The T3 Watershed Experiment Upland Silviculture Study Plan

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We acknowledge the Indigenous Peoples on whose homelands this research is being conducted, including the Makah Tribe, Quileute Tribe, Hoh Tribe, and the Quinault Indian Nation. We have a responsibility to improve relationships between nations and to improve our understanding of local Indigenous Peoples and their cultures.

EXECUTIVE SUMMARY

The T3 Watershed Experiment seeks to build institutional and societal capacity to learn and adapt at a pace responsive enough to address present and anticipated dangers to forests and communities on the Olympic Peninsula — impacts associated with climate change, social dynamics, and other forms of uncertainty. Scarcity of new solutions in Pacific Northwest forestry over the last 25 years motivates this effort. Several possible innovations and solution spaces emerged through the T3 learning-based collaborative approach. Designing the study was able to bring in knowledge and ideas from participating researchers, managers, stakeholders, and tribal members. For the upland areas of the watershed experiment, these potential solutions have taken the form of 4 new management tools (alder:cedar polyculture, variable-density planting, complex early-seral, and accelerated variable-density thinning prescriptions) to be tried out for possible broader use in the future in second-growth forests on Washington trust lands. The new tools seek to diversify stands and landscapes, speed late-seral development, support wildlife (e.g., insects, birds, elk), diversify forest products (e.g., alder, cedar, culturally important understory plants), build back early-seral habitat, and increase revenue and certainty for trust beneficiaries. A basic premise of this study is that diversification of management at small to large scales is key to resilience given the many uncertainties we face. Key to our approach to adaptation is trying new forest management tools at an operational scale where true costs and benefits are easier for all to see and to potentially adopt. Expanding the management toolbox is expected to provide more benefits to people and the environment, while meeting the legal requirements of the trust mandate and the state lands Habitat Conservation Plan.

This is a complex and ambitious study: 4 new silviculture prescriptions for managing upland forest are examined in the context of watershed-scale management strategies and associated social and economic responses. The new tools are implemented on operational-scale and compared with standard management practices on state trust lands and no-action controls. Nested sub-studies, applied at smaller scale, are included to explore a greater variety of silvicultural approaches and to examine some of the mechanisms behind the success or failure of the new tools. Simple randomized-block designs are used where possible and monitoring is focused on emerging remote-sensing technologies to minimize ground-based measurements. Where sample sizes are limited, the focus will shift to exploratory data analysis and case study methods. The study plan identifies key questions that can be asked at different spatial scales and describes monitoring that to address these questions. In order to make the document more accessible, we do not include as much background knowledge in individual prescriptions as might be present in study plans that address narrower questions.

The T3 Watershed Experiment is planned and implemented by University of Washington's Olympic Natural Resources Center and Washington State department of Natural Resources with other key partners. The project is supported by the Washington State Legislature.

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Chapter 1: Expanding the Toolbox

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Introduction

The University of Washington's Olympic Natural Resources Center (ONRC) and Washington State Department of Natural Resources (DNR), with other key partners, are collaborating to create and run the "T3 Watershed Experiment"[1]. This effort is supported by the Washington State Legislature and the study is being designed, implemented, and monitored to help improve DNR management of state trust lands[2]. The management experiment will provide evidence of effectiveness of a variety of new forest management approaches and also will garner more goodwill between beneficiaries, stakeholders, tribes, DNR, and ONRC. Seeking evidence-based improvement is a long-standing adaptive management goal for ONRC and DNR (WDNR 2016a). We also seek to learn more about the mechanisms behind our success that can help support future studies and improvements in forest management beyond Washington state lands. The experiment is being implemented on the Olympic Experimental State Forest (OESF) on the western Olympic Peninsula. A discussion of current DNR forest management policies and practices is found in Appendix 1.

Included in the overall study are potential improvements in:

- Landscape strategies for managing type-3 watersheds with small fish-bearing streams—through cumulative effects of combinations of forest management prescriptions and natural processes in un-entered and reserve areas;
- Active forestry prescriptions for managing stands and riparian buffers, large enough to directly evaluate key biotic responses and economic feasibility at operational scale;
- Understanding of specific silvicultural and ecological relationships through smaller, nested research-scale treatments in some of the watersheds and prescriptions; and
- Social relationships by increasing inclusion, transparency, and trust.

We evaluate potential improvements by using a new "ecosystem wellbeing" framework where both community and environment wellbeing are considered together (Fig. T3-1). This framework seeks to find more benefit to the forests and people of Washington, especially those in nearby dependent communities, while meeting the legal requirements of the trust mandate and the state lands Habitat Conservation Plan (HCP; WDNR 1997).

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[1] DNR classifies type-3 watersheds as the drainages surrounding the smallest class of fish-bearing streams (type-3 streams)—this is the basis for T3 in the study title. This scale was chosen so that fish response could be directly measured. It also matches the spatial units for the riparian ecological analyses used in DNR management plans.

[2] State trust lands are lands held as fiduciary trusts for specific trust beneficiaries, such as schools and universities.

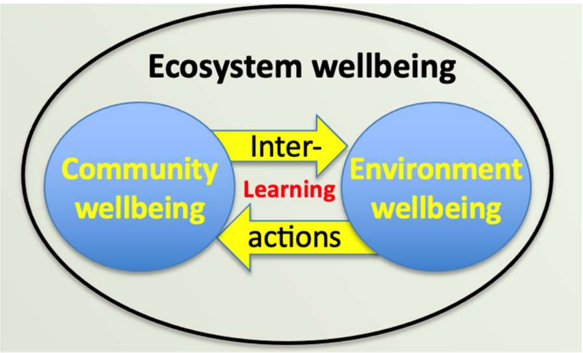

Figure T3-1. The ecosystem wellbeing framework based on a co-equal focus on community and environment wellbeing, and on learning to guide innovation and adaptation (see Bormann et al. 2018).

Many kinds of questions are being asked in this study. Some are broad and policy oriented, some are focused on practical questions from managers and stakeholders, and others dive into processes that drive biophysical and social/economic responses. We also seek to learn how to better adapt management to future climate and other uncertainties.

This study is motivated by the broad, ongoing debate about forestry in Washington and the interests of different groups: foresters, scientists, stakeholders, tribes, and legislators. It reflects a long-term commitment to improve both ecology and economy reflected in mandates to ONRC and DNR to collaborate on important issues, and "puts the E in OESF." A study concept was proposed (Bormann and Minkova 2017) that was shared with DNR managers and stakeholders. As the study took shape, it came to be called the T3 Watershed Experiment. To implement this complex learning enterprise, three plans - overview, riparian, and this upland silviculture study plan - have been prepared (Table T3-1).

Table T3-1. Current Study Planning Documents for the T3 watershed experiment.

Module	Contents
Overview plan	Describes the overall context, goals, and philosophy of the T3 Watershed Experiment as well as management strategies (Bormann et al. 2021)
Riparian study plan	Describes the riparian component of the T3 Watershed Experiment, including riparian prescriptions designed under the four management strategies (Martens et al. 2020). Peer reviewed in 2021.
Uplands study plan	This document; describes upland prescriptions designed under the four management strategies and various sub-studies.

An enhanced need for collaboration was quickly identified—given the importance of community to ecosystem wellbeing—which requires learning about behavioral patterns, knowledge, feelings or affect, and preferences of affected communities. Collaborating effectively across government agencies, universities, and with the public groups is a tall order, especially given the tendency of management, research, and regulatory institution decision-making to be stove-piped and insular, and because stakeholder engagement was initially designed only to meet minimum NEPA/SEPA requirements. We approach this problem through a concept we call learning-based collaboration (LBC)[3]. The goal of LBC has been to build collective adaptive capacity to find innovative solutions quickly enough to positively respond to the rapidly changing, complex world we live in. Our approach to LBC has evolved through study development and is founded on an expanded understanding and application of the social sciences (such as sociology, cultural anthropology, political science, human geography, and history) and engagement best practices developed by facilitators and conflict-resolution professionals.[4] This concept continues to be applied to the development and implementation of the T3 Watershed Experiment.

The study is based on an initial agreement between ONRC and DNR that the project will be:

1. Providing three kinds of plausible benefits to meet the trust mandate:
    - High (but not necessarily maximum) net revenue;
    - Science[5]-based learning focused on trust management issues; and
    - Increased public support for management of trust lands.

2. Implemented as operational-scale prescriptions sufficiently different from one another to reduce the threshold for detecting statistically significant differences.

3. Finalized to allow for timber sales implementing the experimental prescriptions to be planned and auctioned in calendar years 2021/2022 and to make other arrangements such as ordering seedlings to regenerate the harvested areas.

Watershed and Landscape Context for Upland Prescriptions

Many ecological, economic, and social processes express themselves at a large landscape scale which drives some DNR planning and management to be conducted at this scale as well. Examples include distribution of forest successional stages, setting sustainable harvest levels, and effects of management on fish populations. The minimum scale to study these processes/issues is that of type-3 watersheds (area ranges 300 to 3000 acres in the study area). Accordingly, a management experiment was proposed on type-3 watersheds (Bormann and Minkova 2017) to address these key DNR management and ecological uncertainties. During the

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[3] We define LBC as an iterative process in which 3 distinct groups: (a) natural resource managers; (b) natural, social, and policy researchers; and (c) other collaborators including tribal and other leaders engage with one another, focusing on asking and answering questions about options and effects of management choices through formal and informal exchanges and activities—with the common goal of increasing ecosystem sustainability as measured by environment and community wellbeing.

[4] With oversight from the ONRC-Washington Rural Ecosystem Sustainability Team [online], the T3 LBC effort benefitted greatly from the insight and experience of both Jenifer Arnold (Reciprocity Consulting) and Angie Thomson (EnviroIssues).

[5] Natural and social sciences

design phase, participants also recognized the importance of DNR operational decisions on smaller, stand scales, such as typical timber sale units (often 30 to 50 acres). They also recognized that various ecological processes driving changes are best studied at stand or stream reach scales less than 30 acres. Therefore, to link learning to DNR decisions holistically, the final study design includes 3 scales of nested experimental units: (1) watersheds (500 to 2000 acres), that possibly can be extrapolated to the entire OESF; (2) individual timber-sale units (often 30-60 acres), where individual prescriptions are applied; and (3) more typical research-plots (4+ acres), to test specific silvicultural and ecological relationships. This makes the study as a whole quite complex (Fig. T3-2; Table T3-2; Chapter 6 summary).

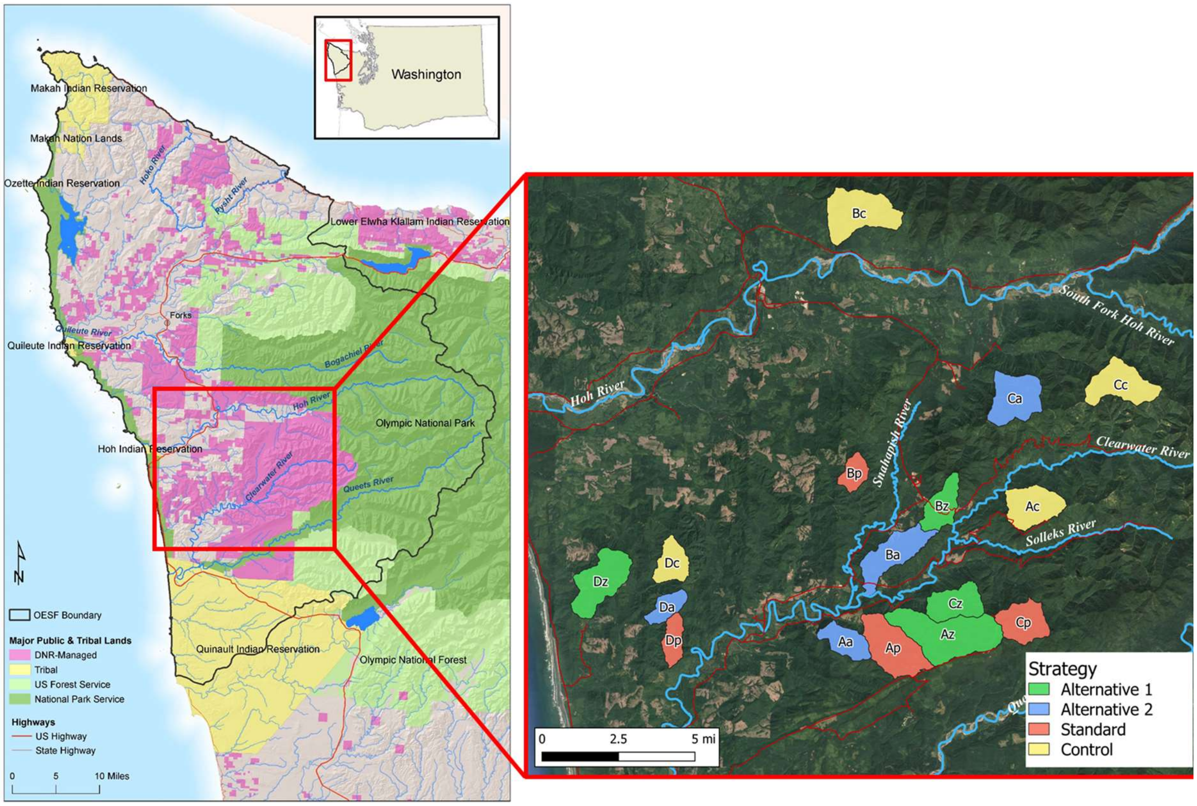

Figure T3-2. The T3 Watersheds on about 20,000 acres of DNR-managed Common School trust land in the western Olympic Peninsula. Watersheds were grouped based on similarity into 4 blocks and management strategies were assigned randomly within blocks. Specific prescriptions and sub-study treatments (not shown on this map) will be applied in riparian and upland units based on assigned strategy. Prescriptions that include harvesting will be applied through standard timber sales on about 2000 acres (10% of the total watershed area).

Table T3-2. Landscape-scale questions in entire watersheds and beyond (see Chapter 6 for more detail including the broad statistical design)

Question	Core monitoring
What are the cumulative ecosystem effects of the 4 watershed strategies (combined influence of all upland and riparian prescriptions along with natural processes)?	• Cumulative net revenue and net present value;* • Consistency with HCP and other rules and regulations; o Watershed pour-point metrics (stream temperature, sedimentation, dissolved organic matter, and chemistry); and o Fish populations in the lowest stream reach; • Other ecosystem benefits: o Other social and cultural benefits, such as job creation, valuing traditional knowledge, and empowerment of affected parties; o Other ecological benefits such as net primary production, carbon sequestration, and food chains; and o Increased adaptation and resiliency to climate and other uncertainties.
How do beneficiaries, tribes, and stakeholders perceive and value watershed strategies and the study as a whole?	• Interview and questionnaire responses about relative perceptions of: o Watershed strategies (including one that was based on their input); o Individual prescription outcomes (including ones based on their input); and o Learning-based collaboration.
How have management, regulatory, research, or social institutions responded?	• Adaptive management efficacy; • Learning-based collaboration; • Institutional adaptation; and • Increased use of social science expertise.

* Net present value is the difference between the present value of cash inflows of timber and the present value of cash outflows of management costs over a stand rotation.

Four watershed-level management strategies guided the development of riparian prescriptions (Martens et al. 2020) and the uplands prescriptions in this study plan. They influence the upland prescriptions' makeup, placement within watersheds, and size. This design focuses on comparing the four watershed strategies using a complete randomized block design with four blocks. The strategies are:

- **Control (no-action).** The Control serves to provide evidence of changes due to natural disturbances and succession thus helping discern the management effects of the other three strategies. It is not possible on a widespread basis on state lands given the current legal interpretation of the trust mandate. DNR has committed to 1 decade of no action in the designated control watersheds starting in 2018.
- **Standard.** Continue the current best practices as set forth in the OESF Forest Land Plan (WDNR 2016b) including harvesting for revenue and management for various upland and stream habitats. Our application avoids any riparian entry for the purpose of the study, although riparian thinning and limited regeneration harvest there is permitted.
- **Alternative-1 Integration.** Seeks greater integration of current habitat mandates and additional ecological concerns (complex early-seral habitat and faster restoration of

riparian functions) with continued revenue generation by applying the latest environmental-science knowledge.

- **Alternative-2 Integration.** Seeks greater integration of community wellbeing concerns, by applying perspectives and traditional knowledge from diverse collaborators, along with social and environmental-science developments, including increasing culturally significant understory plant species, elk, alder, cedar, fish populations, and stakeholder and tribal engagement.

Upland Prescriptions

Here, we develop and explore new upland prescriptions (experimental treatments), background knowledge, and an experimental framework to evaluate them by comparing to controls, standard practice, and each other. Some of these operational-scale prescriptions include sub-studies nested within to better explore the reasons why they work well or not. A control and two standard prescriptions are needed to evaluate new tools:

- **No-Action Controls (Control).** Typical operational-scale (30+ acres) areas are identified within the Control watersheds that are ready and appropriate for entry. They would have been managed like the other designated prescription areas (timber sale units) if not randomly being set aside as a control. The control is considered as a prescription that may have advantages, for example maximizing carbon sequestration at least in the near term, even though it is not currently a viable DNR trust lands practice.
- **Standard Variable-Retention Harvest (SVRH).** This prescription is the predominant operational-scale treatment on the OESF, and serves as a standard to compare to all other prescriptions. Its simplest description is a regeneration harvest with retention of 8 trees per acre and other biological legacies such as dead down wood. Other required protections (e.g., stream buffers, unstable slopes, and wetlands) exist. Planting (mainly Douglas-fir; *Pseudotsuga menziesii* (Mirb.) Franco) and tending of conifers in a 40-to 60-year rotation[6] follows. Timber sale units implementing this prescription are applied in the Standard-strategy watersheds and on some other watersheds just to meet the study requirement of consistent level of upland harvest across the 12 actively managed watersheds[7].

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[6] DNR extends rotations on some stands to better meet Spotted Owl habitat concerns at the landscape scale.

[7] The harvest level is 13% of the watershed area. It is determined by applying the average decadal sustainable harvest level of approximately 10% of the OESF to the individual experimental watersheds in this study. Since the 4 Control watersheds will not be harvested for a decade, their harvest level is applied to the other 12 watersheds resulting in 13% harvested area per watershed.

- **Standard Variable-Density Thinning (SVDT).** This is another standard practice applied on DNR-managed lands since 2006. The current sustainable harvest level for the OESF (WDNR 2019) calls for about 2% of the OESF to be harvested using SVDT vs about 9% to be harvested using SVRH per decade. We were only able to identify 3 units to apply this prescription (placement and cost considerations), although there are some previously applied SVDT units that we can examine retrospectively.

We developed four new operational-scale upland prescriptions, constrained only by theoretical consistency with the DNR trust mandate to produce net revenue +/-15% of the current projections and/or by their ability to address broad HCP and agency requirements:

- **Ethnoforestry[8] with Variable-Ratio Polyculture (EVRP).** Stakeholders and tribes raised concerns about the supply of red alder (*Alnus rubra* Bong.) and western redcedar (*Thuja plicata* Donn ex D. Don) wood for jobs-intensive production facilities and for cultural uses of these species. Combining these concerns with consideration of the potential ecological benefits of these species (soil productivity and long-lasting late-seral structure) and added spatial heterogeneity (expected to provide increased resiliency to climate and other uncertainties) suggested this tool was worth testing. The treatment is applied in timber sale units in the Alt-2 strategy watersheds; see Chapter 2.
- **Ethnoforestry with Variable-Density Planting (EVDP).** This prescription seeks to address people's concerns about losses of certain understory plants, and forage for deer and elk regionally and on Trust lands. It also seeks to actively extend time and space for the early-seral stage, known to be in decline in the coastal Pacific Northwest, and adds stand- and landscape-scale spatial heterogeneity to provide increased resiliency to climate and other uncertainties. To accomplish these objectives, the prescription develops and explores a clumping-strategy sub-study that may find ways to better segregate conifer and non-conifer production to achieve more of both. The treatment is applied in timber sale units in the Alt-2 strategy watersheds; see Chapter 3.
- **Complex Early Seral (CES).** This prescription focuses on addressing the declines in early-seral habitat and associated species and ecological processes in coastal Pacific Northwest as an emerging threat to biodiversity and long-term ecosystem productivity. The regional decline results from the land managers' primary focus on late-seral conditions and the effective, intensive conifer regeneration. Relative to EVDP, this prescription takes a more passive approach through natural regeneration to extending

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[8] We define the field of ethnoforestry as people-focused forest management. Ethno comes from the Ancient Greek εθnɒs 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.

the time for and quality of this important seral stage while simultaneously providing a fully-stocked stand available for future silvicultural prescriptions. The treatment is applied in timber sale units in the Alt-1 strategy watersheds; see Chapter 4.

- **Accelerated Variable-Density Thinning (AVDT).** The SVDT is modified in this prescription to further speed development of late-seral structure through wider and variable spacing, larger gaps, and increased spatial variability. These units may be either re-entered after 20 years using a SVRH or added to the designated late-seral-structure pool of stands. This long-rotation prescription may produce better overall late-successional habitat, increase carbon sequestration, and produce more initial benefits to the trusts than SVDTs. Units are applied in the Alt-1 strategy watersheds; see Chapter 5.

The four new prescriptions are described in individual chapters that follow, where they are considered partly as stand-alone studies in their own right. Chapters include rationale for operational prescriptions and research sub-studies, specific research questions, and core monitoring. Chapter 6 describes the comparison of upland prescriptions at the typical DNR scale of forest management operations (30+ acres) across the watersheds. Chapter 7 details the implementation plan for the study including the harvest and silviculture treatments, monitoring activities, data management, modeling, project management, and funding.

Economic Sub-studies

Before we dive into the details of each of the prescriptions, we establish here a set of economics-oriented sub-studies that apply to all of them. The economics of individual prescriptions is a key focus of the study given the DNR trust mandate, the need to inform the application of the study findings for future management improvements, and as an element of the broader ecosystem wellbeing goal. Economic factors were not well developed in the study's Overview Plan, which did address other social factors critical to ecosystem sustainability. To address economics, we will initially undertake three sub-studies—that apply to every prescription:

Implementation economics sub-study. We will track total and net revenue generated from implementing individual prescription operational-scale units, with a focus on a wide range of revenue and costs, including timber purchase pricing and costs of timber sale planning, layout, research, monitoring, and compliance with regulations. Special administrative accounts have been set up by DNR to track layout and other costs. This tracking will extend into post-harvest activities including site preparation, planting, vegetation management and pre-commercial thinning. We planned series of time and efficiency studies of timber harvest operations to produce operational-scale harvest cost information and cost estimating models. Refer to the conceptual study plan online for overview of the proposed study methods and potential field studies. The data will be used to identify operational variables that significantly influence operational efficiency and that estimate future implementation costs of prescriptions under various work conditions. Road construction and maintenance is not likely to be followed as it occurs at a scale larger than these watersheds. Collaboration with purchasers and operators is critical and these relationships are being developed. Tracked implementation costs will flow into the other two sub-studies. This sub study begins right away and will be ongoing.

Long-term economic projections sub-study. A second study will produce quantitative projections of growth and yield of the stands developing after treatments and all of the activity revenues and costs (elements) that go into calculation of net present value (NPV) for entire lifespan of each prescription. Projections will be used as quantitative hypotheses. Deviations from projections, documented through monitoring, may be used to re-project lifespan NPV at milestones in the future. The sub-study is limited to best-available estimates of the costs of post-harvest activities, research and management administration, future saleable wood volume based on current growth and yield models, and future wood, carbon, and other markets. We anticipate that the uncertainties with future growth and yield, markets, and costs will be high and vary between prescriptions and elements, and this clouds all projections. Thus, increased understanding of the uncertainties themselves is a critical aspect of the sub-study. For example, we will first use the forest vegetation simulator (FVS; Dixon 2002) growth and yield model used by DNR, with its Pacific Northwest variant (Keyser 2008). This model, however does not account for prescriptions that fall outside the data on which it was based, including conifer growth in clumps or at wide spacing, growth of alder and cedar—especially in mixture, future climate, and emergence of new threats from wind, fire, insects, and disease (including Swiss Needlecast effects on Douglas-fir) or other unexpected disturbances.[9] Certainty in markets and their values, especially at first rotation in our study (2060 to 2090), is problematic along with available harvest technology, and of course changes in policies. Our challenge is to define reasonable ranges of values to conduct a useful sensitivity analysis. The purpose of this analysis is to determine which element has the most potential to change the NPV and to the extent possible, other value-added effects such as jobs, taxes, and mill infrastructure. Projection ranges will be used to extrapolate potential impacts of individual prescriptions to the OESF at large. The economic projections sub-study will be completed in 2023 to establish milestones that can be tracked through time.

