wellbeing model that prioritized both environmental and community wellbeing was helpful and allowed stakeholders and tribes to understand how serious we took their input and needs. We believe this helped to foster and build trust, rapport, and relationships. This can differ from other contexts, especially in urban settings, where there is no established rapport prior to the engagement and deep seeded disagreements between groups have a harder time being resolved. This may be especially true in places where there is not an existing trust built between state and federal agencies and communities. In those cases, building trust will need to be a key first step.

In addition, many collaborative efforts with members who tend to be on opposing sides often focus on their "zone of agreement", moving forward only on projects no members object to (Schultz et al. 2012). Though this has worked well to build trust, it fails to facilitate learning about areas of disagreement. We suggest a "zone of learning" approach embodied in the T3 Watershed Experiment and in the LGs. In effect creating an environment where ideas and innovations by others are tolerated enough to try and compare them to each other. Learning, at least at smaller scales, initially includes some environmental and social/economic risks, but perhaps a larger risk to the status quo. This could be challenging for other traditional collaboratives, especially those with members who are quite satisfied with the status quo. In our case, we found that stakeholders and tribes were hungry for change and innovation, believed in our commitment to address their economic and spiritual wellbeing, and were interested in working together through the LG process.

Lastly, we believe that having all three key groups (researchers; managers; and stakeholders and tribes) work meaningfully together is critical to the success of this type of work. Each bring their own knowledge and expertise and influences on one another, without which this type of large-scale study would not be possible. These groups must have an interest and willingness to work together as well as a commitment to the learning process. Finding people from these key groups that have the capacity and professional flexibility to attempt this will be a constraint. Here is where the retired professional community is especially important. Other collaborative efforts have noted the difficulty and time-consuming nature of this type of work, putting a burden on all involved (Urgenson et al. 2017). Oftentimes, researchers, bound by a requirement to produce scientific publications quickly, are not able to spend time cultivating relationships and participating in collaborative efforts like LGs. However, in the face of a changing climate and increasing real-world issues that forestry can tackle, it is critical that we prioritize adaptative and collaborative approaches.

5.8 CONCLUSIONS

Having consistent engagement with stakeholders and tribes was a priority for the T3 study designers. This allowed all parts of the study, from design to monitoring, to include the input and knowledge from those that are affected by its outcomes. The learning groups were a way to work together towards additional elements of the study with a narrower focus while learning through the process together. In the first year after launching the groups, we have seen some success and have offered insights and reflections on potential causes. This type of approach can be tailored to other studies and regions beyond the Olympic Peninsula to assist in collaboration and social learning going forward.

5.9 REFERENCES

Argyris, C. 2002. Double-loop learning, teaching, and research. *Academy of Management Learning and Education* 1(2):206–218.

Bidwell, R. D., and C. M. Ryan. 2006. Collaborative partnership design: The implications of organizational affiliation for watershed partnerships. *Society and Natural Resources* 19(9):827–843.

Bobsin, C. R., B. T. Bormann, M. L. Miller, and B. D. Pelach. 2023. Perspectives: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest. *Forest Ecology and Management* 529:1–10.

Bormann, B. T., R. Haynes, and J. Martin. 2007. Adaptive management of forest ecosystems: Did some rubber hit the road? *BioScience* 57(2):186–191.

Chauvin, C., T. Minkova, and B. Bormann. 2021. Expanding the tool box: The type 3 watershed experiment. *The Learning Forest* :2–5.

Cheng, A. S., and K. M. Mattor. 2010. Place-based planning as a platform for social learning: Insights from a national forest landscape assessment process in western colorado. *Society and Natural Resources* 23(5):385–400.

Cundill, G., G. S. Cumming, D. Biggs, and C. Fabricius. 2012. Soft systems thinking and social learning for adaptive management. *Conservation Biology* 26(1):13–20.

Diaz-Kope, L., and K. Miller-Stevens. 2015. Rethinking a typology of watershed partnerships: A governance perspective. *Public Works Management and Policy* 20(1):29–48.