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[9] Further discussion of growth and yield projections is found in Chapter 3.

Management decision support sub-study[10]. Currently, the main path for new knowledge to enter into many DNR decisions is through a forest estate model[11] called Woodstock model (WSM) which helps set: (a) the sustainable harvest volume for entire landscape units (e.g. total harvest volume for the entire OESF for a decade); and (b) an optimal set of prescriptions needed to maximize NPV for beneficiaries within HCP and other constraints and general levels of uncertainty. This approach means that NPV of an individual prescription does not necessarily relate to the maximum NPV on the landscape—that is, choice of prescription has to take into consideration all of the factors that go into the WSM. This model currently would not be able to accommodate the new prescriptions for a variety of reasons. Once we have projection ranges in hand (above), a suite of research WSM runs might be able to capture potential impacts of the prescriptions if widely applied. A broader look at the decision processes—including for example: (a) changes in policies, e.g., about early-seral habitat, or (b) the leeway that OESF managers have in making site-specific decisions within the harvest and environmental constraints—is also needed to see how study results could lead to different decisions. This sub-study may also feedback to identify new specific implementation data or projection elements needs. This sub-study will likely be completed by July 2024. Long-term economic responses will be placed in context of social and environmental factors, in a complementarity (or tradeoff) analysis in future years.

Learning-Based Collaboration in Practice

The new prescriptions, questions, monitoring, and analyses in the T3 Watershed Experiment are greatly influenced by the LBC process as applied. This process stands in contrast to traditional engagement around forestry research and management decisions. Research projects are typically designed around ideas coming from researchers and managers examining potential ways to fill information gaps for current forest management or respond to lawsuits. Decision-process collaboration has often been geared to building trust and finding consensus. Stakeholder influence tends to be focused on nearly completed research designs or management/policy decisions. By focusing on questions, ideas, and learning, LBC takes a different tact—to engage around designing and participating in a study undertaken collectively by researchers, managers, stakeholders, and tribes. Learning about learning effectiveness is key to putting LBC into practice. Here, we review the process as it unfolded and make initial conclusions about effectiveness to inform others about the approach.

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[10] It is important to recognize that this is still research – we are building decision support tools, and quantifying the economic feasibility of the alternative prescriptions. The final management decisions of which prescriptions to implement and where on state lands are made by DNR managers. The study's goal is to provide them with the information and tools to make better informed decisions.

[11] A forest estate model is a mathematical computer model that aids the decision-making process by finding an optimized solution to the problem of how to manage forest resources efficiently and effectively. DNR uses the Remsoft Spatial Planning System developed by Remsoft Incorporated.

The following partial list of engagement illustrates our commitment to LBC:

- Learning groups have formed that focus on individual aspects of the study: tribal, invasive species, economics & operations, carbon, cedar-browse, aquatics, history, and remote sensing;
- An interactive web presence and outreach through the Learning Forest Newsletter;
- Study principal investigators (PIs) fanned out to participate in a wide array of other collaborative efforts (e.g., Olympic Forest Collaborative, The Nature Conservancy's Emerald Edge program, salmon restoration (NPCLE), economic development (NODC);
- PIs met repeatedly with county, local and tribal governments to discuss study ideas;
- Dozens of presentations were given to a wide variety of groups;
- One-on-one discussions with tribal members, tribal councils, other residents, and activists;
- Social science researchers conducted semi-structured and key informant interviews with a diversity of community and tribal members;
- Two OESF science conferences were focused on study development to date;
- A formal field trip to introduce the project was completed in late 2021 where nearly 40 people attended from small business, forest industry, tribes, and environmental, forest management, and research organizations; this was followed by a field trip for the members of the learning groups in October 2022;
  and
- Stakeholder and tribes were asked to comment on the plan before scientific peer review.

The influences of this engagement on the study design have been far too numerous to fully document here. Direct influence is seen in the Alt-2 strategy prescriptions and in developing the idea of ethnoforestry, which seeks engagement to make forestry more people-oriented (Bobsin et al. in review). Influence was also subtle at times and developed organically. For example, we had a pivotal moment July 8, 2017 with a Hoh Tribe member, Viola Reibe, who lamented at a canoe ceremony at ONRC on the long-term decline in beargrass (*Xerophyllum tenax)* to use in her weavings. This inspired us to wonder if there was any reason why we could not grow culturally important understory species in conifer rotations. This led to further discussions with tribes and stakeholders that revealed broad support for increasing elk forage, first foods, access, and other issues. We heard concerns about extensive conifer monocultures and their negative effect on song birds and pollinators, and about invasive species. When combined with some long-standing research questions about clumped planting of conifers, innovation in active management of understory between clumps emerged in the ethnoforestry-variable-density planting prescription.

Potential loss or gain in revenue on state trust lands was the focus of an intense but respectful exchange of views. We heard concerns that revenue from some prescriptions might not be maximized relative to standard practice, noting that beneficiaries would carry the risk of studying them. Others noted that economics when used as a key driver, stifles development of new tools as envisioned in the HCP plan for the OESF that might prove beneficial in unexpected ways. This is a complex issue, but we responded by including in most designs an objective of +/- 15% of the net present value relative to standard VRH[12]. Other prescriptions (CES and AVDT) were modified after discussions with practitioners to minimize expected losses of NPV in exchange for meeting key habitat, carbon, or other needs in ways that fit the trust mandates.

We heard a range of stakeholders and tribes promote increasing the role of two tree species, red alder and western redcedar, based on strong cultural, economic, and ecological reasoning. Again, combining science, managerial experience, and engagement resulted in the ethnoforestry-variable-ratio polyculture prescription. Concerns raised by some about prescription particulars and future markets will help focus monitoring efforts.

To be fair, many questions have been raised that have not yet been fully addressed in the current study design. These included alternative road construction techniques, effects on intermittent headwater streams and wetlands, mixed species plantings in EVDP including hemlock, widespread planting of culturally important plants, prescriptions' effects on invasive plants, and planting less common trees species (vine maple, redwood). Possibilities remain to add specific monitoring or small-scale sub-studies or do future studies to address some of these issues. We expect learning groups to discuss and develop ways to address as many of these topics as possible.

We learned that engagement is not an easy process and that it takes considerable time and energy to learn from others knowledge and perspectives, for ideas to take shape, innovations to emerge and sink in, for research designs and land-management operations to blend, and to build rapport and trust. We cannot say if minimal acrimony resulted from the process or simply from the amazing positive attitudes of people involved. Maybe the raw grandeur of Olympic Peninsula is connected to the people who so admire it. We can now offer a future-looking social-science hypothesis based on this exercise that we would like others test: Expanding the forest management toolbox, and collective adaptive capacity, emerges easily only when leaders can facilitate a collaborative learning environment that includes these entities: managers, researchers, diverse stakeholders, and tribes.

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[12] Given what we know now about the high uncertainty in growth and yield and economic projections for all, but especially novel, prescriptions, further changes in design are not envisioned even if the projections study suggests differences greater than +/- 15%.

Chapter 2. Ethnoforestry—Variable-Ratio Polyculture (EVRP)

Coordinating Authors: Rob Slesak, Andrew Bluhm, and Florian Deisenhofer

Prescription Abstract

We describe a novel ethnoforestry-based, variable-ratio polyculture (EVRP) prescription that seeks to add more elements of community and environment wellbeing compared to the standard VRH reforestation prescription typically applied on the state lands on the Olympic Peninsula. The EVRP prescription increases landscape heterogeneity by creating 5- to 10-acre patches with five different ratios of planted western redcedar and red alder all within operational sized units (30+ acres). If applied widely in the future, it would add heterogeneity in management and forest condition across the landscape. The primary objectives are to produce net revenue from rotations of high-value cedar and alder, and at the same time co-produce additional benefits such as increased jobs through value-added manufacturing, improve habitat quality and diversification, enhance soil productivity and its effects on growth and yield, and provide future options for late-seral habitat. In outreach efforts, growing more cedar and alder were frequently mentioned by tribal members, environmentalists, and cedar and hardwood industry representatives. Researchers also have long championed the positive environmental effects of these species, which have been overshadowed and diminished by short-rotation conifer culture. The ratios of cedar to alder included in this prescription are 100:0, 25:75, 50:50, 25:75, and 0:100. For those ratios with alder present, two alder rotations will occur for every one cedar rotation with rotation lengths of 30-35 years for alder and 60-70 years for cedar to maximize their timber values. At year 60-70, a new option to switch to late-seral trajectory focused around large cedars becomes available as well. The different ratio patches within the prescription also serve as a nested sub-study with ratios assigned randomly. Exploring ratio effects, ways to minimize post-harvest vegetation management costs, learning about the best cedar browse protection methods, and better evaluating environmental effects and social perceptions including better engagement with stakeholders—will be pursued to help optimize this approach in the future.

EVRP Prescription Background and Objectives

The ecology of alder and cedar is well documented. Alder is the predominant N_2-fixing species in the Pacific Northwest that can also build mineral-soil organic matter and speed weathering release of nutrients from minerals (Binkley et al. 1992, Edmonds and Tuttle 2010). Soil in pure alder stands in western Washington can accumulate over 1 ton N acre^{-1} over 50 years (50 kg ha^{-1} yr^{-1}); 10-times higher than typical onetime N fertilizer applications in PNW forests; and as nutrient-rich litter is incorporated into increasingly aggregated mineral-soil layers, soil organic matter also increases 40-60 Mg ha^{-1} over a similar period (Bormann et al. 1994). Improved soil structure and water- and nutrient-holding capacity are important in degraded soils during periods of drought. Remarkable effects on growth of intermixed crop conifers have also been well documented on intensely burned soils (Tarrant and Miller 1963; Binkley et al. 1992). By accelerating weathering, alder grows well on young glacial and alluvial soils and roads and in the laboratory on ground rock alone (Yamanaka et al. 2002). Alder may not improve highly weathered or skeletal soils where acidification may occur (Cole et al. 1991) or grow as well as Douglas-fir on some sites. Other ecological roles include higher understory biodiversity (Deal 2007; Deal et al. 2017) and greater understory biomass (Hanley et al. 2006). Rapid early stand growth has the potential to capture carbon more effectively than conifers at least for the first 20 to 30 years (for 2050 climate targets; Binns et al. 2021).

Western redcedar is one of the longest living and largest trees of special importance to late-seral conditions, such as nesting and roosting for owls and murrelets. Cedar is also resistant to root pathogens, shade tolerant, and grows across a wide range of sites (Antos et al. 2016). Large trees can often survive wind by top breakage and crown regeneration rather than uprooting. Cedar calcium accumulation (Prescott and Preston 1994) may have important site productivity effects.

The abundance of western redcedar has declined substantially in the last 75 years, resulting from its great lumber value, difficulty in re-establishment, and lower compatibility with short-rotation silviculture. 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, clothing, canoes, totems are well known (Johnson et al. 2021). Abundance of harvestable red alder on the Olympic Peninsula has also declined to the point that local alder mills are importing logs from Canada to remain in business.

We speculate that cedar:alder polyculture prescriptions have been rare because of poor understanding of the potential costs and benefits, other uncertainties, and the specific steps needed for successful implementation. Western redcedar has slower, and red alder faster, initial growth than Douglas-fir or western hemlock (*Tsuga heterophylla* (Raf. Sarg.) (Fig. EVRP-1). Cedar also is often heavily browsed by deer and elk. The stumpage values of alder and cedar have been consistently higher than Douglas-fir and hemlock for decades. We also know of a variety of beneficial effects of alder and cedar on soil productivity and habitat.

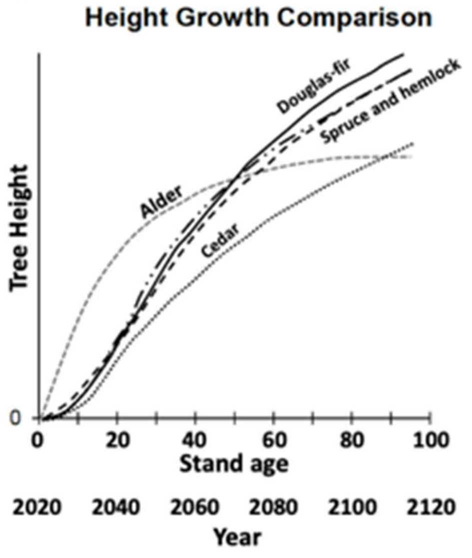

Figure EVRP-1. Comparison of site index curves of tree species common in the study area (modified from Green and Klinka 1994).

Growing cedar and alder in a mixture is not entirely new as several trials are underway (Courtin and Harper 2017).

The objectives of the ethnoforestry/variable-ratio cedar:alder polyculture silviculture prescription are:

1. Continue to grow tree crops in repeated rotations (~30-years for alder and ~60 years for cedar) to generate trust revenue as mandated in state law, at levels +/- 15% of that produced by standard VRH and post-VRH practices.
2. Provide for endangered- and other species considered in the habitat conservation plan (HCP) through habitat management under regulatory agency agreements.
3. Develop and learn about new operational-scale tools that in addition to producing revenue and meeting HCP requirements, can provide new benefits for the ecosystem as a whole (both community and environment under the ecosystem wellbeing framework) such as:
    - Reduce declines of job-intensive, value-added manufacturing of red alder and western redcedar by increasing their harvested volume over time;
    - Maintain or improve soils and productivity impacted by past practices of harvesting, slash burning, and biomass and nutrient removals;
    - Increase adaptation and resilience to climate and other uncertainties by giving trees more space and increasing species, stand, management, and product diversity relative to standard crop-conifer management;
    - Meet cultural needs of tribes and stakeholders for both cedar, alder, and other species associated with them; and
    - Provide an option for transitioning to late-seral structures focused on long-lived cedar.
4. Conduct a nested sub-study to examine individual ratio treatments and how they contribute to the success of the variable-ratio prescription, to inform future applications of the idea.

EVRP Experimental Design

Variable-ratio polyculture sub-study design

We identified a set of 5 cedar:alder ratios to include in the variable-ratio prescription: 100:0, 75:25, 50:50, 25:75, and 0:100% where individual ratios are applied on 4- to 10-acre sub-units within a 30+ acre operational unit (Table EVRP-1). One entire variable-ratio prescription (containing all ratio treatments) will be applied as an operational unit in each of the 4 Alt-2 watersheds (Fig. EVRP-2). All EVRP prescriptions were placed next to a riparian prescription planted with alder[13] (Rip RA HT) (Fig. EVRP-2) for the purpose of making future alder harvests cost effective. In addition to providing within-unit heterogeneity, sub-unit variable-ratio treatments also comprise a nested sub-study, consisting of a replacement series similar to Courtin and Harper (2018). Sub-study ratio treatments will be randomly assigned to sub-units, using a complete block design (Table EVRP-2). The scale of these sub-study units allows for evaluation of mechanisms driving the observed responses in tree growth and soil. For example, effects of shading, compatibility of alder and cedar growth, incidence of logging damage in different alder densities can all be quantified to determine the optimal ratio.

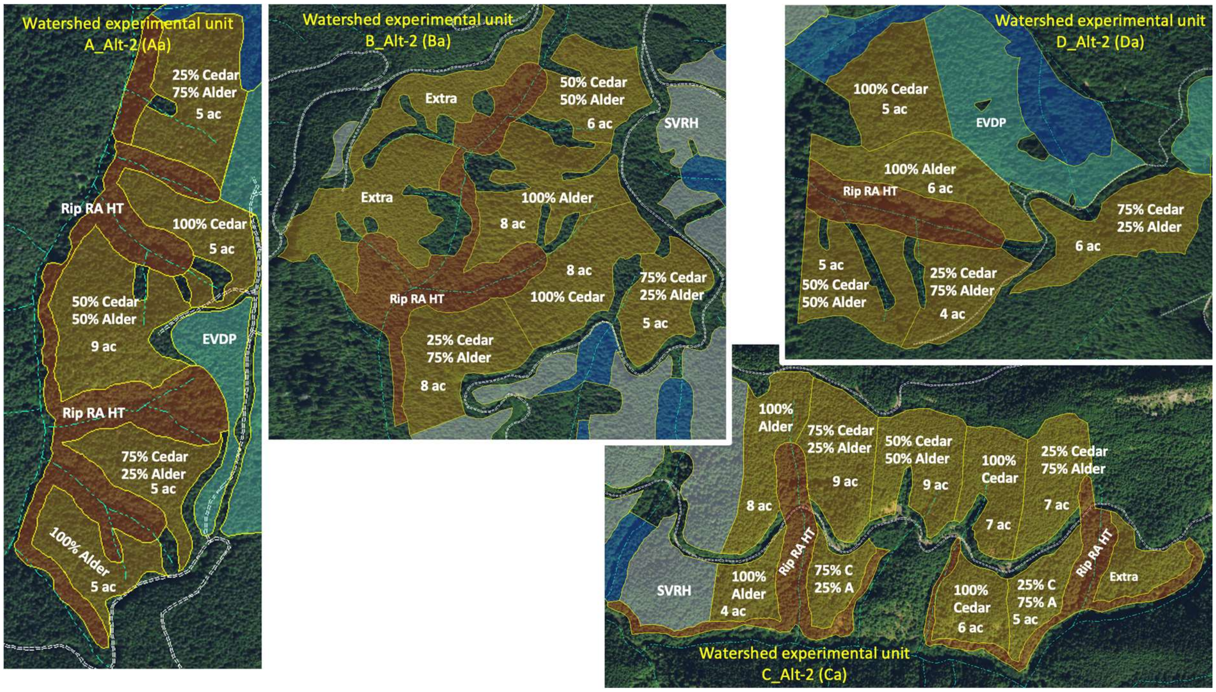

Figure EVRP-2. Layout of the Ethnoforestry/variable-ratio polyculture prescription (yellow shade) in the 4 Alt-2 watersheds (Aa, Ba, Ca, and Da), with the associated Riparian red alder/heavy thin prescription (orange). Other colors are other prescriptions. Maps are oriented north.

Table EVRP-1. Acres in sub-units across watersheds; WT Rip RA is a riparian alder rotation under widely spaced conifers spatially linked to EVRP and described in the T3 riparian study plan

	Watershed			
Sub-unit	**Aa**	**Ba**	**Ca**	**Da**
1	4.6	8.0	7.9	5.3
2	4.9	7.9	7.3	4.1
3	8.3	5.3	6.4	5.9
4	5.0	8.7	9.9	5.5

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[13] This prescription includes a riparian alder rotation under widely spaced conifers as described in the T3 Riparian Study Plan (Martens et al. 2020).

5	7.8	6.0	7.8	5.2
Prescription total:	**30.6**	**35.9**	**39.3**	**26.0**
Browse study	4.2	5.4	4.2	0
Rip RA HT	36.2	13.2	15.9	4.3
Combined Total:	**71.0**	**54.5**	**59.4**	**30.3**

Table EVRP-2. ANOVA table for replacement series sub-study

Source	Degrees of Freedom
Treatments (k-1)	4
Blocks (b-1)	3
Error (k-1)(b-1)	12
Total (n-1)	19

Statistical note: This is a simple, complete randomized block design with 5 ratio treatments and 4 reps (blocks). Other more flexible statistical models, such as exploratory data analysis, will also be used opportunistically.

Other design and implementation considerations with EVRP

***Operational and research consistency*.** Blending economic viability and study design to both expand DNR's toolbox and better understand why different approaches worked is no easy task. After harvesting and planting, developing conditions may require decisions that could affect study design and economic viability. Continued debate among PIs to maximize overall learning will apply this decision hierarchy:

- Seek a low-cost method to achieve production of revenue and other benefits, especially in early rotation actions that have high impact on rotation net present value;
- Intervene with more costly actions (keeping close track of added costs) only when faced with a major prescription deviation such as seedling mortality or massive hemlock ingrowth that endangers the study design, revenue, or other benefits; and
- Maintain the study degrees of freedom by applying interventions to all replicates in the same way to maintain/achieve the best average outcome—this means there may be sub-optimal effects on some blocks or in some sub- units (a major failure in one replicate is useful information about the geographic response).

In EVRP, a key decision point will occur after the first alder harvest. For example, planting in for a second alder rotation in 75:25 cedar:alder may not make sense, while retaining hemlock ingrowth might be useful where cedars failed. Close coordination between researchers and DNR Olympic region staff was established during the study planning and is expected to continue for the duration of the project. This will ensure that future changes in the research design will be incorporated in and tracked by DNR operations.

Harvest systems. The next harvest (around 2055) will likely use tethered, remotely controlled logging systems, compared to the saw-felled, cable system used during implementation (pers. comm. Woodam Chung, Oregon State University, October 2020). This logging system will seek to remove alders between cedars where excessive damage to cedars is avoidable. A second planting of alder would follow and both cedar and second-growth alder would again be harvested in 2090, unless a decision is made to divert to a late-seral objective. Long-term plans are to repeat this rotation sequence.

Aspect. Placement of the EVRP prescription was sought to avoid harsh south-facing slopes, given regional experience suggesting that alder seedlings are more likely to survive establishment if they are not planted on south-facing slopes. The only area available in watershed Ca has a south-facing slope, but at a higher elevation than most alder plantings residual sandstone soil which should have reasonably high water-holding capacity. Alder survival will be examined using a case-study approach.

Planting. All planting stock will come from the DNR Webster Forest Nursery. Generally, alder and cedar will be planted on an even spacing (Fig. EVRP-3) to achieve full stocking after anticipated mortality (Table EVRP-3). Extra cedars will be planted with about 400 trees/acre, which is 1.14 times more than Douglas-fir to account for likely higher mortality (or terminal hedging) from browsing. Planting will occur in the spring after herbicide site preparation to reduce the understory competition (see below) as soon as possible after threat of frost has passed to reduce alder mortality. If mortality proves an issue, as documented by regeneration surveys, a re-planting may be required.

CCCCCCCCC	CCCCCCCCC	ACACACACA	AAAAAAAAA	AAAAAAAAA
CCCCCCCCC	CACACACAC	CACACACAC	ACACACACA	AAAAAAAAA
CCCCCCCCC	CCCCCCCCC	ACACACACA	AAAAAAAAA	AAAAAAAAA
CCCCCCCCC	CACACACAC	CACACACAC	ACACACACA	AAAAAAAAA
CCCCCCCCC	CCCCCCCCC	ACACACACA	AAAAAAAAA	AAAAAAAAA
CCCCCCCCC	CACACACAC	CACACACAC	ACACACACA	AAAAAAAAA
CCCCCCCCC	CCCCCCCCC	ACACACACA	AAAAAAAAA	AAAAAAAAA
CCCCCCCCC	CACACACAC	CACACACAC	ACACACACA	AAAAAAAAA
CCCCCCCCC	CCCCCCCCC	ACACACACA	AAAAAAAAA	AAAAAAAAA
CCCCCCCCC	CACACACAC	CACACACAC	ACACACACA	AAAAAAAAA
100:0	75:25	50:50	25:75	0:100

Fig. EVRP-3. Planting plan to achieve different ratios.

Table EVRP-3. Planting densities (trees acre^{-1})

	Cedar:Alder ratio (%)				
	100:0	**75:25**	**50:50**	**25:75**	**0:100**
Planted cedar	600	450	300	150	0
Cedar mortality*	100	75	50	25	0
Planted alder	0	150	300	450	600
Alder mortality*	0	25	50	75	100
Total seedlings$^{\delta}$	500	500	500	500	500

* Expected from ungulate browsing or other causes

$^{\delta}$ Expected after combined mortality

Initial vegetation management. The current plan is to apply herbicides (but not a pre-emergent with lingering negative effects on alder) to reduce competition and increase survival and growth. Because of expected post-harvest vegetation dynamics, competing vegetation will be allowed to grow for one growing season after harvest before herbicide is applied. Subsequent treatments, if any, will not involve herbicides because both alder and cedar are too sensitive to them.

Pre-commercial thinning. Cost-effectiveness will guide the development of specific stand-tending actions. The objective will be to maintain appropriate research stocking levels. As mentioned above, the interventions will be applied to all replicates in the same way in order to maintain the study's integrity.

EVRP Key Questions and Monitoring

Analytical framework

Key questions are derived here that lead to specific monitoring. Funds for monitoring come primarily from Washington State Legislature proviso funding to ONRC and DNR, but may also be covered by other ONRC funds, DNR funds, and grants (see Chapter 7). Questions are very broad under the ecosystem wellbeing framework which means that detailed monitoring will not be possible in many cases. Key questions and core monitoring are described below that could be expanded with additional resources.

Key questions specific to the polyculture sub-study:

1. How will different cedar:alder planting ratios affect:
    A. Total, cedar, and alder growth and yield, including effects on site index and aspects of wood quality?
    B. Timber and revenue production through at least 1 full cedar rotation (2 alder rotations)?
    C. Net revenue and DNR administrative costs after specific investments in site preparation, planting, and tending are accounted for?
    D. Other ecosystem benefits including for example,
        i. Jobs in value-added manufacturing compared to hemlock and Douglas-fir lumber production; and
        ii. Carbon sequestration (aboveground, belowground, and secondary effects on primary productivity).
        iii. Habitat for early-seral-dependent species (including ungulates, insects, birds, plants) through measures of understory species composition and structure;

    iv. Actual browsing and cultural uses (alder and cedar manufacturing, and cultural uses);
    v. Increased adaptation and resiliency to climate and other uncertainties (including soil nutrients and productivity and response to disturbances); and
    vi. Quality of options to move stands to late-seral conditions;

2. Does polyculture differ in production or other measures from pure cedar or pure alder; and if so, is there an optimal ratio?
3. How well does the DNR's alder suitability (soil productivity) model perform on our sites?
4. How do deer and elk affect the growth of cedar and alder and does this interact with ratio?
5. To what extent will co-production suffer to avoid damage to residual cedar when removing the first rotation alder (either by damage or by reduced access to alder)?

EVRP core monitoring to answer polyculture sub-study key questions

The EVRP sub-study consists of 20 sub-units (5- to 10-acres each) distributed in 4 operational units (132 acres total). Traditional experiments would typically establish a large network of permanent monitoring plots with at least 1 large plot in each sub-unit. Such a network is not feasible for the sub-studies, let alone the larger operational scale prescriptions, given current funding, nor is it the best approach to take. The approach we take at this time is a dual track of establishing some standard permanent plots while simultaneously developing remote sensing methods that can reduce re-measurement costs and can better assess effects over larger, more complex landscapes. All permanent plots will be large enough and accurately located to feed into remote-sensing models. This approach will allow us to concentrate on average wall-to-wall responses that explicitly incorporate within-unit variability. However, some important measures will not be possible using remote-sensing methods, so additional traditional sampling will be required as well (e.g., soil responses). This monitoring framework is applied below to answer the key questions starting with the smallest sub-study scale followed by questions for entire operational units and cross-prescription comparisons:

Question 1.A: How will different cedar:alder planting ratios affect total, cedar, and alder growth and yield, including effects on site index and aspects of wood quality?

To address these traditional silviculture questions, we plan to deploy standard permanent plot methods after treatments are established up until the point that remote-sensing models of sufficient accuracy become available. These will be permanently located by locking in stem maps to LiDAR and monumenting them by leaving a taller stump near their centers. All trees in permanent 35-m radius plots will be assessed for species, dbh, height, live-crown ratio, and condition (including mortality and various forms of damage such as browse and form). After planting, most plots will be established in a central portion of the experimental unit to avoid edge effects. Some edge-affected, buffer plots will be added to assist in developing remote sensing models that can provide responses across entire units. Individual trees (tagged when large enough) will be measured on a 5-year schedule. Drone, aerial, or satellite remote sensing may have a more or less frequent schedule. Various equations will be used to calculate tree volume (e.g., Kozak 1995) and site index. Monitoring will be designed to feed into a 10-year-milestone assessment. Planning for longer-term monitoring will be addressed at that time.

Questions 1.B, 1.C, and 1.D.i: How will different cedar:alder planting ratios affect various costs, revenues, and economic and social consequences?

Costs for specific sub-unit activities will be captured as much as possible. Most socio-economic questions will be addressed at operational and larger scales (measures and projection protocols being developed separately). Some extrapolations from sub-studies may be attempted. For example, jobs per unit harvested volume can be projected for different species and uses based on current information, including jobs associated with management, research, harvest, transport, milling, post-milling manufacturing. Social consequences will be assessed or projected in a variety of ways, including sequential formal interviews.

Question 1.Dii: How will different cedar:alder planting ratios affect the ecosystem benefit of Carbon sequestration?

The tree plots described above will also provide biomass and carbon response over time using available equations. These can be used also to develop new and test existing LiDAR-based biomass and C models. Understory plots described below, when combined with tree estimates, will provide estimates of aboveground increments in standing biomass (helping to directly assess net primary production). Soil C changes will be assessed on EVRP units with repeat sampling.[14] We will project ecosystem C changes using available tools along with growth and yield models. For example, FVS has a fire and fuels extension that can estimate stand-level C. We hope to parameterize one or more ecosystem process models (e.g., 3-PG, iLand) when funding is secured to better project and extrapolate ecosystem C findings more widely. We also plan to build on work underway by UW and OSU through a The Nature Conservancy grant to examine relative effects of planting alder versus conifer in the next 30 years (2050 climate targets.

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[14] Mineral soil layers on EVRP units were sampled in July 2022 for pre-treatment conditions. Samples were collected at two depth increments and bulk density was measured to estimate soil compaction, and C and nutrient content.

Question 1.D.iii: How will different cedar:alder planting ratios affect the ecosystem benefit of habitat for early-seral-dependent species (including ungulates, insects, birds, and plants)

Within permanent tree plots, standard 3- by 3-m understory plots, 15 per experimental unit, will be created to collect data on non-tree vegetation, including species, cover, height, and aboveground biomass. Aboveground understory biomass will be determined with a photo-series previously developed for the Olympic Peninsula replicate of the Long Term Ecosystem Productivity study[15] plots. Fewer plots and measurements may be possible through drone-based remote sensing systems being developed concurrently. Direct measures of browse may be possible, especially in conjunction with some game cameras (a system being developed in small-scale field trials near La Push that will attempt to link browse measures on plants to frequency of game-camera activations). Avian response via acoustic monitoring (as in the Complex early seral prescription described in Chapter 4) is not possible because sub-units are too small. Traditional methods may be considered (standard listening post arrays). In the absence of direct measures, understory composition and biomass will be used to infer animal activity, with appropriate recognition that grazers affect composition and biomass.

Question 1.D.v: How will different cedar:alder planting ratios affect the ecosystem benefit of increasing adaptation and resiliency to climate and other uncertainties?

Many individual-tree and stand resiliency responses, costs, revenues, products, as well as various habitats will be evaluated while addressing questions 1.A-D. These measures will help evaluate related expectations under future climate (likely warmer, more variable), for example:

- Inter-species compatibilities in some of the cedar alder mixtures will be expressed as higher total stand growth and C sequestration relative to Standard VRH planted to Douglas-fir (possibly because of increased N_2 fixation, light sharing, mycorrhizal connections, weathering release of non-N nutrients, soil aggregation, and total mineral-soil organic matter—these could be studied in more detail but would likely need added funding);

- Total stand failures whatever the cause will be lowest in some cedar-alder mixtures by combining species with different vulnerabilities (especially wind since alder leaves drop during storm season and cedar sprouts after breakage). Most disturbances are better evaluated at the operational or larger scale so that wind exposure and other factors can be factored in (see cross-prescription and watershed questions and monitoring below); and

- Cedar-alder mixtures will create the best long-term prescription option for growing late-seral structures and habitat because of historical diminishment,

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[15] For more information on the LTEP study, refer to https://www.onrc.washington.edu/long-term-ecosystem-productivity-study/

special structural attributes of cedar, increased landscape diversity, resistance to root diseases and large-scale wind events, and cedar longevity.

Question 1.D.vi: How will different cedar:alder planting ratios affect the ecosystem benefit of quality of options to move stands to late-seral conditions?

Answers to questions 1.A, 1.D.ii, and 4 will be combined to determine relative condition at the end of the second alder rotation of the soil and cedar trees as a basis for projecting success of a transition to late-seral habitat if this option is chosen.

Question 2. Does polyculture outperform pure cedar or pure alder; and if so, is there an optimal ratio?

Answers to all of questions will be combined to evaluate optimal cedar:alder ratios. A single optimum is possible that produces an acceptable value to trust beneficiaries with the highest sum of other community and environment wellbeing measures. Multiple optima seem more likely depending on the differences in weighting among revenue and various wellbeing objectives. Multiple acceptable optima give managers more leeway in varying future practices to meet complex decision criteria.

Question 3. How well does the DNR alder soil productivity model perform on our sites?

The model included very little data from the outer Olympic Peninsula soils. Hence, managers need a better sense of this model’s uncertainty in this area, and a simple assessment of alder height growth in different locales will help them determine how much they should rely on it. Deviations from model predictions can be examined to see if patterns emerge relative to soil types, slopes, proximity to coast, elevation, and other factors. A thorough model review would need to include more of the alder range, and our analysis might contribute to this.

Question 4. How do deer and elk affect the growth of cedar and alder and does this interact with ratio?

Damage will be evaluated across all treatments to examine interactions between ratios and browse. An additional study is planned in adjacent stands to examine alternative browse avoidance strategies.

Question 5. To what extent will co-production suffer to avoid damage to residual cedar when removing the first rotation alder (either by damage or by reduced access to alder)?

Bark damage to cedar during alder removal will be broadly assessed and damaged trees can be tracked to evaluate any growth impacts.

Key questions specific to the EVRP operational scale including contributions to cross-prescription comparisons

These questions apply at the scale of entire operational units (30-60 acres) and are contributed to a compilation across all prescription treatments (see Chapter 6):

1. How do the variable-ratio polyculture sub-units combine to provide operational unit-scale, ecosystem-wellbeing responses—as compared to all the other upland treatments (EVDP, AVDT, CES, Control) consisting of:
    A. Net revenue (see economics sub plan).
    B. Consistency with regulations (from other prescriptions?).
    C. Other ecosystem (community and environment) benefits (see above + others from other prescriptions).
2. Will the non-uniform, stand-scale, mosaic prescriptions (EVRP, AVDT, EVDP) and sub-studies provide more adaptation and resiliency to climate and other uncertainties in terms of revenue, regulation consistency, and other ecosystem benefits compared to uniform prescriptions (Standard, CES, Control)?
3. How do beneficiaries, tribes, and stakeholders perceive different prescriptions?

Core monitoring to answer operational-scale key questions

There are 30 operational-scale experimental units across all upland prescriptions including 4 from EVRP (Table Watershed-2 in Chapter 6). These may total to nearly 1000 acres (including no-action controls) when tallied across the T3 watershed experiment. The approach we take at this scale is a dual track of summing responses from the sub-studies, and mainly relying on remote sensing to assess entire operational units that include internal variation and edge effects.

Question 1: How do the variable-ratio polyculture sub-units combine to provide operational unit-scale, ecosystem-wellbeing responses of net revenue, consistency with regulations, and other ecosystem benefits?

Economics of activities costs will be closely tracked at this scale (described in detail in the socio-economic protocol document (under development). Compliance with regulations will be described through timber-sale documentation. Other ecosystem responses (measures and projections) will be summed from sub-studies where available and from remote sensing.

Question 2: Will non-uniform, stand-scale, mosaic prescriptions (EVRP, AVDT, EVDP) and sub-studies provide more adaptation and resiliency in terms of revenue, regulation consistency, and other ecosystem benefits compared to more uniform prescriptions (Standard, CES, Control)?

Measures of adaptation and ecological resiliency are yet to be fully developed that can be applied to all operational-scale experimental units, but can be largely derived from other measurements described above. At operational and larger scales, we can evaluate, for example:

- Patterns of major disturbances (e.g., wind, insects, disease, landslides, fire, heat domes, drought, ice) can be tracked across watersheds in managed and unmanaged areas. Controls will provide a background on which to compare with active treatments. We expect some short-term increases in disturbance associated with stresses related to newly created edges (we can track propagation of disturbance and edge effects with wall-to-wall remote sensing) and long-term decreases associated with more growing space for individual trees. Swiss Needlecast may be an increasing problem for Douglas-fir and we should not be surprised by other emerging problems for hemlock, alder, or cedar.
- We expect improved response to large disturbance simply by improving the distribution of the seed bank of all species (especially early seral that could re-start a normal successional process when management will not be possible; any large event would swamp timber markets prohibiting funding for restoration activity).

Evaluating adaptation and resiliency of institutions and communities can be evaluated through extrapolation to larger scales, for example:

- Continued support for active management (by maintaining or improving social acceptance—measured directly and indirectly, e.g., lawsuits) and providing a greater diversity of tree species and sizes will help reduce loss of—or possibly increase—diversity in manufacturing infrastructure. The current diversity is endangered by declining alder and cedar supply, maintaining or expanding this diversity is central to aspects of community wellbeing given multiple uncertainties.
- At a meta-level, successful implementation of the study is a test of increased adaptation capacity by DNR and its partners. We have expected that the focus on designing an operational-scale experiment by researchers, managers, and stakeholders) will facilitate increased adaptation and resiliency by overcoming institutional and other barriers to change (many to draw from). A social science case study with tracking the process and formal interviews will help uncover these.

Question 3: How do beneficiaries, tribes, and stakeholders perceive different prescriptions?

Tracking changes in perceptions is critical as it may imply learning or other social shifts deserving consideration when making decisions. Initial interpretations from our stakeholder workshops suggested that Alternative-2 prescriptions (EVRP, EVDP and riparian alder underplanting) were of more interest than Alternative-1's CES and other riparian treatments. Discussion on AVDT was insufficient to determine its priority. We speculate that these perceptions may result from the community outreach where ideas for EVRP, EVDP, alder treatments came from individuals in the community and were then shaped by scientific understanding afterwards. Ideas coming straight from the scientific community tended to be less inspiring and perhaps not well understood. It will be interesting to track changes as learning-based collaborators get more engaged and as results begin emerging. Our basic hypothesis is that increased participation in collaborative learning will increase support and goodwill. Formal interview methods are being documented that can be repeated over time.

Chapter 3. Ethnoforestry—Variable-Density Planting (EVDP)

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Prescription Abstract

We describe a potential new tool: an operational-scale prescription that follows a standard VRH, which seeks to add more elements of community and environment wellbeing compared to standard practice. The prescription increases heterogeneity by adding a variety of clumped planting patterns (variable-density plantings) combined with a variety of open, "interstitial" areas across the operational unit. If applied widely in the future, it will add resiliency through heterogeneity in management and forest condition across the landscape. The main purpose of the areas planted with Douglas-fir is to rapidly achieve revenue objectives; the main purpose of the interstitial is to co-produce various non-timber objectives by extending the time and space given to plants other than conifers relative to standard practice. This prescription also features a sub-study to explore, at a smaller scale, different clumping/interstitial patterns and densities. This prescription emerged from stakeholder outreach on how to increase ecosystem wellbeing in the Alternative-2 strategy watersheds using a new concept of ethnoforestry, defined as people-focused forest management. We have little experience with this approach, but there are many intriguing possible positive and negative possibilities for growth of Douglas-fir and other species on a stand basis. Early seral successional habitat will be extended to improve quality and quantity of forage for ungulates and to favor plants used for cultural or non-timber economic purposes such as native weaving and foods (i.e., ethnobotanically important plants). The latter half of the rotation is designed to be dominated by conifer wood production. We will compare 5 new planting treatments that vary the number of trees per clump and spacing of trees in clumps to the standard DNR practice of planting 350 trees per acre with uniform spacing on 11' centers. Two 4-tree-clump, a 16-tree-clump, and two 36-tree-clump treatments are used to efficiently vary clumping and intra-clump tree spacing.

EVDP Prescription Background and Objectives

The concept for the EVDP prescription was developed to meet the goals of the Alt-2 integration strategy, which includes drawing inspiration for new ways to integrate community and environment wellbeing that come from social-science-based engagement with stakeholders and elevated concerns for rural livelihoods. We define the field of ethnoforestry as people-focused forest management[16]. Ethnoforestry better applies knowledge and input from local people in dependent rural communities to forest management within DNR trust mandates

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[16] *Ethno* comes from the Ancient Greek meaning 'nation' or 'race'. In the forestry 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.

using the ecosystem wellbeing framework and through the process of learning-based collaboration. Both EVRP and EVDP are examples of ethnoforestry in a remote rural area. In the Alt-2 strategy, we expand on the trust lands' integration focus (revenue production and ESA-related habitat concerns) to build in other community and environment benefits that can be co-produced (i.e., ecosystem services).

We apply this new tool in 4 watersheds designated for Alt-2 integration strategy to compare to standard practice and other T3 prescriptions. On the west end of the Olympic Peninsula over the last 5 years, DNR's standard practice includes planting 1-2 years after timber harvest 60% of the time with Douglas-fir and 40% with western redcedar, western hemlock, or Sitka spruce[17].

Applications of herbicide is site and time dependent. Typically, stands are planted at a density of 350 trees per acre with a goal of harvesting units at approximately 50 years with 250-300 trees per acre if not pre-commercially thinned (100-150 trees per acre with a PCT). Planting at a higher density ensures that an adequate number of trees survive despite anticipated mortality on site. Naturally regenerated hemlock usually becomes a major, if not dominant, part of the stand. When timber harvests occur, slash is left on site, often with large piles left near roads.

Depending on site conditions, crew availability, and time, piles may either be burned or left to decompose naturally. Fixed, evenly spaced Douglas-fir plantations have been the dominant production-oriented silviculture system in western Washington and Oregon for more than 50 years (Talbert and Marshall 2005). The system has been very widely applied with science developed to guide: growing nursery stock, planting (ideal spacing and stocking), management of competing vegetation, timing of pre-commercial thinning for respacing and selecting crop trees, and genetic gains through time. Planting success on mesic sites is 80-90%, and initial planting spacing of 6 ft (681 trees/acre) to 20 ft (109 trees/acre) all hold some Douglas-fir plantation appeal. Tighter spacings provide increased early growth (a.k.a. Weyerhaeuser effect, Woodruff et al. 2002), and provide options for selecting straight, good crown ideotype crop trees but with added planting costs and losses of other species and habitat. In contrast, widely spaced plantations provide the possibility of reducing planting and pre-commercial thinning treatments costs, but run the risk of lower volumes and increasing branch retention thereby reducing wood quality. On the Olympic Peninsula, fully stocked Douglas-fir plantations may reduce western hemlock ingrowth, but regardless of initial planting density, pre-commercial thinning is often desirable. Today the most common initial spacings are 10' to 12' (300-425 trees/acre) in Douglas-fir plantations.

The Douglas-fir plantation system has been so successful that it accelerated conversion of native forest habitat to plantations. On public lands there have been efforts to restore native forest habitat by converting young and maturing plantations back to more diverse species and

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[17] Personal communication, Matt Perry, regeneration silviculturist Olympic Region DNR.

structural composition. Ecological silviculture (Palik et al. 2020) suggests variable retention harvest and variable density thinning strategies in western Washington as approaches to restoring native species and structural diversity. Diverse forest structure is deemed a key to converting some younger forests to a late successional habitat pathway; a pathway which is less likely from natural stand development of abandoned plantations. No fully developed late-successional habitat has yet been created through restoration treatments; the importance of time, initial stocking and species composition, and small disturbances in facilitating old-growth like habitat are not well understood. Some DNR-defined "old-forest habitat" has been created by commercial thinning in '21 Blow[18] stands. Donato et al. (2012) suggested that initial forest conditions may be important in determining forest successional trajectories but little silviculture work has focused on initial tree composition and spacing as a driver of old-growth habitat development. Multispecies and variably spaced plantations will likely provide new insights into stand development for production and ecological objectives. We explore the role of initial vegetation and pattern on stand development.

The EVDP treatments provide a silviculture approach to explore the importance of initial stand-level variation in stocking (spacing and clumping pattern) and diverse understory and non-crop tree variation on stand development. The design focuses on managing both Douglas-fir tree crop space with clumped patterns and the interstitial stand space (between tree clumps). The interstitial space is where ungulate browse and culturally important understory plants will be favored over conifer ingrowth, nonnative and invasive plants, and other domineering evergreen shrubs that compete with desired species and have little browse value (e.g., salal). The species favored may include huckleberries, native raspberry and blackberry, salmonberry, elderberry, Labrador or Indian tea, beargrass, sweetgrass, and various herbs.

Specific EVDP objectives are to:

1. Continue to grow repeated conifer rotations to generate trust revenue as mandated in state law, at levels +/- 15% of that produced by standard VRH and post-VRH practices;
2. Provide for endangered- and other species considered in the state lands Habitat Conservation Plan (HCP; WDNR 1997) through habitat management under agreements with regulatory agencies;
3. Develop and learn about our new concept of "variable-density planting" (parallel to VDT) which seeks to meet revenue and habitat requirements by both (a) growing conifers planted in a mosaic of clumping patterns and (b) growing

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[18] '21 Blow stands refers to the forest stands originating after the hurricane-force 1921 wind storm, which blew down thousands of acres of trees along the Washington coastline including the OESF.

vegetation in a mosaic of interstitial spaces between clumps for other purposes. Potential advantages include:

- Improving elk and deer browse and habitat;
- Increasing culturally valued plant species and other potentially valuable non-timber products;
- Extending the time and space given to dependent early-seral birds and insects (with possible effects on stream food chains).
- Diversifying management at the sub-stand (less uniform spacing), the operational (different patterns), and larger landscape scales (different prescriptions)—reducing the all-eggs-in-one-basket problem;
- Better distributing early-seral plant diversity and seed sources within stands and landscapes that can respond better to future large-scale disturbances (when normal operations will not be possible);

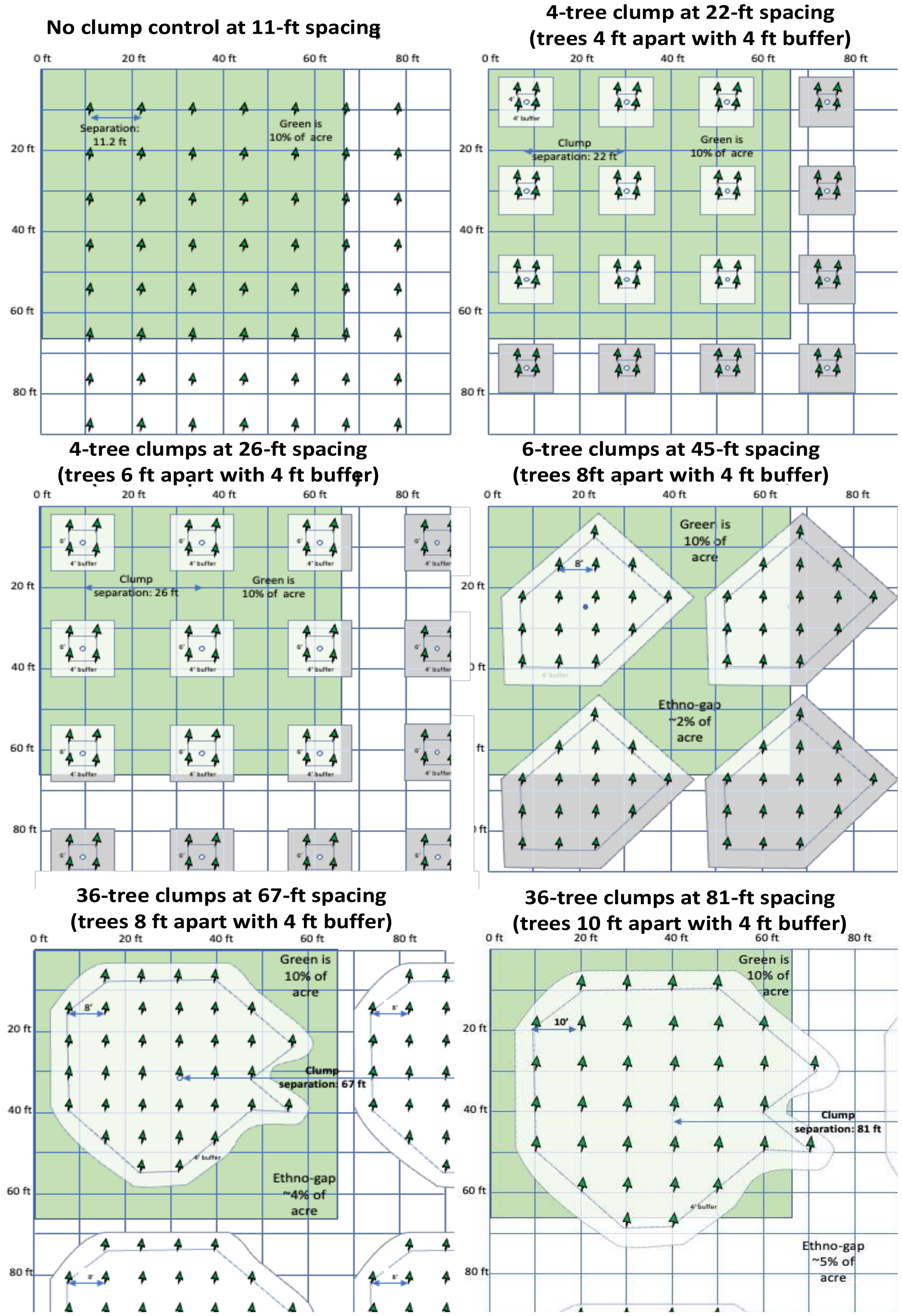
4. Examine individual clumping/interstitial patterns from the mosaic in a nested sub-study, looking at total production as well as individual tree health (resilience to insects, diseases, and wind damage) by increasing live-crown ratios and stronger mycorrhizal connections and connected crowns in clumps.