Fabricius, C., and G. Cundill. 2014. Learning in adaptive management: Insights from published practice. *Ecology and Society* 19(1).

Fernández-Giménez, M. E., D. J. Augustine, L. M. Porensky, H. Wilmer, J. D. Derner, D. D. Briske, and M. O. Stewart. 2019. Complexity fosters learning in collaborative adaptive management. *Ecology and Society* 24(2).

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30:441–473.

Hill, R., C. Grant, M. George, C. J. Robinson, S. Jackson, and N. Abel. 2012. A typology of indigenous engagement in Australian environmental management: Implications for knowledge integration and social-ecological system sustainability. *Ecology and Society* 17(1).

Jordan, R., S. Gray, A. Sorensen, G. Newman, D. Mellor, G. Newman, C. Hmelo-Silver, S. Ladeau, D. Biehler, and A. Crall. 2016. Studying citizen science through adaptive management and learning feedbacks as mechanisms for improving conservation. *Conservation Biology* 30(3):487–495.

Keen, M., V. A. Brown, and R. Dyball. 2005. Social learning: a new approach to environmental management. Pages 1–270 *Social Learning in Environmental Management: Towards a Sustainable Future*. Taylor & Francis Group.

Keen, M., and S. Mahanty. 2006. Learning in sustainable natural resource management: challenges and opportunities in the pacific. *Society and Natural Resources* 19(6):497–513.

Kolb, D. A. 1984. *Experiential learning: experience as the source of learning and development.* Prentice-Hall.

Leach, W. D., and N. W. Pelkey. 2001. Making watershed partnerships work: a review of the empirical literature. *Journal of Water Resources Planning and Management* 127(6):378–385.

Lee, K. N. 1993. *Compass and gyroscope: integrating science and politics for the environment*. Island Press.

Margerum, R. D. 2008. A typology of collaboration efforts in environmental management. *Environmental Management* 41(4):487–500.

Moore, E. A., and T. M. Koontz. 2003. A typology of collaborative watershed groups: Citizen-based, agency-based, and mixed partnerships. *Society and Natural Resources* 16(5):451–460.

Muro, M., and P. Jeffrey. 2008. A critical review of the theory and application of social learning in participatory natural resource management processes. *Journal of Environmental Planning and Management* 51(3):325–344.

Pahl-Wostl, C. 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19(3):354–365.

Reed, M. S., A. C. Evely, G. Cundill, I. Fazey, J. Glass, A. Laing, J. Newig, B. Parrish, C. Prell, C. Raymond, and L. C. Stringer. 2010. What is Social Learning? *Ecology and Society* 15(4).

Rodela, R. 2011. Social learning and natural resource management: The emergence of three research perspectives. *Ecology and Society* 16(4).

Schuett, M. A., S. W. Selin, and D. S. Carr. 2001. Making it work: Keys to successful collaboration in natural resource management. *Environmental Management* 27(4):587–593.

Schultz, C. A., T. Jedd, and R. D. Beam. 2012. The Collaborative Forest Landscape Restoration program: A history and overview of the first projects. *Journal of Forestry* 110(7):381–391.

Schusler, T. M., D. J. Decker, and M. J. Pfeffer. 2003. Social learning for collaborative natural resource management. *Society and Natural Resources* 16(4):309–326.

Spradley, J. 1979. *Asking Descriptive Questions*. First edition.

Tosey, P., M. Visser, and M. N. K. Saunders. 2012. The origins and conceptualizations of “triple-loop” learning: A critical review. *Management Learning* 43(3):291–307.

Urgenson, L. S., C. M. Ryan, C. B. Halpern, J. D. Bakker, R. T. Belote, J. F. Franklin, R. D. Haugo, C. R. Nelson, and A. E. M. Waltz. 2017. Visions of Restoration in Fire-Adapted Forest Landscapes: Lessons from the Collaborative Forest Landscape Restoration Program. *Environ. Manag.* 59(2):338–353.

Walters, C. 1986. *Adaptive Management of Renewable Resources*. MacMillan Publishing Company, New York.