EVDP Experimental Design

Clumped planting sub-study

Many clump densities, planted tree spacings, and other arrangements were evaluated. Principal investigators agreed on a set of 6 treatments to include in the sub-study in June, 2021 (Table EVDP-1; Fig. EVDP-1). Chosen sub-study treatments affect initial interstitial area and maximum opening size in different ways. These clumping patterns are expected to affect eventual timber volume at rotation, costs of post-harvest management such as planting, tending, and PCT, and amount of space and time for browse and other non-conifer early-seral vegetation. Other effects are more speculative, including optimal forage/cover (hiding, thermal, edge; Witmer and Kuttel 1985), browse damage, wood quality, hunter success, mycorrhizal sharing, and windfirmness in clumps. Even with the interesting possibilities and large uncertainties, all patterns are expected to provide net revenue +/- 15% of standard (no clump) controls. Analyzing and projecting future economic, and other ecosystem costs and benefits will be a major study goal in the next two years.

Treatments will be assigned to sub-units by using a complete randomized-block design, with the set of clump treatments applied in 4 operational units, 1 in each of the 4 Alt-2 watersheds (blocks; Table EVDP-2). Questions at this scale change to address more mechanistic explanations for larger responses. For example, intra-clump tree growth, survival, and competition; rate of interstitial area closures; planting arrangement feasibility; effects of shading; with many other possibilities.


No clump control at 11-ft spacing

4-tree clump at 22-ft spacing (trees 4 ft apart with 4 ft buffer)

4-tree clumps at 26-ft spacing (trees 6 ft apart with 4 ft buffer)

6-tree clumps at 45-ft spacing (trees 8ft apart with 4 ft buffer)

36-tree clumps at 67-ft spacing (trees 8 ft apart with 4 ft buffer)

36-tree clumps at 81-ft spacing (trees 10 ft apart with 4 ft buffer)

Figure EVDP-1. The 6 clumping arrangements: an un-clumped control, an intermediate 16 tree clump, and two each 4-tree and 36-tree clump treatments with narrow and wide inter-tree spacings. These represent a range of many possible clumping options. These will be assigned randomly within the sub-units that constitute the operational-scale unit. The interstitial space will be managed for elk forage, culturally valuable species, and early-seral species and habitats. The clumps are for timber production primarily.

Table EVDP-1. Characteristics of the chosen clump/interstitial patterns (see Fig. EVDP-2)

Clump ID*	Trees Clump^{-1}	Planted spacing (ft)	Planted Trees acre^{-1}	Initial interstitial area (%)	Initial Clump area (%)	Clumps acre^{-1}	Clump spacing (ft)	Maximum opening (ft^2)
Control	0	11	350	0	100	0	0	0
4@4	4	4	350	71	29	88	22	205
4@6	4	6	255	71	29	64	26	260
16@8	16$^{\Psi}$	8	350	51	49	22	45	850
36@8	36$^{\Omega}$	8	350	51	49	10	67	1742
36@10	36$^{\Omega}$	10	240	49	51	7	81	2072

***Clump ID is trees clump^{-1} @ tree spacing**

$^{\Psi}$Square spacing would allow 4 interior trees surrounded by 12 trees; and be planted as 4 x 4 rows.

$^{\Omega}$Square spacing would have 6 x 6 rows with 4 interior trees, surrounded by 12 second-row, and finally 20 edge trees.

Table EVDP-2. ANOVA table for clumping sub study

Source	Degrees of Freedom
Treatments (k-1)	5
Blocks (b-1)	3
Error (k-1)(b-1)	15
Total (n-1)	23

We designed the 5 clumping treatments and a regularly spaced control as a way to explore effects of various nonuniform Douglas-fir tree spacings. We chose clumping patterns based on trees per clump (4, 16, or 36) and intra-clump tree spacings (4’, 6’, 8’, and 10’) to maximize contrasts among clumps and to compare to the unclumped 11’ x 11’ control. The patterns will variably affect interstitial space between clumps, length of time and space for understory plants to dominate until the tree canopy closes, total stocking, and perhaps the need for PCT.

Understanding the response of Douglas-fir canopies to clumping patterns is one goal of this design—we envision a stand of (theoretically) all dominant trees with large canopies on 1/2 of their crowns extending later into rotation. The clumping pattern allows theoretically more growing space which we utilize to increase the interstitial space between clumps. It would also be possible to increase the stocking with the clumped pattern. The 6’ spacing between trees in the second 4-tree clumping design allow exploration of the effects of the intra-tree spacing on canopy length and form which ultimately impact growth.

Larger clumping patterns of 16-tree and 36-tree clumps allow us to explore operational efficiency and differences in growth and growth form between interior and clump edge trees. The 36-tree clumps with both 8’ and 10’ spacing between trees within the clumps provide an efficient way to both plant and to create large openings of interstitial space. The 36-tree clumps are designed to be planted roughly as 6 rows by 6 columns (Fig. EVDP-1), and with this approach 18 trees are on the edge, 12 trees are one tree from the edge and 6 trees are interior. We anticipate a similar response of edge trees in larger clumps to smaller clumps, however the larger interstitial space suggests full crowns will be maintained on one side until the end of rotation. The penetration of light into the clumps is poorly understood and may provide more light for all crop trees; 4-tree clumps will likely maintain light, 16-tree clumps will have more interior light than 36-tree clumps. The comparison of edge trees to interior trees over a gradient of clump sizes (4, 16, and 36-tree) allows efficient exploration of interactions between clump size. The 8’ and 10’ intra-clump space explore spacing tradeoffs. The 16-tree clump provides an intermediate treatment between 4-tree and 36-trees clumps which will allow us to understand the attenuation of light through the clumps, and changes in growth with changing clumping size. The 16-tree clumps created 12 edge and 4 interior trees, again an intermediate condition from the 4-tree and 36-tree clumps. More clump sizes would be desirable but more difficult to implement operationally.

Clumping sub-study layout

Six- to 15-acre sub-units were identified in the 4 operational areas chosen for EVDP prescription that lay inside the four Alt-2 strategy watersheds (Fig. EVDP-3). Together the sub-units provide variably clumped plantings together in a mosaic parallel to the variable-density thinning concept, with heterogeneity providing potential resiliency value for unknowable future conditions of various kinds. Individually, sub-units constitute a smaller-scale research experiment on clumping patterns (Table EVDP-3). Operational areas were divided up in roughly sixths often using riparian buffers when available. Where possible, sub-units were drawn from ridge-top roads down to riparian buffers near larger streams. This size is thought to provide sufficient space to evaluate growth and yield of trees and understory—where understory response will be used to examine effects on habitat. This is true for the largest clump pattern which would have about forty 36-tree clumps in the smallest sub-unit.

Small areas adjacent to roads along ridges in each Alt-2 watersheds were also set aside to plant a range of culturally important species in small demonstration areas (not part of the sub-study). These demo areas will be planted and tended by university staff at no expense to DNR. These areas will be used to study how nursery-available plants grow in an agro-forestry system. Additionally, the interstitial areas with the sub-studies are often on steep slopes with tough terrain, making it difficult for local community members to safely and reliably access. These demonstration areas provide an easier place for local tribal and community members to visit. Specific culturally significant understory plants will be based on the small-scale ethnoforestry field trial underway in 2020 by ONRC on land managed by DNR near La Push, WA as well as direct input from local people via semi-structured interviews conducted over the last several years. Demonstration sites will be made available for field trips and for tending and harvesting by interested tribal and other communities.

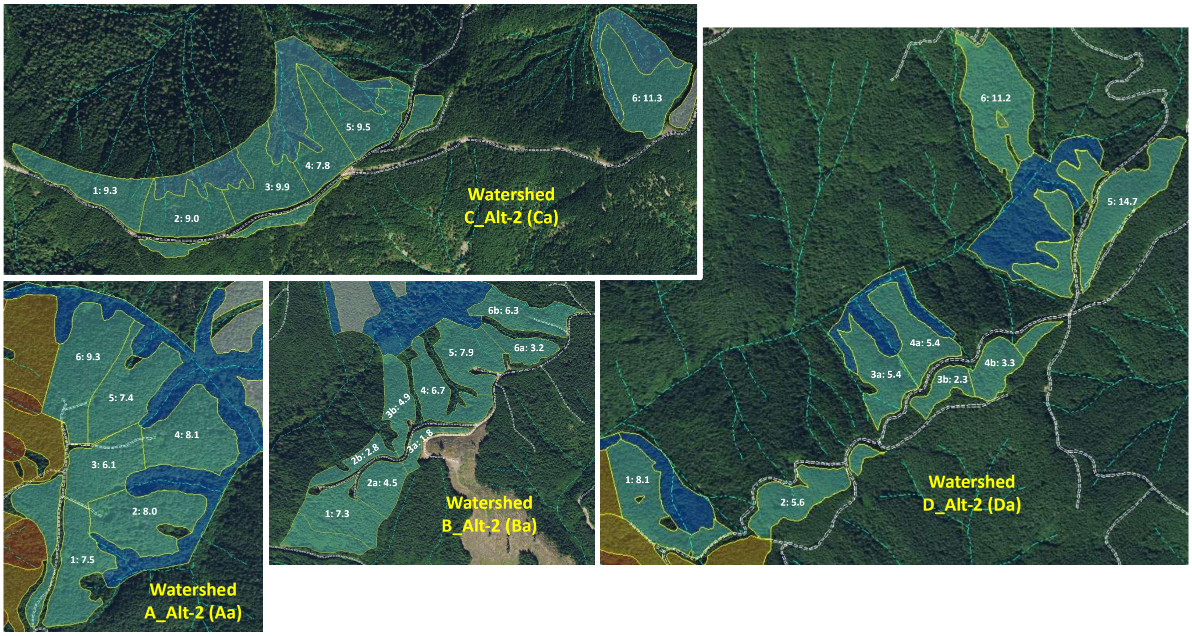


Figure EVDP-3. Layout of the Ethnoforestry/variable-density planting prescriptions (light green). The EVDP prescription treatments are uphill from various riparian treatments (blue). Other colors are other prescriptions. Sub-unit numbers (1: to 6:) precede acres (use to compare scales). Maps are oriented north. Clumping treatments will be assigned randomly to available sub-units creating a variable-density planting array across the operational-scale unit as well as a randomized-block sub-study for comparing different clumping designs.

Table EVDP-3. Acres in sub-units of the clumping sub-study treatments

	Watershed (experimental unit)			
Subunit	**A_Alt-2 (Aa)**	**B_Alt-2 (Ba)**	**C_Alt-2 (Ca)**	**D_Alt-2 (Da)**
1	7.5	7.3	9.3	8.1
2	8.0	7.3	9.0	5.6
3	6.1	6.7	9.9	7.7
4	8.1	6.7	7.8	8.7
5	7.4	7.9	9.5	14.7
6	9.3	9.5	11.6	11.2
Sum	46.4	45.4	57.1	56.0

Statistical note: this is a simple, complete randomized block design with 6 clumping/spacing treatments and 4 reps (blocks). Other more flexible statistical models, such as exploratory data analysis, will also be used opportunistically.

Other design and implementation considerations for EVDP

***Operational and research consistency*.** Blending economic viability and study design to both expand DNR's toolbox and better understand why different approaches worked is no easy task. After harvesting and planting, developing conditions may require decisions that could affect study design and economic viability. Continued debate among PIs to maximize overall learning will apply a decision hierarchy described in Chapter 2.

Planting. For the sake of better understanding clumping effects, only Douglas-fir will be planted in sub-study units. Training planting crews to implement desired clump patterns may provide some special challenges, including a possible need for training, and even assistance in the field. For large 16- and 36-tree clumps, getting crews to plant trees at an 8- or 10-ft spacing should be straightforward, but perhaps requiring pre-setting of clump-center posts to assure good clump spacing. For small 4-ft clumps, posts might be required along unit boundaries to better assure proper spacing as planters work across slopes. Although we intend to have seedlings planted as close to the desired spacing as possible, forest conditions (e.g., level of slash, stumps, etc.) may result in minimal levels of deviation from the intended plan. We do not foresee this substantially impacting the planting design. Some post-planting assessment might use drone photography to assure contract compliance and to best understand variation in initial conditions. Trees will be planted as soon as possible and no longer than 2 years after harvest.

Swiss Needlecast. Swiss Needlecast is an increasing threat for young Douglas-fir stands in coastal Pacific Northwest. Block D, lies in the zone (<25 k from the ocean) where severe Needlecast has been observed in Oregon and SW Washington (Ritokova et al. 2016). Severe Needlecast can reduce Douglas-fir growth by up to 50% (Maguire et al. 2011). We chose to plant only Douglas-fir in this sub-study because this is DNR's most common practice, seedling availability, and to have a uniform species for the experiment. Several stakeholders suggested using hemlock or mixed species plantings to better accommodate potential Needlecast effects. This idea is appealing but was rejected for now because it would hinder study of the main effects of variable-density planting and reduce comparison among other T3 prescriptions. Replicating the variable-density planting design with hemlock could be undertaken in nearby areas outside of this experiment (under discussion). Ongoing monitoring by DNR Forest Health Division could help evaluate needlecast effects in these stands.

Managing interstitial vegetation. The ecosystem wellbeing framework seemingly provides a paradigmatic shift in forest management from an establishing-conifers-excluding-brush mentality to managing for crop-trees and other plants on more equal footing. We can manage vegetation for a new variety of objectives, including plants important to tribes, providing forage for early-seral herbivores (e.g., insects, ungulates), pollen and nectar for pollinators, food for insectivores and frugivores, and to minimize invasive species. We can help develop this new paradigm within the broad objectives that include minimizing early-rotation costs. The current plan is to apply vegetation management 3 to 5 years after planting (depending on conditions) to allow understory to develop, before applying highly selective vegetation management, possibly including herbicide and/or manual control. Extra focus will be placed on controlling all vegetation in clumps and clump buffers competing with Douglas-fir plantings. For the interstitial, we will develop a list of most to least desirable plants (e.g., cultural species and forage near the top and hemlock and invasives near the bottom). Criteria will include value to ungulates, tribes, non-timber forest products, and early-seral-dependent species. Prior to timber harvests, crews will evaluate the sub-study areas and identify patches of important understory species to preserve, for example areas of mature huckleberry or beargrass. These areas will be protected during logging and will be avoided during the vegetation management. We presume that natural hemlock regeneration, certain nonnative plants, and aggressive species with little browse value would be reduced in favor of those that otherwise fit the criteria. For example, if salal is present, it might be targeted for reduction through a special permit for pickers. Post-intervention assessments are needed here as well, also using drone photography and LiDAR, if possible, for contract and study purposes. Researchers will offer training and work with contractors to develop this approach.

Pre-commercial thinning**.** Cost-effectiveness will guide the development of specific stand-tending actions, as they have a large impact on projected future revenue since they occur long-before harvest. We envision applying pre-commercial thinning (PCT) in some clump patterns but not others based mainly on economic criteria. Optimal timing of PCT might vary as well. Criteria will be developed to optimize late-rotation timber production and net revenue. The hope is that the need for PCT will vary among patterns, and that patterns may be applied differently depending on conditions. For example, more remote portions of the OESF may benefit from a clumping pattern that does not require any PCT, while a unit close to highway 101 would have clear PCT benefit.

EVDP Key Questions and Monitoring

Analytical framework

Key questions are derived here that lead to specific monitoring. Funds for monitoring come primarily from Washington State Legislature proviso funding to ONRC and DNR, but may also be covered by other ONRC funds, DNR funds, and grants (see Chapter 7). Questions and monitoring are very broad under the ecosystem wellbeing framework which means that detailed monitoring will not be possible in many cases. Key questions and core monitoring are described below that could be expanded with additional resources.

Key questions specific to the variable-density planting sub-study:

1. How will clump/interstitial patterns and different inter-tree spacing (within 4- and 36-tree clumps) affect (relative to sub-study un-clumped controls):
    A. Total and net revenue (after admin and other costs) through at least 1 rotation?
    B. Growth and yield of conifers, including merchantable volume, biomass, site index, and possibly wood quality as affected by:

        i. Sunlight as a function of distance from clump/interstitial edge?
        ii. Stand establishment, development, and form?
        iii. Ingrowth of hemlock?

    C. Other ecosystem benefits including for example,
        i. Composition, growth, and yield of understory plants providing early-seral habitat (for early-seral-dependent species including ungulates, insects, birds, and plants) as measured inside interstitial areas and clumps over time?
        ii. Actual browsing and cultural uses?
        iii. Carbon sequestration (aboveground, with consideration of potential belowground) and secondary effects on primary productivity?
        iv. Resilience of individual trees and clumps and within-clump tree density to climate and other uncertainty; and
        v. Quality of options to move stands to late-seral designation?

2. How well will existing growth models predict growth and yield on these non-uniform plantings?
3. Will selective understory management (herbicide applied in year 2) succeed in favoring ungulate or culturally preferred species?
4. Will PCT be needed in all clump patterns and tree spacings, and thereby will some clumping patterns be better suited for remote stands where other costs are higher and growth slower?

There are many other process- and biodiversity-related questions yet to be developed, including effects of Swiss Needlecast. With additional resources, this design will allow for assessing effects of experimental treatments on other aspects of biodiversity including upland insects, amphibians, canopy fauna, and soil organisms.

Core monitoring to answer key questions in the variable-density planting sub-study

The EVDP sub-study consists of 24 sub-units 6- to 15-acres each within 4 operational units (205 acres total). Traditional research would have established a large network of permanent plots with at least 1 large plot in each sub-unit. Such a network is not feasible for the sub-studies, let alone the larger operational scale prescriptions, given current funding, nor is it the best approach to take. Instead, we will shift to remote sensing using the latest drone-LiDAR and other technologies. This will allow us to concentrate on average wall-to-wall responses as well as within-unit variability. Many important measures will not be approachable with these remote-sensing methods, so some additional traditional sampling will be required as well, but on a limited basis. The approach we take at this time is a dual track of establishing some standard permanent plots while simultaneously developing remote sensing methods that can reduce re-measurement costs and can better assess effects over larger, more complex landscapes. All permanent plots will be large enough and accurately located to feed into remote-sensing models. Studying clumps and interstitial spaces represents some spatial-analysis problems. The approach we propose is to create a subset of 20 to 30 permanent plots consisting of entire individual clumps and interstitial spaces placed on all treatments and blocks representing the full range of outcomes observed. A transect approach (center to edge) also may be tried on larger clumps and interstitial spaces. We will use these ground plots to develop remote sensing models that can provide evidence on all clumps and spaces. Throughout the summer of 2021 and 2022, drone-LiDAR was flown over portions of the T3 watersheds. These data are currently being analyzed and models are being developed to determine the potential this monitoring approach may have on this and other treatments. Early-stage analysis suggests that this approach holds promise for assessing tree growth and canopy structure. This monitoring framework approach is applied below to answer the key questions starting with the smallest sub-study scale and then contributions to questions for entire operational units and cross-prescription comparisons.

Question 1.A: How will clump/interstitial patterns and different inter-tree spacing affect total and net revenue through 1 rotation?

There are too many uncertainties pushing possible revenue responses in different directions to make useful hypotheses in this study plan. Net timber revenue to the trusts is highly dependent on growth and yield and also more near-term costs (planting, tending, PCT, roads). It is also highly influenced by changes in markets, technology, management goals, and legal directives. How to project (hypothesize) and track revenue is addressed in the economics/ecoservices white paper (under development).

Question 1.B.i: How will clump/interstitial patterns and different inter-tree spacing affect sunlight availability?

Plants display foliage to capture sunlight that then affects other plants of lower stature. Deciduous hardwood shrubs are adept at unfolding leaf area quickly and spreading horizontally over the initial annual-plant display. Conifers tend to grow upwards more than outwards and hence it takes them longer to display enough foliage to shade out others. Eventually, they can dominate once overtopping height-limited shrubs or small trees. Different plants have different tolerance for shade so some linger without much light. Broad leaves of hardwoods allow sun flecks and transmit more of some light spectra, while conifer needles tend to scatter reflected light. Taken together, we expect rather complex changes in the light environment through time and space. Responses to edges and transitions will be of particular interest. Transects with ceptometer or spectometer readings and perhaps drone-LiDAR models should allow us to characterize the light environment across entire units.

Question 1.B.ii and 1.B.iii: How will clump/interstitial patterns and different inter-tree spacing affect stand establishment, development, and form?

We expect that planting patterns will have some effect on 2-year survival of planted Douglas-fir, and that differences in initial diameter, height, and form will emerge years 3 to 9. Longer-term, the growth (height, volume, biomass), live-crown, and mortality of trees (planted and ingrowth) as individuals and clumps will be tracked every five years in permanent plots. Drone-LiDAR and other available remote sensing (RS) options will be used with ground data to create RS models that apply to all clumps, to achieve entire sub-plot averages. There are too many uncertainties pushing possible responses in different directions to make useful hypotheses in this study plan.

Question 1.C.i: How will clump/interstitial patterns affect composition, growth and yield of understory plants providing early-seral habitat?

The growth and diversity of plants in the interstitial spaces will be examined in parallel with conifer clump measurements. We define early-seral (ES) habitat quality in terms of its likely value to ES-dependent species of concern (ungulates, adapted neotropical birds, pollinators, and insects in general). This definition favors herbs, grasses, and deciduous shrubs and flower and fruit producers, and disfavors hemlock, poorly digestible evergreen shrubs like salal, and invasive non-native species like Scotch Broom. For the first 10-15 years, we expect higher quality ES habitat in small compared to large clumps (simple initial area difference). We expect this pattern to fully reverse over time with higher quality ES habitat in large compared to small clumps (as conifer crown cover from adjoining clumps reduces incoming light). We expect a variety of mechanisms to influence qualities of ES habitat through the entire rotation in complex ways, including ungulate browsing, deciduous growth (e.g., cascara) that shades understory, nutrient availability, and ingrowth of undesired species such as hemlock or non-native species. Use of center-to-edge transects will be used to capture space averages, if entire space measures are unfeasible. Cover and biomass of interstitial species (Estornell et al. 2011; LTEP biocube protocols on file at ONRC), with a growth model over time is feasible. Species composition may not be possible with RS models (drone-LiDAR and multispectral models are a possibility), so some sort of subsampling approach based on ground measurements will likely be needed. We may be able to develop better methods to follow energy into various food webs by quantifying biomass per acre of fruit, seeds, flowers, nectar, and other palatable native vegetation through time broken out by category.

Question 1.C.ii: How will clump/interstitial patterns affect actual ungulate and cultural uses?

We expect greater browsing and elk presence (culturally important animal) in treatments with higher quality and abundance of early-seral habitat as define above. We also expect more culturally valued plants in treatments with interstitial spaces. A game-camera system is being tested in the ethnoforestry field trials near La Push seeking a regression between image captures and treatment type/ early-seral habitat quality. This will also be compared to measured browse. We need to further consult with ungulate experts to see what other data/methods are possible to quantify ungulate use (pellet counts, browsing losses). We may be able to have cultural uses quantified through a permit system.

Question 1.C.iii: How will clump/interstitial patterns affect carbon sequestration?

We expect faster initial increases in aboveground C mass in treatments with more early-seral plants (they grow outwards and produce leaf area faster than conifers). As conifers capture most of the incoming light, aboveground C mass shifts to them later in the rotation. Net aboveground totals for the rotation will be highest in treatments with the most conifer volume. We can evaluate existing remote sensing models for aboveground C on our forests (Stovall et al. 2017). This can begin with tightly georeferenced pre-treatment stand measurements. Ecosystem and belowground C mass is more complex and difficult to measure. We expect declines in O-horizon C after initial harvest with increased temperature and summer moisture. The higher C sequestration in shrubs is expected to rebuild this C pool faster than under conifer clumps. Losses of C from the mineral soil are also expected to be higher under fast-growing conifers than under deciduous shrubs. Douglas-fir in particular is known for “mining” nutrients associated with organo-mineral compounds (Bormann et al. 2015; Hicks et al. 2021). Aboveground C can be calculated from tree and understory biomass data. O-horizon C in transect sampling is feasible but time consuming. O horizons are problematic in many PNW forests because of their transitory nature (lots of through flow) but might work better in this hyper-humid environment with lots of input and slower decomposition[19]. Detecting changes in mineral soil C is very demanding given inherent variability and costs of sampling and processing quantitative samples. We have some experience measuring soil respiration at the stand scale (Bormann et al. 2015), which may be helpful especially if autotrophic root respiration can be subtracted. Other methods can be explored such as Plant Root Simulator probes (cations and anions) to give us a time series of change. Genomic analysis of rhizosphere among the VDP treatments in order to characterize the community type and diversity may prove helpful as well. We will pursue belowground C in a way that is proportional to new funding sources.

Question 1.C.iv: How will clump/interstitial patterns affect resilience of individual trees and clumps to climate and other uncertainty?

At the sub-study scale, we expect different clump patterns and conifer spacing within clumps to provide different levels of resilience to individual trees and clumps as a whole. Metrics of individual-tree resilience will likely include live-crown ratio, needle retention, and taper (more

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[19] Based on preliminary data from the Long Term Ecosystem Productivity Study in the OESF; refer to https://www.onrc.washington.edu/long-term-ecosystem-productivity-study/

light provides more resources to produce healing and defensive compounds). This kind of resilience should be highest in edge trees. Clump resilience will be assessed by summing tree resilience across the clump, and by evaluating resistance to wind and other damages. Conifers planted closely maintain interwoven branches which may protect members of the clump better than evenly distributed trees. The wide array of existing and yet-to-emerge disturbance factors makes forming conclusions about resilience difficult. For example, Swiss Needlecast is likely expanding with climate change, and it can have dramatic effect on young, exposed, full crowned Douglas-fir trees (Maguire et al. 2011). The recent heat dome in July 2021 appeared to hit Douglas-fir harder than other species and is possibly interacting with Needlecast. Bears also appear to strip bark on conifers with the most sugars. So, metrics of resilience can counter each other. The DNR uses a model to project wind throw based largely on exposure, terrain, and fetch. Monitoring tree losses to wind will help evaluate this model over time.

Question 1.C.v: How will clump/interstitial patterns affect quality of options to move stands to late-seral designation?

Clumping patterns and variability are expected to produce stands that are better suited to conversion toward late-seral conditions, assuming DNR has a shortage at the time of the decision. This is based on the premise that increased variability within and between clumping/interstitial treatments better matches the natural variability of old-growth stands. The presence of lingering early-seral species between large conifers also better matches late-seral conditions and creates stands that if disturbed with a massive wind storm help restart succession more similar to natural succession. Metrics to evaluate this question are collected while addressing the other questions.

Question 2: How well will existing models predict growth and yield on these non-uniform plantings?

Projecting growth for entire rotations is central to estimating net revenue, but there is much uncertainty in current technology. For example, the forest vegetation simulator (FVS; Dixon 2002) which is a distance-independent growth model was not designed to project prescriptions that fall outside the empirical stand data on which it was based, including many of our novel prescriptions. Special application of the model is being explored in our economics projection study along with sensitivity analyses to better apply and evaluate projection uncertainties. This effort includes collaboration with the BC Ministry of Forests to get a preliminary cross-check on projections using the BC tree and stand simulator as a distance-dependent model. Ecosystem process models, such as iLand or 3PG, will also be considered in future work that can be linked to other regional efforts, with a goal of extending projections to other areas and treatments. A side issue with these models is to get a better handle on how they predict mortality which might increase with changing climate and other disturbances. Distance-dependent models will require detailed stem maps, which we think we will be able to provide with current drone-

LiDAR. More work is needed to understand if live crown can be determined with this type of LiDAR or if crowns will need to be mapped from the ground with the inventory software FieldMap.

Question 3:. Will selective understory management succeed in favoring ungulate and culturally preferred species?

Selective control of understory plants is rarely attempted. Many managers view understory as 'brush' that causes competition and interference with the growth and development of the timber crop (Rose et al. 2006). Crews may not be trained to differentiate between understory species in the field, and might only be able to differentiate conifer species. It remains to be seen if protocols (specific herbicides and/or manual brushing) can be developed and crews trained that can economically achieve the multiple objectives of reducing competition in clumps and favoring certain ungulate and culturally preferred species in the interstitial.

Question 4: Will PCT be needed in all clump patterns and tree spacings?

Pre-commercial thinning is expensive and has a large effect on net present value. Two countervailing concerns will determine if clumping increases or decreases the need for PCT. High competition between trees in the clump drives the need up and distance between clumps drives it down. We expect the 4-tree clump with fewer trees per acre and 6 ft spacing to have the lowest PCT need perhaps aided by some within-clump mortality. This approach may apply well to remote stands where other costs are higher and growth slower. The response will only be apparent after 15 to 20 years. Additionally, if the removal of hemlock in-growth occurs during vegetation management 3-5 years post-planting, this may limit the need for a PCT.

Key questions specific to the EVDP operational scale including contributions to cross-prescription comparisons

These questions apply at the scale of entire operational units (30-60 acres) and are contributed to a compilation across all prescription treatments in the compiled upland study plan:

1. How do the variable-density planting sub-units combine to provide operational unit-scale, ecosystem-wellbeing responses—as compared to all the other upland treatments (AVDT, CES, EVRP, Control) consisting of:
   A. Net revenue (see economics white paper);
   B. Consistency with regulations (from other prescriptions?); and
   C. Other ecosystem (community and environment) benefits (see above + others from other prescriptions).
2. How do the two early-seral oriented prescriptions (CES and EVDP) compare?

3. Will the non-uniform, stand-scale, mosaic prescriptions (EVRP, AVDT, EVDP) and sub-studies provide more adaptation and resiliency to climate and other uncertainties in terms of revenue, regulation consistency, and other ecosystem benefits compared to uniform prescriptions (Standard, CES, Control)?
4. How do beneficiaries, tribes, and stakeholders perceive different prescriptions?

Core monitoring to answer key cross-prescription questions

There are 22 operational-scale experimental units (4 from EVDP). These may total to nearly 1000 acres (including no-action controls) when tallied across the T3 watershed experiment. The approach we take at this scale is a dual track of summing responses from the sub-studies, and mainly relying on remote sensing to assess entire operational units that include internal variation and edge effects.

Question 1.A, 1.B, 1.C: How do all the new prescriptions compare to each other and controls and standard practice?

Net revenue, growth of trees and understory, C sequestration, tree and stand resilience, and various habitat qualities will be evaluated on all prescriptions so that their relative performance can be considered. Management decisions will be based on consideration of all of the similarities and differences.

Question 2: How do the two new early-seral prescriptions (CES, EVDP) compare to each other?

Complex early-seral (CES) is a mostly hands off approach to increasing the time and space for early-seral conditions and species (with planting only to avoid very low stocking). It also focuses on structural elements by leaving more legacies from the previous stands. The EVDP approach is more active management with direct manipulation of planted trees and interstitial spaces to produce a composition of plants and tree spacing to better match historical successional patterns, but without leaving more snags or logs like CES. CES will have low initial costs, although also lower initial revenue since fewer trees are harvested. EVDP will have high costs associates with planting and initial tending. Which approach achieves conifer crown closure sooner is unclear. This depends on the amount of hemlock ingrowth in CES, and the success of keeping hemlock out in EVDP. Both are expected to produce within-stand heterogeneity through natural and intentional processes. We are not able to compare animal responses the same way on both. The acoustic monitoring of songbirds in CES requires uniform habitat plots too large for EVDP and resources for ungulate monitoring in CES are not available at present.

Question 3: Will mosaic prescriptions (EVDP, EVRP, AVDT) provide more resilience at the operational scale than uniform prescriptions (Standard, CES, Control)?

Although diversification is thought to be one of the best measures of resilience, it is also a direct manipulation so cannot be used for evaluation. Wind effects, as the most likely disturbance measure, can substitute but only when it exceeds allowable levels, as some wind losses are even desired in the AVDT for example. Wind is also tricky in that thinned stands are more susceptible generally until trees adjust. Afterward, dense stands with spindly trees become more susceptible to large scale blowdown. In post-VRH treatments (EVDP, EVRP, CES, Standard) wind effects will not emerge in the first decade. Response in the Control will be of particular interest. These previously managed stands are often very dense and might be susceptible to a large wind event.

Question 4: How do beneficiaries, tribes, and stakeholders perceive different prescriptions?

Tracking changes in perceptions is critical as it may imply learning or other social shifts deserving consideration when making decisions. Initial interpretations from our stakeholder workshops suggested that Alternative-2 prescriptions (EVRP, EVDP and riparian alder underplanting) were of more interest than Alternative-1's CES and other riparian treatments. Discussion on AVDT was insufficient to determine its priority. We speculate that these perceptions may result from the community outreach where ideas for EVRP, EVDP, alder treatments came from individuals in the community and were then shaped by scientific understanding afterwards. Ideas coming straight from the scientific community tended to be less inspiring and perhaps not well understood. It will be interesting to track changes as learning-based collaborators get more engaged and as results begin emerging. Our basic hypothesis is that increased participation in collaborative learning will increase support and generate more goodwill. Formal interview methods are being documented that can be repeated over time.

Chapter 4. Structurally Complex Early Seral (CES)

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Prescription Abstract

Early-seral, or pre-forest, habitat is the successional stage between a stand-replacing disturbance and subsequent tree canopy closure. The habitat function and structural complexity of this stage have often been overlooked or oversimplified in past models of forest succession, which were traditionally focused on canopy trees. Structurally complex early seral (CES) is currently the rarest forest habitat in the Pacific Northwest – rarer than old-growth in both an absolute sense and relative to its historical levels under natural disturbance regimes. As such, there are increasing calls to actively create or promote CES habitat, and public land agencies are beginning to do so – most notably the US Forest Service and Bureau of Land Management. However, the potential trade-offs associated with this approach are not well quantified, particularly for lands also managed for timber production. This sub-study tests an experimental prescription designed to create early seral habitat at the beginning of a rotation while keeping a stand on a production trajectory.

The CES prescription is intended to produce, with the least possible economic impact, a habitat stage similar to that produced by a severe windstorm, the most frequent large-scale natural disturbance in the region. The goal is to quantify the potential trade-offs – ecological, silvicultural, economic – of using the CES prescription to produce small (<40-acre) patches of CES habitat. Specific trade-offs will be evaluated by comparing the CES prescription to DNR's standard variable-retention harvest with conventional reforestation practices (SVRH). The CES prescription will consist of a VRH modified to leave additional dispersed residual trees likely to incur windthrow or stem breakage, scattered logging slash, and patches of undisturbed understory vegetation. In this prescription, no site preparation will occur, and natural regeneration will be used to the extent possible, supplemented by planting of hemlock plugs only where natural regeneration is not successful.

Comparisons between the CES and SVRH treatments will include habitat conditions (e.g., vegetation structure and composition), avian response measured by passive acoustic monitoring, stand regeneration, and an economic evaluation that includes various stand growth-and-yield scenarios. The outcome of the CES prescription will also be compared to that of the ethnoforestry variable-density planting (EVDP) prescription in the Alternative-2-strategy watersheds. This will contrast the more passive CES approach with the more active EVDP approach, both geared to increasing the space and time for early-seral species and habitat.

CES Prescription Background and Objectives

The purpose of the CES sub-study is to assess outcomes associated with the intentional creation of structurally complex, early-seral habitat following a variable-retention harvest (VRH) but before trees once again dominate the site. This research effort supports the concept of the Alt-1 Strategy: it applies current science to seek integration of additional ecological concerns with continued revenue generation and habitat mandates.

Early-seral habitat is the successional stage between a stand-replacing disturbance and subsequent tree canopy closure. On forested sites, this stage is unique in being the only period in which trees (not counting seedlings and saplings or hardwoods) do not fully dominate the plant community (Franklin et al. 2018). Ecosystem structure in this stage is shaped by a plant community dominated more by non-tree life forms (e.g., shrubs, herbs, grasses), combined with regenerating trees and biological legacies from the previous stand (e.g., snags, down wood, surviving overstory trees) (Swanson et al. 2011) (Fig. CES-1; Table CES-1). Early-seral habitat is occupied by a wide range of plant and animal species. Across the Pacific Northwest, the number of early-seral obligate species (i.e., species highly reliant on early-seral habitat) is actually similar to the number of old-growth obligate species – and even more are facultative users of early-seral habitats (Swanson et al. 2014).

Figure CES-1. Example of natural early-seral conditions following a recent severe blowdown near Lake Quinault on the western Olympic Peninsula.

Table CES-1. Characteristics of early-seral forests after severe windstorms.

Ecosystem element	Character
Live trees	Variable, often abundant and more scattered than clumped
Snags	Variable, often partial height due to wind-snapping
Downed woody debris	Abundant
Undisturbed understory	Abundant
Spatial heterogeneity of vegetation	Variable, depending on distribution of advance regeneration (i.e., seedlings or saplings surviving the disturbance) and natural regeneration
Time in early-successional condition	Variable, depending on abundance and growth of advance regeneration

Structurally complex early seral is currently the rarest forest habitat in the Pacific Northwest – rarer than old-growth in both an absolute sense and relative to its historical levels under natural disturbance regimes (Franklin et al. 2018). The amount of "missing" early-seral habitat relative to historical or characteristic levels is not well quantified for the Olympic Peninsula, but studies from other landscapes west of the Cascades generally indicate that natural post-disturbance conditions ranged from ~1-30% of the landscape at any given time historically, compared to near zero currently (Wimberly 2002; Donato et al. 2020). The decline in the amount of CES habitat between 1985 and 2012 is most pronounced in the Coast Range ecoregion, with the declines in this ecoregion occurring across all land ownerships (Phalan et al. 2019). Similarly, studies indicate declining abundance of early-seral associate species, such as birds, in recent decades (e.g., Betts et al. 2010; Phalan et al. 2019).

Public land agencies in the Pacific Northwest are beginning to actively create early-seral forest habitats – most notably the USDA Forest Service and USDI Bureau of Land Management. But for lands managed for timber production, the trade-offs of intentionally inserting an early seral stage into a rotation, thereby delaying establishment of trees, are not well quantified. Anticipated economic risks include a greater rotation length and reduced control over the density, spacing, and species composition of the developing stand of crop trees.

As awareness of the role of early-seral habitat and its scarcity on the landscape grows in the scientific community and among the public, there will be increasing benefit in demonstrating that DNR is being proactive in testing practical management solutions. This study will play a pioneering role in learning about the trade-offs associated with including complex early-seral habitat in an active timber program.

The broad goal of the CES sub-study is to quantify the potential trade-offs – ecological, silvicultural, economic – of a prescription designed to produce structurally complex early-seral habitat at the scale of a timber sale unit (up to approximately 40 ac). This experimental prescription will be implemented through DNR's timber sale program, through modifications in the timber sale contract and reforestation prescription. To the extent practicable, the treatment will be designed to emulate conditions that would result from the predominant natural disturbance affecting coastal Pacific Northwest forests: severe wind storms (Table CES-1). The intent is to explore the practicality of promoting an early-seral habitat stage while keeping stands on a production trajectory.

The objectives of the CES sub-study are:

1. Test an experimental prescription designed to maintain the production of timber revenues, as mandated in state law, while also providing additional ecological benefits early in the rotation;
2. Continue to provide habitat for endangered- and other species considered in the habitat conservation plan (HCP) through habitat management under agreements with regulatory agencies;
3. Evaluate outcomes of the experimental CES prescription by comparing them to those of the SVRH approach:
   - Compare habitat conditions (e.g., vegetation structure and composition) produced by the CES prescription to conditions produced under SVRH[20]. Inference will be based on comparing these two treatments via field data and modeling, as well as comparing with information from the scientific literature on natural post-windstorm conditions and/or tree plantations.
   - Assess the avian response to the experimental CES prescription relative to that of SVRH by using passive acoustic monitoring. This post-harvest acoustic monitoring is the second stage of the acoustic avian monitoring study, the first stage of which is occurring pre-harvest and is described in a separate study plan (Minkova et al 2020).
   - Evaluate stand regeneration resulting from the CES prescription, including young stand development, relative to conventional post-VRH reforestation.

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[20] Ideally, these two habitat conditions would also be compared with two book-end conditions: a) naturally generated early-seral conditions following a severe wind-disturbance event, and b) full plantation-style management as practiced on many industrial lands. However, it is highly uncertain/unlikely that a severe wind event will occur within the timeframe of this study, and resources currently do not afford an additional set of sample units on industrial lands.

- Perform an economic evaluation drawing on data from this study, including any differences in initial harvest and regeneration costs and long-term stand growth differences. The latter will be modeled using DNR's version of Forest Vegetation Simulator (FVS) or other growth-and-yield model, and using assumptions based on scientific literature. An economic analysis will provide data to help inform decisions about when and where this early-seral prescription may or may not be consistent with various management objectives. Trade-offs among biodiversity and timber yield outcomes will be analyzed by combining data on avian occupancy rates and/or other indicators of biodiversity and habitat function with forecasts of timber yield and economic return.

CES Experimental Design

CES sub-study design

This sub-study consists of two treatments: the CES and SVRH prescriptions (Table CES-2). The experimental CES prescription is designed to produce habitat similar to the early-seral conditions that follow stand-replacing, severe wind storms in coastal Pacific Northwest forests. It will consist of a modified VRH with enhanced legacies (Table CES-1), followed by an emphasis on natural regeneration with no site prep or vegetation control. The prescription is intended to create both horizontal and vertical structural complexity, by retaining and promoting biological legacies from the harvested stand and spatially variable natural regeneration.

The CES treatments will be implemented in the Alt-1 strategy ("z") watersheds of the T3 watershed experiment, while SVRH treatments will be sampled on similar sites in Alt-1 and Standard ("p") strategy watersheds. Although it would have been preferable to place all SVRH treatments only in the Standard strategy watersheds, this was not possible for these reasons:

- A target of 13% harvest per decade was set for each treated watershed to meet aquatic and stream sampling goals of the study;
- DNR was hesitant to replicate new, unproven prescriptions within watersheds, so additional harvest to achieve the target % harvest had to be SVRH in larger watersheds; and
- Added harvests were also needed to provide access to riparian treatments below them.

The CES units are distributed across 4 Alt-1 watersheds, with corresponding SVDT units in some Alt-1 and Standard watersheds (Fig. CES-2). The CES units total about 160 acres, with individual sub-units ranging from 10 to 60 acres. The SVRH units have a similar total acreage and distribution as the CES units and were chosen, to the extent possible, to be similar to the CES units in aspect, slope, and elevation.

This sub-study is designed around a peer-reviewed avian acoustics monitoring study (Minkova et al. 2020); online study plan). Two or more acoustic monitoring stations were set up in CES units (blue) in each of the Alt-1 (z) watersheds for a total of 16 stations representing the CES treatment. Six monitoring stations were set up in SVDT units (tan) in Standard (p) watersheds; 9 stations in Alt-1 (z) watersheds; and 1 outside of the study watersheds, for a total of 16 stations representing the SVRH treatment. Ground tree and understory plots were installed around each station. See the avian study plan for statistical design. Further analysis will be available from drone LiDAR-based models covering entire units.

Table CES-2. Management treatments in the CES and SVRH units

Item	Complex Early-Seral units	SVRH units
Leave tree density	12 tpa across unit	8 tpa across unit
Leave tree selection	In addition to largest trees, intentionally include tall/skinny trees to promote breakage, wind effects. Emphasize species other than DF or WH, when present	Normal; VRH practice, determined by Forest Practices rules and foresters considering local conditions
Leave tree clumping	60% as dispersed individuals 20% in clumps of ~5 trees 20% in clumps of ~10 trees	
Leave clump placement	Where possible, place clumps to protect best-developed patches of understory shrubs and advance regeneration	
Leave trees and unit edges	Okay to have leave trees near edges, but only at same density as rest of unit and not interfering with riparian study buffers	
Leave tree marking	Mark individual trees or clump edges	
Leave trees & acoustic stations	Only restriction is no large clumps (10 trees) within 50 m of station	
Slash management	Leave slash as-is on site; do not pile. A specified number of 5-inch tops per acre will be left on site.	Normal VRH practice (e.g. whole tree)
Down wood	Leave in place.	Normal VRH practice
Snags	Leave trees are expected to produce snags in some cases; consider girdling to create new snags in subsequent years if not naturally recruiting.	Normal VRH practice

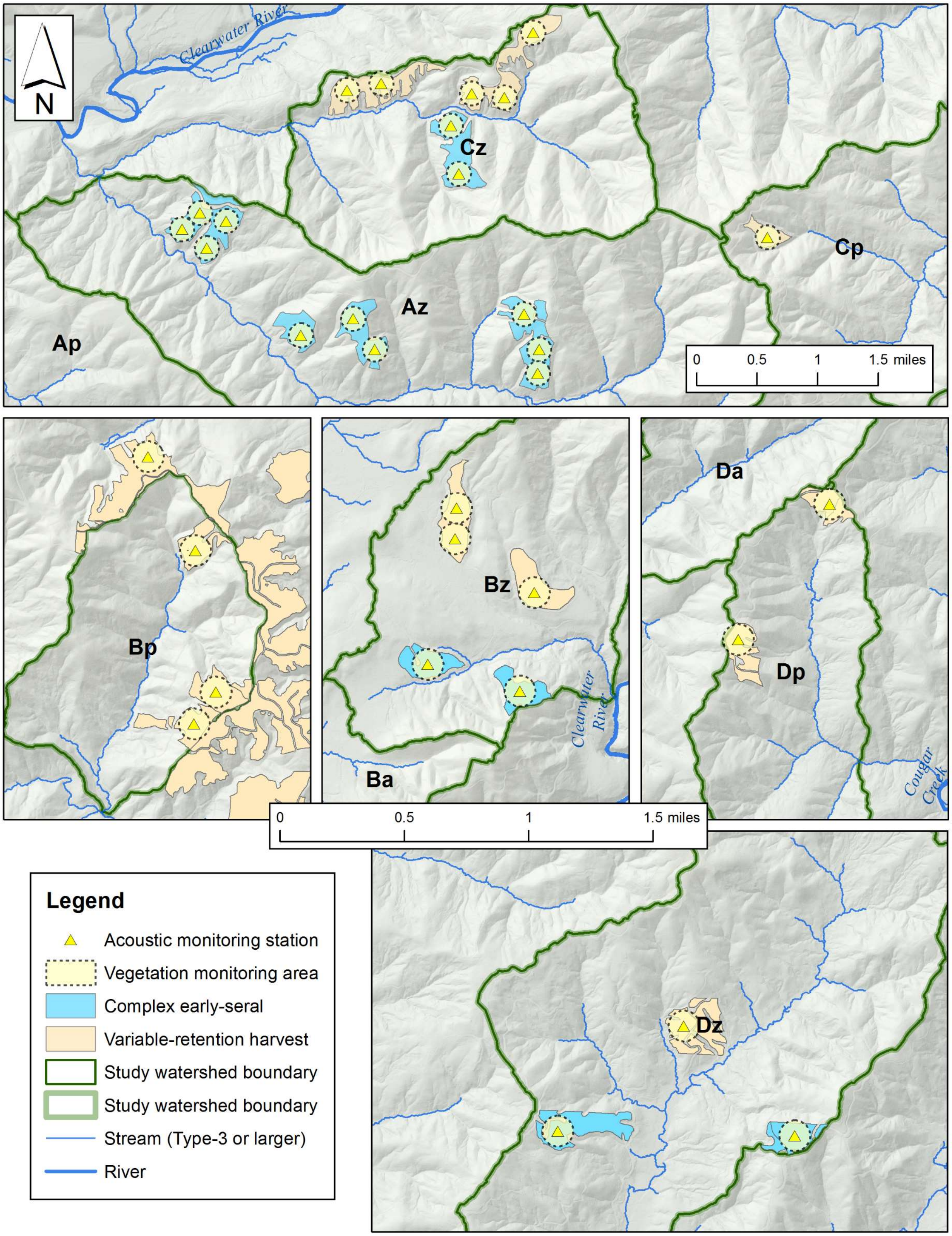

Figure CES-2. Map of complex early-seral and control SVRH treatment units, with acoustic and vegetation monitoring sites indicated. There will be a total of 32 monitoring sites.

Other design and implementation considerations with CES

Safety. Snags within leave-tree clumps will be left standing where this can be done in compliance with L&I regulations.

***Operational and research consistency*.** Blending economic viability and study design to both expand DNR's toolbox and better understand why different approaches worked is no easy task. After harvesting, the developing conditions may require decisions that could affect study design and economic viability. For CES, the key issues are minimal stocking and applying the same treatments in all replicate watersheds. Continued debate among PIs to maximize overall learning will apply a decision hierarchy described in Chapter 2. Natural regeneration following the CES harvest prescription is unlikely to provide sufficient stocking across the entire harvest units. Planting of hemlock plugs (P+0), based on the results of a reproduction survey, is planned for the CES units as insurance against this potential stocking problem (Table CES-3). These planted plugs are not expected to significantly impede development of early-seral habitat, because they will not be planted until the second or third growing season after harvest and their initial growth will not be as rapid as that of larger bare-root seedlings. Therefore, the planted hemlock plugs will not occupy the site and shade out competing vegetation initially.

Table CES-3. Planting prescriptions for early-seral and control VRH units.

	CES units	SVRH units
Objective	By 2-3 years post-harvest: ● Achieve unit-wide average ≥ 200 tpa ● Minimum 150 tpa at acre scale[ξ] ● To extent possible, above includes natural regeneration	● ≥ 250 tpa conifers, evenly distributed across the unit, 1 year after planting ● ≥ 250 tpa free-to-grow conifers, 3 years after planting
Approach	● Skip planting the first growing season (possibly the second depending on timing of harvest) ● Conduct reproduction surveys prior to planting, as late (close to planting season) as possible o Install two 1/50th-acre plots per every 2-5 acres; plan for 50-100 plots/day/person ● Plant zero-year plugs 2nd (possibly 3rd) growing season to fill gaps in natural regen o Order enough plugs to regenerate units assuming some likely minimum level of natural regen o Shift leftover plugs to other projects as needed	● Site prep may be applied on some sites, as necessary ● Plant bare-root conifer mixture including Douglas-fir and western hemlock (360 tpa; 11-ft spacing) ● Control of competing vegetation applied where necessary (based on results of reprod. surveys)

[ξ] Note: a variance may be needed (190 tpa required by Washington Forest Practices).

***Management of competing vegetation*.** It is recognized that at some point the development of a viable stand may require control of vegetation that is directly competing with tree seedlings. In this situation, seedlings would be released by targeting the vegetation in their immediate vicinity rather than broadcast control which would impede the early-seral habitat.

***Precommercial thinning*.** Precommercial thinning is compatible with the CES prescription, given the anticipated timeline of stand development.

CES Key Questions and Monitoring

Analytical framework

Key questions are derived here that lead to specific monitoring. Funds for monitoring come primarily from Washington State Legislature proviso funding to ONRC and DNR, but may also be covered by other ONRC funds, DNR funds, and grants (see Chapter 7). Key questions and core monitoring are described below; these could be expanded with additional resources.

Key questions for the CES sub-study:

1. How does the CES prescription affect habitat development?
    a. Can the CES prescription produce habitat conditions similar to the conditions that have been documented in natural early-seral habitat?
    b. Which elements of the CES prescription produce habitat conditions that differ from those following SVRH, and which do not?
    c. How long does the CES stage last until canopy closure reaches > 75% tree-canopy coverage over at least 90% of a stand area?
2. How do birds respond to the CES prescription?
    a. Does occupancy (presence-absence) of indicator bird species differ between the CES prescription and SVRH?
    b. Which stand-level habitat elements and landscape-level covariates explain the occupancy rates of indicator bird species?
    c. What are the differences in habitat function (occupancy rates of bird species or by other indicators) between the CES and SVRH?
3. What are the differences in stand regeneration?
    a. What is the rate of establishment and the composition of natural regeneration after the CES treatment?
    b. What is the spatial distribution of natural regeneration within the units and what factors are affecting this distribution?

   c. How does regeneration (density, species, canopy cover) and competing vegetation compare between the CES and conventional reforestation treatments over time?

4. How do economics differ between CES and SVRH?
   a. What is the economic cost, in terms of net present value, of implementing the CES prescription, compared to conventional VRH management practices?
   b. Can specific elements of the CES prescription be adjusted to improve its economic outlook, while minimizing loss of ecological benefits?
   c. What is the nature of potential trade-offs occurring between avian occupancy and economic return?

Four types of monitoring will take place, to answer research questions associated with the four objectives of this sub-study: habitat, avian response, stand regeneration, and economics. Habitat and avian acoustic monitoring will take place at 16 locations in each of the 2 treatments for a total of 32 monitoring locations (Fig. CES-2). Stand regeneration will be monitored in each of the harvest units that include these 32 monitoring locations. The economic analysis will draw on implementation cost data and growth projections for the stands resulting from the two treatments.

Core monitoring to answer CES questions

Question 1: How does the CES prescription affect habitat development*?*

Habitat monitoring will consist of vegetation and down wood measurements designed to characterize biological legacies from the previous stand and vegetation development following harvest (Table CES-4). To optimize consistency and efficiency across the study, habitat sampling will follow the general approach described in the passive acoustic monitoring study plan (Minkova et al. 2020), with additional sampling of biomass and botanical diversity.

Habitat sampling will occur on four plots surrounding each of the 32 acoustic monitoring stations – 16 in CES and 16 in control VRH units. The station locations were established in the summer of 2021, prior to harvest. Each station’s coordinates were recorded using GPS, and the base of the tree at the station’s location was marked with yellow paint.

In addition to vegetation and down wood measurements, landscape attributes will be recorded for each of the 32 locations to further characterize the local habitat and its functionality. These include, but are not limited to, elevation, slope, aspect, and distances to nearest stream, road, and forest edge. To the extent possible, these attributes will be measured in ArcGIS; otherwise, measurements will be made in the field. Habitat conditions will be measured once in the year prior to harvest and once per year in the three years following harvest (with additional years of data collection desirable but contingent upon funding).

Statistical analysis of habitat data will be performed by linear modeling. Models will include the treatment fixed effect (CES vs. control VRH) and an array of stand- and landscape-scale covariates included to account for natural variation across the landscape.

Table CES-4. Field measurements used to assess habitat (biological legacies and vegetation development). Measurements will be performed on plots surrounding each acoustic monitoring station (Appendix 2).

Attribute	Measurement approach
Biological legacies	
Live trees	As part of the timber sale, all leave trees (individuals and clumps) will be marked and inventoried in each unit prior to harvest. Clumps will be mapped using GPS.
Snags	Following the acoustic monitoring habitat protocol, snags will be assessed at least twice, once before and once during the first year after harvest.
Downed woody debris	Following the acoustic monitoring habitat protocol, down wood will be measured at least twice, pre-harvest and in the first year after harvest.
Undisturbed understory	Following the acoustic monitoring habitat protocol, the understory will be measured once per year in early-to-mid summer. Measurements taken pre-harvest and in the first year after harvest will be used to characterize legacy understory.
Spatial heterogeneity of treatment response	Each harvest unit will have at least four vegetation plots on which herbaceous plants, shrubs, and trees of all sizes will be measured annually. The variation among these plots over time will provide information on spatial heterogeneity.
Time in early-successional condition	The difference in vegetation development over time between the early-seral harvest units and the control VRH units will indicate how long the early-seral prescriptions extend the period until trees dominate the site.
Vegetation development	
Understory and mid-story species	Following the acoustic monitoring habitat protocol, herbaceous plants and shrubs will be measured once per year in summer for 3 years post-harvest.
Tree regeneration (forest canopy species)	Regeneration (natural and planted) will be surveyed once per year for 3 years post-harvest in the CES treatment. In coordination with the DNR Olympic Region's reproduction survey procedures, the control VRH treatments will be surveyed in years 1 and 3. Surveys in years 5 and 10 are also desirable, but will be contingent upon funding.

Question 2: How do birds respond to the CES prescription*?*

Avian passive acoustic monitoring will take place at all 32 monitoring stations. At each monitoring station, an acoustic recording unit (ARU) mounted on a leave tree will be used to monitor bird calls. Because the detection range of the acoustic sensors is 328 feet (100 m), each monitoring station can be visualized as being at the center of a circle with a 328-foot radius. Circles will not overlap each other, and to the extent possible, each circle will be entirely contained within the harvest unit. However, because many of the harvest units are inherently small and/or complex-shaped, the acoustic sensors will usually be detecting both patch-interior and patch-edge bird use. The scope of inference is therefore defined as bird use of small patches of early-seral habitat (and control VRH) and their edges. This level of patchiness, although not ideal for experimental purposes, reflects the current management reality in the OESF and the potential spatial allocation of any early-seral treatments in the future.

As described in detail in the acoustic monitoring study plan, ARUs will be deployed at the 32 stations – 16 stations in CES units and 16 in control VRH units - for a two-week period or longer during the bird breeding season (April-August). The goal is to obtain at least 4 repeated independent acoustic survey per station per season in order to minimize the possibility of a false absence and to estimate the probability of detection of an indicator species. This will be achieved by programing the ARU to record at least four 24-hour periods spaced at least 2 days apart. Monitoring will occur during two years pre-harvest and at least three years post-harvest. Further monitoring is contingent upon funding.

The presence/absence data for each indicator bird species at each station is derived from the acoustic recordings. These data will be analyzed with stand-level and landscape-level habitat data using occupancy modeling (MacKenize et. al 2002). The goal is to assess the importance of habitat differences resulting from the two prescriptions to bird occupancy rates and to habitat function. Details of this sampling and analytical approach are described in the passive acoustic monitoring study plan for pre-harvest sampling (Minkova et al. 2020). In addition to using bird occupancy rates, the habitat function of the two prescriptions can be compared using acoustic indices of biodiversity (such as species richness and evenness), derived from the acoustic data sets (Sueur et al. 2014).

Question 3: What are the differences in stand regeneration*?*

Natural regeneration will be monitored during the first three years post-harvest in the CES treatment. Small monitoring plots will be located along transects that span the units; this will allow analysis of spatial patterns in regeneration, such as distribution and edge influence. The density of natural regeneration and the size of the largest seedlings will be measured. After any supplemental hemlock plantings are completed, surveys will distinguish these from the naturally established seedlings, so that they can both be analyzed. In year 3 and (assuming funding is available) year 5, surveys will be made in both the CES and the SVRH treatments. These surveys will allow comparisons between treatments and will provide data to inform the economic analysis.

Question 4: How do economics differ between CES and SVRH*?*

An economic analysis will initially be performed after three years of post-planting data are collected on seedling survival, growth, and competing vegetation. The early years during stand establishment are of key importance to the entire rotation, both silviculturally and economically. Costs incurred early in the rotation have a substantial effect on net present value calculations. Therefore, to analyze the economics of the experimental CES prescription, it will be vital to document early-rotation costs as well as to have a reasonably accurate understanding of the future trajectory of the young stand, including possible future silvicultural treatments. Early growth and survival data of planted and naturally established seedlings will help in estimating future stand performance.

Data on harvest costs for the control VRH and the CES prescription will be collected during the harvest contract. Data on regeneration costs - standard reforestation and CES regeneration - will be collected during the first 3 years post-harvest. Stand growth and projected yield will be modeled to rotation length for both the CES and control VRH treatments using FVS or another growth-and-yield model. Using modeled stand growth, an economic comparison of the two treatments will be made, based on several scenarios (e.g., pre-commercial or commercial thinning in the early-seral and/or control units).

Key questions specific to the CES operational scale including contributions to cross-prescription comparisons

These questions apply at the scale of entire operational units (30-60 acres) and are contributed to a compilation across all prescription treatments in the compiled upland study plan (*Chapter 6)*:

1. How does passive CES compare to active EVDP early-seral management?
2. How does spatial distribution of post-disturbance vegetation differ?
3. Which EVDP clumping pattern matches most closely with the CES prescription?

The EVDP clumping sub-units (Chapter 3) offer an important active contrast to the passive CES approach. More active management offers more control over growth of crop conifers and understory species but this comes with higher post-harvest management costs. Tracking management costs and early stand development in both will provide important data for full-rotation projections, which will be made by year-10. After treatments are installed, monitoring across prescriptions like these will have to be carefully synchronized.

Chapter 5. Accelerated Variable-Density Thinning (AVDT)

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Prescription Abstract

We describe here an accelerated variable-density thinning (AVDT) prescription to be experimentally contrasted with the standard variable-density thinning (SVDT) practice which is currently practiced by westside DNR regions. The AVDT prescription is designed to reduce the time needed to achieve high quality late-seral habitat while producing more near-term net revenue for the State Trusts. A variety of new approaches are included: heavier thinning intensity, more variability in leave tree distribution, gaps fully releasing scattered dominant residuals, and planting primarily with Sitka spruce and western redcedar as a second cohort. In addition to speeding the development of old-forest condition (large trees, snags and down wood, and increased tree- and stand-scale variability), the AVDT prescription is expected to increase adaptation and resilience to climate and other uncertainties by providing greater resistance to drought mortality by reducing overall stand leaf area and thus water use, greater resistance to disease by varying the species composition, and a more diversified portfolio of management actions within AVDT units. The expected longer-term benefits come with a temporary trade-off of reducing the number of current stands with marginal habitat status, and may present other issues including future timber sales of large logs and wind disturbance.

The AVDT prescription will be implemented in 3 operational-scale units (30-45 acres) in Alternative-1 Strategy (z) watersheds. The lack of space in watershed Dz limits replication to 3 blocks. At unit scale, the variation in stand density will be achieved by 1) creating gaps with an area up to 0.4 acres centered around a few of the largest trees; 2) maintaining skips (unentered patches) using interspersed riparian and unstable slope areas; and 3) applying a heavy thin-from-below (66 residual trees per acre, relative density of about 28) in the remainder of each unit. We will quantitatively compare the 3 AVDT units to 3 SVDT units for their trajectory to late-seral habitat; other ecosystem benefits such as carbon storage and resilience; and the total and net revenue at current entry and at a possible final entry in 70-90 years. A nested sub-study will compare two types of thinning treatments within each AVDT unit: even-thin treatment to produce more evenly spaced residuals than the standard DNR thinning practice and a clumped-thin treatment to retain small groups of adjacent 4-11 trees based on observations in unmanaged mature forests. The two sub-study treatments will be compared for growth differences in individual trees, understory responses, and susceptibility to windthrow and disease.

AVDT Prescription Background and Objectives

Variable density thinning (VDT) has been extensively researched and practiced in west side forests in the Pacific Northwest for the last three decades, as well as in many other forest types (Carey 2003, Harrington 2005, Roberts and Harrington 2008, Anderson and Ronnenberg 2013, Puettmann et al. 2016, Franklin et al. 2018, Spies et al. 2018, Willis et al. 2018, Palik et al. 2021). The practice seeks to promote and accelerate the development of older forest characteristics in young, managed stands, including large trees with complex crowns; under and midstory canopy layers; snags, logs and live trees with decay elements, and diverse and abundant shrub, herb/forb, and broadleaf tree communities. The primary objectives of VDT treatment are to improve habitat conditions for a range of species, including those dependent on old-growth forests (e.g. northern spotted owl – NSO), while also providing wood products and revenue.

The VDT approaches and prescriptions have been developed and implemented in a number of different ways in the Pacific Northwest leading to different outcomes. Light or moderate VDT prescriptions (residual relative density of RD 35-50) seek to achieve the benefits of opening the canopy, while also maintaining higher cover in the short-to-medium term to avoid negative impacts to NSO prey species such as northern flying squirrels (Carey and Harrington 2001, Wilson and Forsman 2013), as well retaining sufficient stocking for additional thinning entries. Heavier VDT approaches (RD 20-30) seeks to maximize growth of large trees and crowns, as well promoting greater establishment and growth or abundance of under and midstory canopy layers, broadleaf tree species, and shrubs (Anderson and Ronnenberg 2013).

Another major difference in VDT prescriptions is the amount and spatial scale of variability. The number and size of skips (no – entry areas) and gaps (no trees or gaps with some residual trees) have major effects on the structural development of treated stands (Brodie and Harrington 2020). Also, many VDT treatments employ standard basal area or spacing approaches in the thinned portion of units that space out individual trees, creating patterns than are more uniform than those found in natural forests (Larson and Churchill 2008). Thus, some VDT prescriptions seek to retain clumps or groups of overstory trees, which has been shown to be important for resource sharing among trees through below ground mycorrhizal networks and root grafting (Simard 2018), improved habitat for arboreal mammals (Wilson and Forsman 2013), higher understory plant diversity (Dodson et al. 2012), and potentially greater windthrow resistance. All VDT prescriptions produce substantially less revenue than standard variable retention harvest (SVRH) (since logging cost to harvest volume ratio is higher) and increase windthrow risk for about 5 years after entry (although reducing risks thereafter).

The future development of second-growth stands toward complex old-forest structure, however, is far from certain, even with silvicultural intervention. The ecological patterns and processes behind historical late-seral development differ substantially from that seen in managed stands that saw wood removed, extensive slash burning, soils disturbed by yarding, planting of Douglas-fir at even spacing, vegetation management, and pre-commercial thinning. Pristine old growth stands still found on the outer Olympics have been recently shaped not by extensive wildfire, but by wind storms of varying intensity, and root disease, stem decay fungi, and mistletoe (Edmonds et al. 1993). This disturbance regime leaves abundant structural legacies that included downed trees, snags, and disturbed soils with upturned rootwads creating mound and pit topography. Natural plant succession was likely driven by seed-banks mediated by seed-bed conditions. With seed available, spruce and hardwood shrubs and trees (some Douglas-fir/cedar) were found on more disturbed soils; with hemlock, true fir, and cedar occupying undisturbed soils. It is likely multiple decades of early-seral plant composition persisted before closed conifer stands developed depending on the disturbance regime (see early-seral prescriptions in Chapters 3 and 4). Although natural succession will continue in a few areas where naturally developed stands are disturbed by wind or disease, most future plant succession will be driven by management choices affected by planting, vegetation management, and changes to seed-bed conditions and seed banks (including invasive non-native species).

Future succession from second-growth to late-seral stands also faces shifting climatic conditions which adds to uncertainty, such as changes in storm intensity, rainfall, snowfall, annual rainfall distribution, and emergent insect and disease outbreaks, especially in over-dense stands. Wildfires on the outer Olympic Peninsula in the area of our study have occurred (most recently on the nearby upper Queets valley in 2017), but this risk appears much lower than other disturbances in this location. A troubling concern is how disturbances will interact with one another. Increased variety in approaches to speed old-forest structure may help reduce the risks associated with these uncertainties.

We describe here an accelerated variable-density thinning (AVDT) prescription to be experimentally contrasted mainly with the standard variable-density thinning (SVDT) practice which has been deployed by Olympic Region DNR, as well as other westside DNR regions, over the past few decades on stands clearcut 1960 to 1990 (Holmberg et al. 2006). The DNR uses SVDT in its silvicultural toolbox to meet the requirement of the OESF Forest Land Plan (WDNR 2016) for provision of sustainable economic benefit to State Trusts as well as conservation of threatened and endangered species under the state lands Habitat Conservation Plan (HCP; WDNR 1997). Specifically, the HCP seeks to restore and maintain NSO habitat of varying quality on at least 40% of the landscape. The two ends of the habitat quality spectrum are illustrated in Table AVDT-1. When the landscape habitat threshold is achieved, DNR may harvest NSO habitat (incl. regeneration harvest) so long as the threshold habitat proportions on the landscape are maintained (shifting mosaic concept[21]).

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[21] This shifting mosaic concept is described in the 1997 state lands HCP and further specified in the 2016 OESF Forest Land Plan through NSO implementation procedures (PR 14-004-510)

Table AVDT-1. The lowest and highest quality NSO habitat type described in the OESF Forest Land Plan (PR 14-004-510)

Ecosystem element	Young Forest Marginal	High Quality Nesting
Stand composition (%)	30% or more conifers	2 or more canopy layers, 2 or more conifer species
Stand density (trees/acre)	For ≥4” dbh: 115-280 tpa	● 15 or more ≥31” dbh ● 16 or more ≥21” dbh ● 3 or more ≥21” dbh with broken tops
Relative density (Curtis RD)	For ≥4” dbh: more than 48%	For ≥4” dbh: more than RD 48
Canopy closure (%)	70% or more	70% or more
Tree height (ft)	For 40 tallest: 85 ft or taller	For 40 tallest: 85 ft or taller
Snags (#/acre)	2 or more ≥20” dbh, 16 ft tall	12 or more >21” dbh, 16 ft tall
Downed wood (cu ft/acre)	4800 or more; can be in lieu of snags	2400 or more

Currently, DNR applies two varieties of SVDT: Type-1 SVDT - a moderate thin (RD 35-40) in younger, 40- to 50-year-old second-growth forest, which doesn’t meet DNR criteria for NSO habitat, to promote vigor, eliminate defect, and introduce some complexity while maintaining a viable crop for future harvest options; and Type-2 SVDT a light thin (RD 48-50) in older second-growth forest, which meets DNR criteria for low quality NSO habitat called Young Forest Marginal Habitat (Table AVDT-1), to remove forest products while maintaining the characteristics that meet the NSO habitat definition. Second entries are likely needed in the Type-1 SVDT to produce high-quality late-seral NSO habitat. Maintaining future options to shift to late-seral habitat is critical given potential losses in existing habitat from fire, climate, or other disturbances.

The AVDT prescription is designed to reduce the time needed to achieve high-quality late-seral habitat while producing more near-term net revenue for the State Trusts. A variety of new approaches are included in AVDT: heavier thinning intensity (RD 25-30), more variability in leave tree distribution, and gaps fully releasing scattered dominant residuals and planting primarily with Sitka spruce and western redcedar as a second cohort. These approaches are designed to speed development of high quality old-forest condition including large diameters of trees, snags, and down wood and increased tree- and stand-scale variability. This longer-term increase comes with a temporary trade-off of reducing the number of current stands with marginal habitat status, and may present other issues including future timber sales of large logs and wind disturbance.

The USDA Forest Service, Olympic National Forest has been applying an accelerated form of variable density thinning, that this prescription also draws from. An example is the thinning prescription developed by the Olympic Forest Collaborative for the “HtoZ” stewardship sale near Forks[22]. DNR has also been exploring variations of this approach in the Columbia George and elsewhere. Here, we develop a site-specific approach that can be contrasted to SVDT experimentally and evaluated quantitatively.

Specific AVDT objectives:

1. Generate trust revenue, as mandated in state law, by thinning older second-growth stands (acknowledging that the revenue will be substantially less than that produced by standard VRH prescription);
2. Produce long-term options to:
    - Continue revenue production through additional entries including a possible VRH about 20 years after thinning; and
    - Achieve high-quality late-seral character (Table AVDT-1) sooner relative to SVDT (acknowledging that the stands will drop from marginal habitat status for the first 10 years or so).
3. Study, at the sub-unit scale, clumped versus even spacing of leave (residual) trees, holding density constant, where clumping of residuals might:
    - Reduce unwanted windthrow due to crown and root overlap;
    - Increase growth per unit area from greater mycorrhizal connections;
    - Increase growth of under- and mid-story, shade-tolerant trees; and
    - Increase shrub and other non-tree vegetation, thus providing more forage for ungulates.
4. Increase adaptation and resilience to climate and other uncertainties by providing greater resistance to drought mortality by reducing overall stand leaf area and thus water use and a more diversified portfolio of management actions within AVDT units (gaps, skips, and even and clumped residual-tree spacing), between thinned units (AVDT and SVDT), and at larger landscape scales (all prescriptions)—reducing the all-eggs-in-one-basket, small-toolbox problem.

AVDT Experimental Design

Operational-scale prescription

Operational-scale stands were identified for AVDT in Alternative-1 integration watersheds in Az, Bz, and Cz watersheds (Fig. AVDT-1). Units with areas 30-45 acres were chosen from the pool of operable lands with older second-growth with young forest marginal habitat character and that lay on north- or east facing aspects, as these are expected to be more protected from predominant SW cyclonic winds off of the Pacific. Studies on the Olympic Peninsula, using historic Government Land Office records, indicated a higher likelihood for late-seral forest on these more protected aspects (Edmonds et al. 1993). Younger hemlocks which do not live as long as western redcedar, Sitka spruce, and Douglas-fir dominate south- and west-facing slopes. Stands with these characteristics were not available in the Dz watershed and the prescription

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[22] More information available at https://olympicforestcollaborative.org/projects/

couldn’t be replicated there.

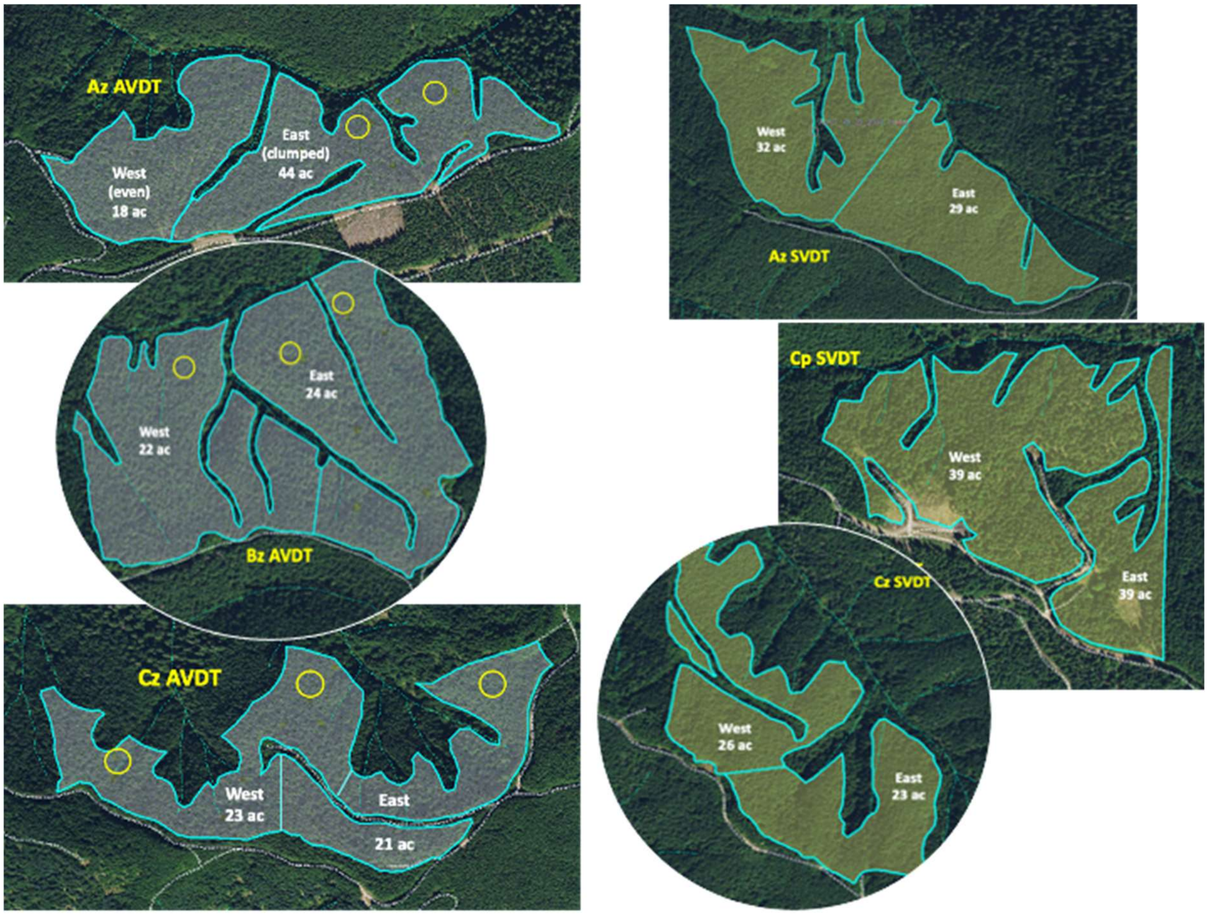

Figure AVDT-1. The AVDT units in watersheds Az, Bz, and Cz (left) and comparable SVDT units in watersheds Az, Cp, and Cz (right). Note east/west divisions for the sub-study on clumping of residuals. Yellow circles are possible locations of gaps centered on large residuals. All images are oriented north; use acre values to compare scales.

The AVDT prescription includes the following elements:

- Heavy thin-from-below to an average residual density of 66 tpa[23] (relative density of about RD28) aimed at providing more growing space for residual trees;
- The individual residual trees in thinned areas are retained using the following criteria:
    - Windfirm conifers (western redcedar, Douglas-fir, Sitka spruce, but not hemlock or silver fir);

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[23] We estimated that 60 trees per acre would provide the minimum number of trees required by the highest quality NSO habitat definition (live, standing dead, and down dead trees combined). We then added 10% (6 tpa) to account for potential mortality after harvest.

  - Trees with the largest diameters;
  - Trees with the highest live-crown ratio; and
  - Trees with little/no apparent damages.
- Gaps up to 0.4 acres (circles with 75-ft radius measured in slope distance) centered at the designated large, center, residual tree; usually close to the bottom of the unit to avoid windthrow, aimed at providing spatial heterogeneity and making thinning more cost-effective;
- High-density skips provided by interspersed riparian and unstable-slope areas aimed at providing spatial heterogeneity and resilience.
- Plant/tend to create a second story of long-lived conifers (western redcedar and Sitka spruce) in large gaps, aimed to diversify species composition
- Allow for likely post-harvest wind disturbance to add more small-scale variation in tree patterns, downed wood, and windthrow mounds.

The 3 AVDT units will be compared to 3 ecologically comparable units where Type-1 SVDT prescription is implemented (Fig. AVDT-1). Similarly, available space limited SVDT treatments to 3 as well. More AVDT and SVDT units are possible in future timber sales in the area outside of the designated watersheds.

Residual-tree clumping sub-study design

Two types of thinning treatments will be compared within each of the 3 AVDT unit. The idea is to examine effects of varying patterns of residual trees with a fixed, thinning-induced, tree density. The Even-thin treatment will produce more evenly spaced residuals compared to standard practice on most DNR thinning sales. The Clumped-thin treatment will retain small groups of adjacent trees (4-11 trees), based on that observed in unmanaged mature and old forests. The thinning treatment sub-units will be 15+ acres, randomly assigned on the west or east side of the AVDT units (Fig. AVDT-1) for a total of 6 sub-units (3 clumped and 3 even). The three SVDT units also provide a total of 6 sub-units without clumping and at a higher relative density. Randomization was not possible in watershed Az, where a previous thin on one side forces us to apply the Even-thin treatment there. The different sub-study treatments will be evaluated for growth differences in individual trees and stands, windthrow resilience, and understory responses.

Given the limited number of replicates (n=3), the inability to randomly assign sub-units in one AVDT unit, and the high environmental variability within and across experimental units, we will emphasize exploratory data analysis techniques rather than ANOVA to evaluate this prescription. This might include multiple regression, simple confidence intervals, and maybe general additive models. We also expect to learn many lessons using case-study methods, given the considerable variability at multiple scales. The sub-unit patches are large enough to evaluate stand-scale responses, and they will serve as demonstrations that may influence forester's decisions moving forward. LiDAR based canopy maps will also allow for finer-scale analyses that are not dependent on standard ANOVA requirements (O'Hara 2014).

Other design and implementation considerations with AVDT

Safety. Snags left standing at the time of harvest present a potential safety issue. Thus, snags present at harvest will only be left standing if they are within a skip area and do not present a hazard. Snags cut will remain on site as large woody debris.

Operational and research consistency. Blending economic viability and study design to both expand DNR's toolbox and better understand why different approaches worked is no easy task. After harvesting, developing conditions may require decisions that could affect study design and economic viability. Continued debate among PIs to maximize overall learning will apply a decision hierarchy described in Chapter 2.

Second Cohort Establishment. Relying solely on natural regeneration following harvest delays the establishment of a second cohort and is unlikely to provide sufficient stocking across an entire harvest unit. Western hemlock ingrowth is expected, particularly in larger canopy openings. In areas that do not have advanced regen post-harvest, planting of western redcedar and Sitka spruce plugs (P+1) will supplement a more uniform stocking level and provide for species diversity in the second cohort.

Management of competing vegetation. Uniformity of the second cohort and canopy layer is expected to be altered as well by established shrub-layer pockets in these older stands. No chemical site preparation will be conducted, as the shrub-layer provides a vital function in late-seral habitat. Mechanical site preparation as a result of harvesting activities are expected to provide enough scarification to assist in the establishment of the second cohort.

Precommercial thinning. Precommercial thinning is a recommended stand management activity for the development of the second cohort. A precommercial thinning may be needed earlier than those of stands regenerated after VRH. Thinning out dense hemlock thickets and reducing competition may assist in expediting the second cohort into the 4+ inch diameter bracket and thus shortening the amount of time the stand needs to return to Young Forest Marginal habitat characteristics.

AVDT Key Questions and Monitoring

Analytical framework

Key questions are derived here that lead to specific monitoring. Funds for monitoring come primarily from Washington State Legislature proviso funding to ONRC and DNR, but may also be covered by other ONRC funds, DNR funds, and grants (see Chapter 7). Questions and monitoring can be very broad under the ecosystem wellbeing framework which means that detailed monitoring will not be possible in many cases. Key questions and core monitoring are described below that could be expanded with additional resources. Although some ground data will be collected, the main focus of monitoring will be remote sensing using plane and drone LiDAR, and aerial photos.

Key questions for the residual-tree clumping sub-study:

1. Holding density constant, will even spacing and clumping affect the thinning response in residual trees, including
    a. Individual tree growth (dbh);
    b. Stand growth rates (basal-area increment) over 20 years; and
    c. Mortality from wind or disease?
2. Will even spacing and clumping affect the thinning response in establishment and growth of understory and midstory conifer cohorts, as well as non-tree vegetation (shrubs, forbs, etc.)?

Key questions for operational-scale comparisons:

1. How do AVDT and SVDT compare in terms of:
    A. Total and net revenue (after admin and other costs) in:
        i. Current entry and
        ii. Possible final entry of first combined rotation (at 70-90)?
    B. Trajectory toward full late-seral character (layers, species, density, size, snags, wood; see Table AVDT-1)
    C. Other ecosystem benefits, including:
        i. Carbon storage and sequestration aboveground?
        ii. Understory and conifer ingrowth with implications for habitat?
        iii. Resilience of individual trees and stands to drought, increased intensity of winter storms, and other uncertainties?
2. Will the short-term cost of dropping below the RD48 (current HCP rule) be overcome by the long-term gain of achieving higher quality late-seral structures *earlier?*

Core monitoring to answer AVDT questions

Question 1.A: Effects on thinning response in trees (sub-study)?

Residual trees spaced more evenly at the same stand density (66 tpa) may or may not respond to thinning as well as trees left in clumps depending on whether clumps provide some adjacency benefits, including protection from wind and disease and whether side lighting produces longer live-crown ratios. Variation in individual tree response is likely to increase with clumped residuals as self-shading will vary more. Monitoring will require ground measures in permanent plots until reliable LiDAR models are developed.

Question 1.B: Effects on thinning response in understory (sub-study)?

Bigger gaps when clumping residuals is likely to produce more understory biomass and more second-story conifers than evenly spaced residuals. Understory, however may be undesirable if dog-hair hemlock emerges. Potential differences in elk forage might push future clumping activities. Monitoring will require ground measures in permanent plots until reliable LiDAR models are developed.

Question 1.A.i: AVDT versus SVDT effects on total and net revenue?

Effects on revenue through the first full rotation will be known much sooner for these prescriptions than others, since full rotation age could be achieved in about 20 years. Tracking of first entry costs will be critical to determine net revenue. Some consideration will be given for the extra time taken to accomplish new tasks to attempt an estimate based on widespread routine application. Net present value projections to age 70 will be more accurate than the prescriptions running more years.

Question 1.A.ii: AVDT versus SVDT effects on late-seral trajectory?

Trajectory for each character element can be forecast based on initial responses. Some perhaps not all characters will decline in AVDT early but later surpass SVDT, so monitoring will need to be long enough to detect any shifts in trajectory.

Question 1.A.iii: Effects on other ecosystem benefits—carbon?

Aboveground carbon can be tacked using conifer biomass. We expect the thinning extending the rotation to 70 will have higher sequestration, especially if the fate of harvested wood and substitution are taken into account. Whether AVDT or SVDT can outperform the Control is another matter. A true accounting would need some measures of decomposition of snags and logs. Past experience from the area[24] suggest rapid decomposition in standing snags created by density-dependent mortality, long before logs reach the ground. Such measures would not be difficult (e.g., through dried cookie samples).

Question 1.A.iii: Effects on other ecosystem benefits—understory?

Wider thinning will allow enough light through to stimulate understory response, and this response should be proportional to the intensity and patterning of thinning. The range of stand

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[24] [24] Based on preliminary data from the Long Term Ecosystem Productivity Study in the OESF; refer to https://www.onrc.washington.edu/long-term-ecosystem-productivity-study/

density will increase heterogeneity in understory response (gaps, variably spaced residuals) over other tools. The ratio of hemlock to other understory with more benefit to ungulates, birds, insects is an important question. Large seed rain in thinned stands can create dog-hair hemlock. Forage and hiding cover are also known to interact to determine value to ungulates. AVDT and EVDP with conifer clumps of different tree sizes provide more cover and likely more forage through time than the other prescriptions and ungulate use could be tracked.

Question 2.A.iii: Effects on other ecosystem benefits—windthrow?

Some to numerous residual trees along edges are expected to be windthrown in the first 5 years after AVDT; increased stability in residual trees is expected after 5 years. If smaller hemlocks are lost, then some benefit can be expected as increased light for understory, natural processes associate with soil mound-pit formation, and increased woody debris. If the magnitude is too large it might reduce late-seral options—in the extreme, perhaps triggering a salvage harvest by DNR.

Question 2.A.iii: Effects on other ecosystem benefits—resilience?

Thinning from below has the potential to increase individual tree and stand health by reducing self-shading and increasing summer soil moisture. It has the potential to make trees and stands more resistant to a variety of stressors after tree rooting responds to the new conditions. Monitoring needs to continue for at least 10 years to draw meaningful conclusions. Other effects are quite uncertain. For example, thinning might reduce the incidence and subsequent spread of root diseases like *Armillaria*. On the other hand, increased sugar content in fast-growing conifers may attract bark stripping by bears. Net effect will determine how resilience changes are assessed. It will be possible to measure changes in fuel loads, if fire risks escalate in this normally wet forest.

Question 2.B: Should the RD 48 rule in the HCP be revisited?

Wider thinning in AVDT temporarily reduces the OESF acres of marginal late-seral habitat (unlike in SVDT), seemingly working against late-seral habitat objectives. Wider thinning, however, is expected to speed up long-term development of full late-seral character. Fuller consideration of short- and long-term implications might suggest changes to the HCP rule.

Chapter 6. Watershed and Cross-Prescription Analyses

Experimental Design for Entire-Watershed Comparisons

The study at the largest scale follows a randomized, complete-block design for the 16 Type-3 watersheds with four experimental blocks designated A, B, C, and D (Fig. Watershed-1). This was achieved by examining 33 T3 watersheds that passed an initial screen based on:

- A predominance of DNR ownership (issue: control over treatment);
- Area of 500 to 2000 acres (issue: minimum landscape-scale with fish above pour point);
- Some amount of older forest and modelled unstable riparian (issue: option to include entry into areas generally avoided);
- Minimal recent harvest activity (issue: all watersheds had to be suitable as a control); and
- Operational difficulties (Issue: mainly road access and availability of harvestable timber in the near term).

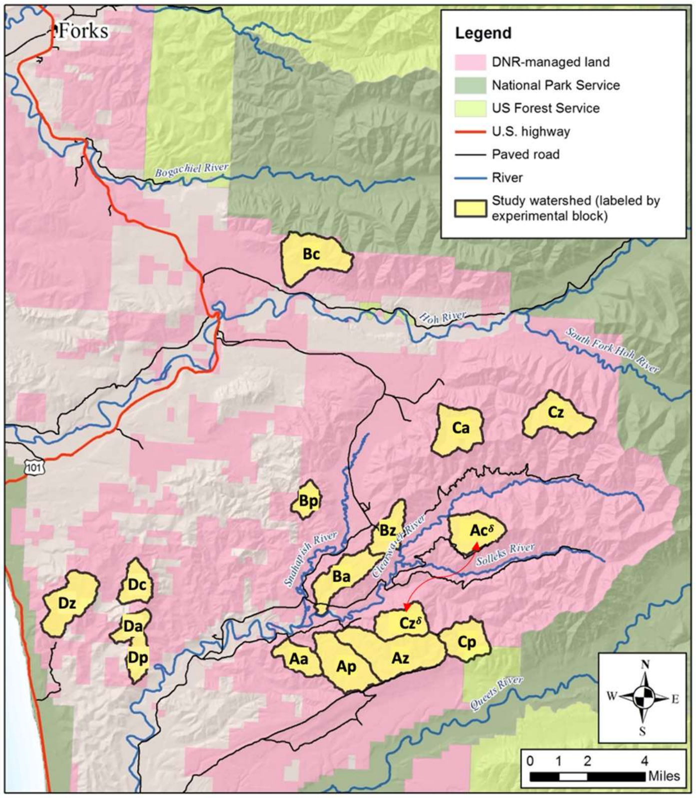

Figure Watershed-1. The 16 watersheds in the T3 Management Experiment on the western Olympic Peninsula, WA, labeled by experimental block (A-D). The arrow and $^\delta$ references on Cz and Ac note the later watershed switch (see text).

Blocks with initially similar watersheds were assembled using 4 traits:

- Watershed size;
- Proportional area of older forest patches designated as habitat for either for northern spotted owl or marbled murrelet);
- Proportional area of stands modeled as too young to be harvested soon; and
- Proportional area that DNR's forest estate model suggested would be operable in the next decade.

Similarity analysis suggested multiple groupings were possible, and in the end, proximity was used as the dominant criteria, assuming that watersheds nearer to one another are more likely to be similar in these respects by acting as a general proxy for past management history, climate, elevation, and soils. A detailed description of the criteria and process used for selecting these 16 watersheds and blocks are given in the Riparian Study Plan (Martens et al. 2020).

The 4 watershed-scale strategies were assigned randomly within blocks with designations as Alt-1 as "z"; Alt-2 as "a"; Standard as "p" and Control as "c." The design suffered a disruption when DNR delineated marbled murrelet sites in older forest to be deferred from management in a C-block watershed as part of the marbled murrelet Long-Term Conservation Strategy (WDNR 2019a), after our designations were made. This precluded our ability to apply riparian treatments in one watershed. After much hand-wringing, Cz and Ac were switched, moving the control strategy to Cz (now called Ac) and the Alt-1 strategy to Ac (now Cz). The desire to maximize replication won out over the consequences of dropping randomization. Future analyses have several ways to handle this disruption. The resulting randomized-block design is quite powerful for an experiment of this scale (Table Watersed-1); more detail is available in Appendix 2.

Table Watershed-1. ANOVA table for comparing management strategies

Source	Degrees of Freedom
Treatments (k-1)	3
Blocks (b-1)	3
Error (k-1)(b-1)	9
Total (n-1)	15

After watersheds were selected, grouped into blocks, and strategies randomly applied, the next step was to identify a pool of operationally viable stands (> 30 acres) within each watersheds for prescriptions. Operational units, which would implement the prescriptions, were selected in the operable areas and included in timber sales based on office and field reviews by DNR Olympic Region staff. Because watershed strategies were assigned randomly within watershed blocks, this means that prescriptions linked to strategies were randomly assigned to watersheds as well. Placement of operational units, however, within a designated watershed was not random; considerations included:

- Harvesting feasibility had to be assured (including Controls) based on:
    - Current stand volumes and potential costs (road/harvesting/hauling);
    - In some cases, proximity to areas outside of the watershed that were being combined to make timber sales and that generated sufficient net revenue;
- Harvesting was required upslope from riparian treatments previously selected[25], since riparian treatments were only possible with harvests above them that provided logging system access;
- Because the EVRP and riparian alder, wide-thin rotations treatment were linked to increase economic feasibility of future alder harvests, EVRP units were fixed based on previous decisions about riparian alder rotations; and

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[25] The placement of riparian experimental units was guided by the Riparian Study Plan (Martens et al 2020)

- Aspect was considered in EVRP and AVDT (both sought to avoid droughty/windy south-facing slopes).

The study Overview Plan (Bormann et al. 2021) called for applying harvests on about 13% of each watershed area per decade. This is slightly elevated over the 10% rate dictated by the DNR sustainable harvest level OESF-wide (WDNR 2019b), to account for loss of harvest in the Controls. Our study currently does not include a direct test of the sustainable harvest calculation, since major variation from this policy at this scale was not possible. A major study goal at the watershed scale is to see if we can detect cumulative effects of both upland and riparian treatments on the fixed 13% of the area subtracting background disturbances.

The watershed design focuses on the relative effects of the four watershed strategies, each reflecting the cumulative effects of the included upland and riparian prescriptions and unentered areas. Where the treatment responses are based on summed effects measured at smaller scales (prescriptions and sub-studies) and watershed-wide, we will utilize remote-sensing-based assessments (e.g., for tree growth and C sequestration), social economic studies (e.g., stakeholder preferences and net present value), and periodic measurements at or just above the designated pour points of the watersheds (e.g., fish, macroinvertebrates, and water chemistry). We hypothesized (Appendix 2) that few if any effects will be detected at this scale given the conservative cumulative treatment. If proved true, this non-effect outcome would help DNR establish that they can pursue a broader array of practice options (tools) without much concern over possible negative cumulative effects. Sustainable-harvest calculations include many considerations set as risk factors and constraints in the DNR forest estate model (Woodstock; see economic drivers; Chapter 1). Finding no effects might be the basis for proposing evidence-based changes to the sustainable harvest calculation, and drive future experiments.

Experimental Design for Cross-Prescription Comparisons

The key operational-scale, cross-prescription questions and monitoring discussed in the prescription chapters will be addressed using a design different than those in the simple sub-study ANOVA designs for EVRP, EVDP, CES, and entire watersheds. Here, we compare responses across entire operational-scale units. Here too, we can ask many economic, ecological, and social concerns (e.g., revenue, logging costs, growth and yield across variable terrain, wind disturbance, and certain wildlife and social responses (e.g., quality of life, livelihood commitment, diversification, and perceptions) that are difficult to evaluate at the smaller sub-study scales. There is a minimum of 30 of these units to work with (Table Watershed-2). The units designated within Control watersheds might be supplemented by identifying additional unit-sized areas not harvested in Control or other watersheds. There will be additional SVRH units in Standard and larger Alternative-strategy watersheds. The entire-watershed remote sensing efforts provide additional ways to compare prescriptions.

Table Watershed-2. Sub-units within operational units

Prescription	Operational-scale prescription experimental units	Stand-scale sub-study treatments	Stand-scale sub-study experimental units
Control	4	0	0
SVRH	4+[Ÿ]	2	16*
CES	4+*	2	16*
SVDT	3	0	0
AVDT	3	2	6
EVRP	4	6	24
EVDP	4	7	28
Total	30+		96

[Ÿ] Additional SVRH prescription units are available in some Standard and the larger Alt-1 and Alt-2 watersheds

*Additional CES prescription units were added in Az, Bz, and Dz watersheds (see avian study with 32 sub-study units)

Key Questions and Monitoring

Analytical Framework

As with most adaptive-management studies at larger scales, statistical purity has to give way somewhat given matters of practicality, pretreatment variability (Appendix 2), and variability added in prescriptions. Limits to possible replication at larger scales constrains statistical power. Also given our interests in: (1) a large number of specific contrasts at smaller scales and (2) gaining confidence in some cases that lack of difference is real; we envision using t-tests, confidence intervals, exploratory data analysis, and case study techniques to opportunistically explore differences meaningful to researchers and decision makers, and to further develop hypothesis for future adaptive-management studies. Perhaps the most important determination of success of individual prescriptions will be to see which ones are most widely applied, where decision makers are weighing many factors such as perceptions by the broad spectrum of stakeholders, legal interpretations, the scientific community debate, as well as the direct magnitude and significance of responses.

Key cross-prescription questions

Key questions of cross-prescription comparisons and associated monitoring are included in the prescription chapters (Chapters 2-5). Certain prescriptions can be combined to address additional questions. For example, we envision to study herbicide effects using an assortment of prescriptions. This question emerges from stakeholder concerns and has been studied in other areas. For example, Strong and Gate (2006) in Alberta, Canada found herbicides reduced winter forage for moose, elk, and mule deer by up to 20%. In western WA, Ulappa (2015) documented how herbicides reduced biomass of deciduous shrubs and trees and herbaceous understory plant species selected by, and acceptable to, foraging deer, where unsprayed plots had 20 to 100% more biomass of selected and acceptable forages from stand establishment to stand closure at 14 to 20 years. The SVRH and EVRP prescriptions use standard herbicide practice to reduce competition with planted seedlings, while the CES and AVDT prescription do not use any. EVDP applies herbicides to clumps, but not interstitial areas, and a different mix of herbicides is used in the EVRP to avoid negative effects on planted alder. This array of herbicide treatments allows us to ask some important questions:

1. How does forgoing herbicide application (in CES, AVDT, and interstitial areas in EVDP), relative to applying it in standard practice (in SVRH) affect:
   a. Hemlock ingrowth?
   b. Non-conifer biomass, fruits, flowers, and browse?
   c. Invasive plant species? and
   d. Insect species and abundance?
2. Do the benefits of herbicide use (especially conifer production) compensate for the costs of its application and other desirable/undesirable effects?

Core monitoring to answer the herbicide cross-prescription questions

Question 1. How does forgoing herbicides affect vegetation?

We will need to document herbicide types and quantity used to establish the treatment. This is especially important in the interstitial areas, which will vary from standard practice. Vegetation changes will be monitored in operational prescriptions treated (SVRH, EVRP, parts of EVDP) and untreated (CES, AVDT, SVDT, parts of EVDP) using techniques developed in EVDP (Chapter 3) and by Ulappa (2015) to the extent possible. We intend to develop insect species and abundance measures (various traps and possible acoustic signatures) as well.

Question 2. Benefits and costs of herbicides?

Herbicides as currently applied are expensive and these costs are carried for about 40 years, affecting rotation net present value. These costs are deemed unavoidable when they imperil achieving a crop with adequate stocking. Costs of alternative methods such as manual slashing will be examined and compared to the extent possible. The extent of under-stocking in the CES prescription will be very interesting, as will the positive or negative effects on excessive hemlock regeneration.

Key questions at the watershed scale

A. What are the cumulative watershed-scale effects of the on novel upland prescriptions (EVRP, EVDP, CES, and AVDT), novel riparian buffers (Active habitat restoration, Riparian alder with heavy thinning, and Variable-buffers), and unentered interstitial areas relative to watersheds with Standard prescriptions and Control, specifically:

1. Cumulative net revenue:
    - First-wave and projected harvests through longest prescription (70-90 years)?
2. Consistency with HCP and other rules and regulations?
    - Pour-point metrics (temperature, sedimentation, dissolved organic matter, and chemistry)?
    - Fish populations in the lowest reach of the watershed?
3. Other ecosystem benefits:
    - Net primary production and carbon sequestration (entire watershed via remote sensing)?
    - Managed (Alt-1, Alt-2, Standard) versus Control? and
    - Increased adaptation and resiliency to climate and other uncertainties?

B. How do beneficiaries, tribes, and stakeholders perceive community-inspired Alt-2 compared to the other management strategies?

C. Did learning-based collaboration among and between researchers, managers, and a wide range of stakeholders, speed up learning and stakeholder engagement, and enhance goodwill and facilitate science-based adaptation:

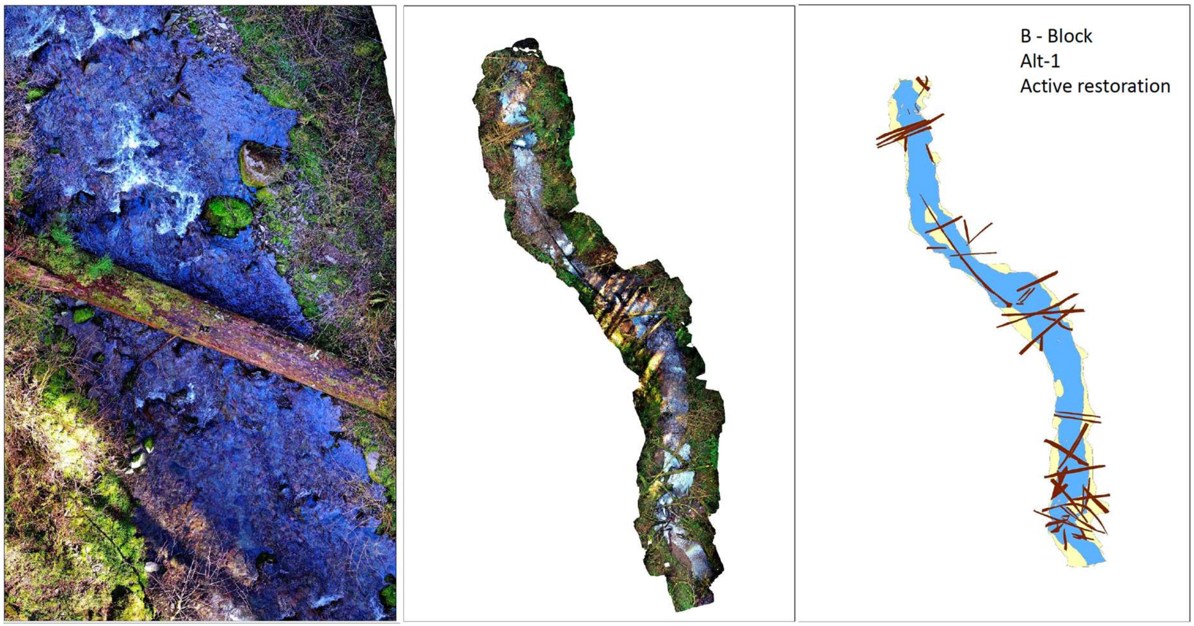
- Stakeholder participation in the final prescription plan?
- Question development and monitoring (for evidence-based decisions)?
- Inclusion of this prescription in a scientifically valid watershed experiment?

Core monitoring to answer watershed-scale key questions

How questions B and C are answered is addressed in the Overview Plan (Bormann et al. 2021). Otherwise, core monitoring for large-scale questions is mostly described in prescription chapters. Many large-scale questions, however, cannot be answered simply by summing up measurements at smaller scales. Therefore, we are developing a remote-sensing-oriented system to maximize entire operational-unit and watershed measurements.

There is a general difficulty using field plots, where sampled conditions represent a small portion of the treated area, to characterize spatially explicit-treatments because conditions are highly variable at the scale of individual plots. Although there is a need for detailed field measurements, selecting representative plot locations and plot sizes is problematic. Some field plots will be established before treatments are in place (e.g. soil and forest habitat surveys) and other will be established after (e.g. regeneration surveys). Although this will help ensure that field measurements capture the full range of conditions produced by the treatments, it is possible that there will be situations where there is bias in the summarized plot measurements due to the complexity of treatments, unforeseen mortality in and around treated areas, and the effects related to future treatments. In addition to field plots, we are planning to use drone LiDAR to assess 100% of the treated areas (and control areas) thus avoiding some sources of bias related to plot locations and size. Potential metrics derived from the drone LiDAR include species composition, stem density, gap frequency and size, canopy cover, and tree clump characteristics (stem count, DBH/height distribution, and species composition).

DNR already has full coverage with a remote-sensing-based inventory system (RS-FRIS)[26] being updated on a regular schedule, and tested with extensive ground plots. We are supplementing existing inventory data (ground, LiDAR, imagery) with drone imagery and LiDAR. Drone-photography approaches are being developed by DNR's UAV program. Flights has been flown along a portion of the study stream reaches and work will begin to connect ground riparian measures (Chauvin and Micheletti 2021; Fig. Watershed-2).



Figgure Watershed-2. Drone photo image, photo mosaic, and resulting spatially explicit map of a studied T3 stream reach (left to right).

We have also started a T3 remote sensing study in 2021 that includes a private-public partnership with Westfork Environmental Inc., and research partnerships with Forest Service Research (Principal Investigator Bob McGaughey) and Microsoft Research scientists. The study

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[26] More information is available on DNR's GIS Open Data at https://data-wadnr.opendata.arcgis.com

is developing methods to do initial pre-treatment monitoring of actively managed prescription stands using new, drone LiDAR. We are flying soon to be harvested T3 areas with a drone-LiDAR system that generates 200 or more compared to 8-10 returns m^2 for aerial LiDAR (Fig. Watershed-3), with the ONRC intern crews establishing ground-truthing plots. This work built off a recently completed study on the long-term ecosystem productivity (LTEP) study, near Sappho, WA (Kruper et al. 2022). Protocols are available upon request, but basically overstory, understory, and surface data; maps of stems and other features; and special characteristics to tie to LiDAR-based GPS positions in 35-m diameter permanent plots. So far, we've installed 33 permanent plots to capture the range of pre-treatment conditions in units to be harvested.

Javad GPS locations will be used as a starting point to connect (and shift locations) to match up with LiDAR-based GPS locations. The LTEP project was able to accurately pin similar stem maps to LiDAR-based locations, with survey-grade GPS technology and additional tree character data. This careful linkage was key to developing new LiDAR models, that for example could separate alder and Douglas-fir from other species using intensity and point cloud metrics. The current effort can also use the available 2016 to 2018 airborne LiDAR in a similar way, but we are attempting to move forward also with a drone-LiDAR system that we expect to provide vastly denser point clouds and many more returns from under the canopy. This system has good potential to capture understory and other characteristics not reliably seen in airborne LiDAR.

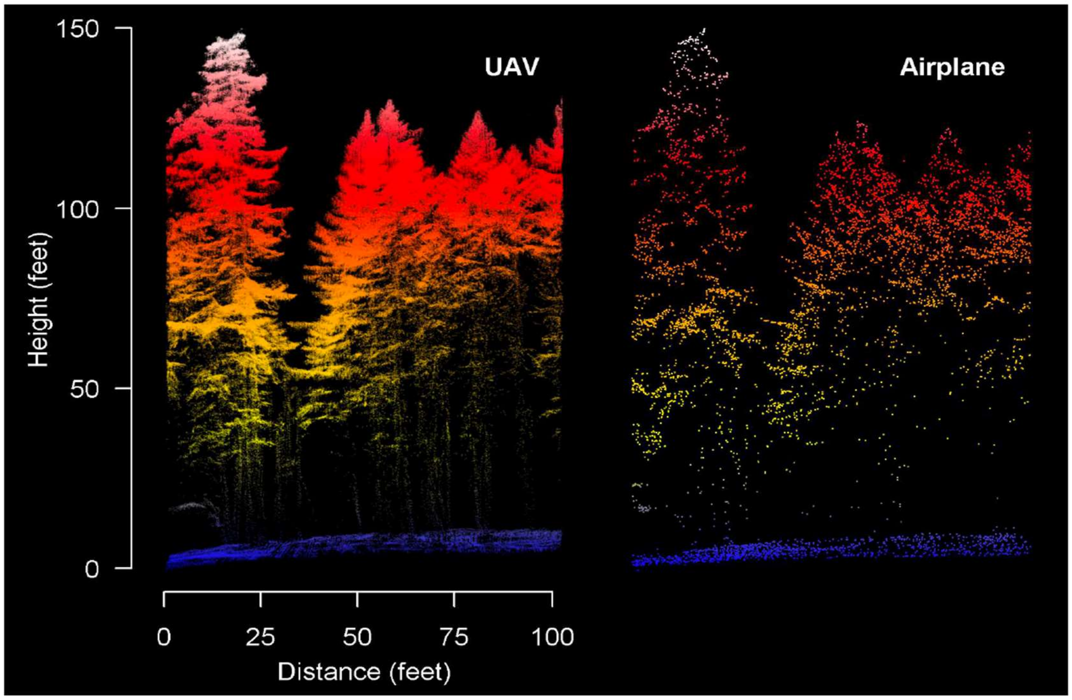

Figure Watershed-3. LiDAR point cloud intensities obtained through unmanned aerial vehice (UAV; drone) and airplane (Jeronimo and Shoot 2021).

The T3 remote sensing team is collaborating with Forest Service and Microsoft Research scientists to address the following initial questions:

1. What ground-based individual-tree, understory, and other characteristics can be seen by drone LiDAR, such as:
   - Douglas-fir from western hemlock and other tree species common to our study area?
   - Different outer canopy shapes and foliar and branch displays?
   - Bare-earth geomorphology?
   - Mortality (from wind or other mechanism)?
2. How do drone and aerial LiDAR point clouds differ, such as:
   - How does the additional detail affect the information derived from the point clouds?
   - What models and metrics are appropriate for high-density drone-based LiDAR data?
   - What information is useful for machine vision or machine learning methods focused on identifying tree species or species groups?
   - What's the best way to test the success of individual-tree methods against field data?
   - How can tree tops and bases be better matched?

Where model accuracies are sufficient, we will use them to provide entire-unit pretreatment conditions and identify what will have to be monitored in other ways, possibly including ground measures. This effort is a precursor to developing post-treatment monitoring.

To address climate and other uncertainties, we would like to know whether new tools are better adapted to climate and other uncertainties compared to SVRH and SVDT and Controls. Determining this will not be easy. We do expect continued climate changes in our study locale, but ones that differ from changes elsewhere in Washington. Proximity to the largest ocean will likely buffer and reduce temperature and drought effects but might intensify storms. Since weather conditions have been officially documented in Forks beginning in 1908, average annual air temperature has increased +1.0 °F (+0.6 °C) which is half the rate of the statewide average, +2.0 °F (+1.1 °C). Regional projections through the 21st-century suggest continuing increase in air temperature (Mote et al. 2013; Abatzoglou et al. 2014; Vose et al. 2017). Projections of future precipitation are far less certain than those of air temperature but overall suggest a slight increase in average annual precipitation by the end of the century (Mote and Salathé 2010; Mote et al. 2013; Janssen et al. 2014; Easterling et al. 2017). Projections for frequency of extreme precipitation events in the Pacific Northwest also vary widely, but on average suggest an increase (Dalton et al. 2013; Janssen et al. 2014; Easterling et al. 2017). Shifts in the annual timing and form of precipitation (i.e., rain vs. snow) and storm intensities could also impact forested landscapes. Wildfire risks here are some of the lowest in western U.S. (Agee 1993), and are expected to remain so, unlike other parts of the Peninsula and state. A number of other possible environmental changes, related to climate or not, are also possible, and in many cases are unpredictable if not unknowable. Change in insect and disease are possible (Agne et al. 2018), including Swiss Needlecast that can reduce growth rates of Douglas-fir. Weather timing can affect species differently, for example snow or wind when deciduous trees still have their leaves on, and stress from exacerbated heat waves such as that of summer 2021 (Overland 2021) are also possible. All of these changes will likely interact, so individual causal relationships are not likely to be easily discerned.

The principal way we want to study effects of climate and other uncertainties is by asking:

1. *Will increasing the heterogeneity of prescriptions within watersheds and within operational-scale prescriptions help avoid large-scale undesirable outcomes affecting a widely applied but narrow range of standard practices?*

Secondarily, we ask:

2. *How well tree species other than Douglas-fir and hemlock perform across the study area under changing conditions* (cedar and alder in EVRP), and also:
3. *Will lower Douglas-fir planting density of (in EVDP) and residual-tree density (in AVDT) perform better because of lower water and nutrient demand per tree*?

The stand-level effects of individual prescriptions on adaptation and resilience to changing climate (and associated uncertainties such as tree survival, growth rate, resistance to diseases, invasive species, resistance to windstorms, etc.,) are also addressed in Chapters 2-5.There are many other questions being asked by others that we are not able to include at this time; for example, those about species or even seed-zone migration and reductions in tree densities.

Connecting climate, disturbance events, and other unfolding changes to experimental treatment responses will likely be challenging. To answer these questions, we will first look for trends in deviations from projected growth and yield (see Chapter 1). We will focus on deviations in the controls and standard prescriptions (SVRH, SVDT), where we have the highest confidence in projections, and examine how well the trends are correlated to environmental changes (i.e., weather, disease, and other drivers). The growth and yield projections in novel prescriptions (e.g., AVDT, EVDP, EVRP) have considerably more uncertainty, thus their deviations are more likely hidden by methods and assumptions. Ecosystem process models that include climatic variables provide an alternative way to explain differences in projected and actual growth & yield and C sequestration dynamics.

Chapter 7. Study Implementation

The T3 Watershed Experiment officially started in 2018 with designation of the 16 experimental watersheds and the random allocation of 4 management strategies. DNR has committed to 10 years of no action in the control watersheds which ensures the study duration to at least 2028. We plan a thorough 10-year review to assess costs and benefits of the study at that point and potential continuation (Table I-1).

Adaptive Management Framework

The goal of this study is to test new forest management prescriptions to expand the DNR existing toolbox. We applied an adaptive management framework (Minkova and Arnold 2020) to achieve this: the research questions address forest management uncertainties and the findings will be formally considered for improvement of management practices. Several elements of the project ensure actionable science: treatments at the scale of timber sale units allow us to answer operational-scale questions and to apply the findings into practice faster; tracking the economic effects of treatments and conducting trade-off analyses of ecological and economic outcomes inform decision makers; and the learning-based collaboration with managers, diverse stakeholders, and tribes facilitates understanding and acceptance of future changes in land management. DNR committed to adaptive management in the state lands Habitat Conservation Plan (HCP; WDNR 1997), specified the process in the OESF Forest Land Plan, and institutionalized it by adopting an administrative procedure (WDNR 2016, Chapter 4). The strongest assurance for acting upon the study results comes from the close collaboration between researchers and DNR practitioners and managers which was demonstrated during the planning stage of this management experiment.

Implementation of Treatments

The standard and the new experimental treatments (prescriptions) are implemented at an operational scale (30+ acres). This scale is large enough to directly evaluate not only the silviculture responses but also key wildlife responses and operational and economic feasibility.

All harvest treatments (tree felling, yarding, hauling) will be implemented through DNR timber sale program in Olympic Region Coast District. Thirteen timber sales, consisting of multiple units, are planned to implement all prescriptions. After the timber sale planning and layout by DNR Olympic Region staff, each timber sale is reviewed for compliance with Washington Forest Practices Rules (SEPA process), approved by the Board of Natural Resources, and auctioned. The experimental designs, described in this study plan, are incorporated in the timber sale design and in the contracts with the purchasers. The purchasers typically have 2-years to complete the harvests. Their implementation schedule vary based on multiple factors such as market conditions, road construction and weather. The harvest operations are compiled by DNR Olympic Region foresters.

Table I-1. Timeframe of major activities associated with the upland prescriptions of theT3 watershed experiment.

Activity	Anticipated timeframe
Coordination between research personnel and the DNR Olympic Region staff regarding timber sales and silviculture activities that implement CES, EVDP, EVRP, AVDT, SVDT and SVRH units	2020-2024
Pre-treatment vegetation, soil, habitat and avian monitoring: research personnel will design and conduct pre-harvest surveys.	May 2020 to November 2022
Sale and harvest of all experimental units: implemented by purchasers, complied by DNR foresters	Timber sales auctions are expected to occur from April 2022 through March 2023. Harvests will be completed within 2 years of sales (likely by late 2023-2024).
Stand regeneration monitoring: DNR Olympic Region staff conducts standard regen surveys, research personnel will design and conduct additional prescription-specific surveys.	Depends on harvest schedule and prescription needs. Three or more growing seasons are needed to determine establishment success, and the needs for additional vegetation control.
Post-treatment soil, habitat and avian monitoring: research personnel will revisit the monitoring stations following treatments and repeat prescription-specific surveys.	Timing depends on harvest schedule and prescription needs (see individual prescription chapters for details).
Study plan to assess implementation costs (operational costs and productivity) of prescriptions: researchers will develop a study plan and start coordination with potential purchasers and operators.	January-June 2022 (refer to the Economic Sub-studies section in Chapter 1).
Collecting data on operational costs and productivity: research personnel will work with DNR staff and purchasers and operators.	Pilot project in summer 2022; Further sampling depends on harvest schedule, prescription needs, and cooperation with purchaser and operators.
Long-term economic projections sub-study: research personnel will produce quantitative projections of growth and yield of the forest stands developing after treatments, incorporate revenues and costs, and calculate net present value (NPV) for entire lifespan of each prescription.	The projections will be completed by July 2023 to establish milestones that can be tracked through time (refer to the Economic Sub-studies section in Chapter 1).
Management decision support sub-study: research personnel will run DNR's forest estate model including silviculture, habitat and economic data on experiential prescriptions to document how study results can lead to different management decisions.	July 2023-July 2024
Comprehensive 10-year review to assess costs and benefits of the study	2028
Stakeholder engagement: research personnel will seek stakeholder feedback and participation through meetings, field tours and learning groups.	Continuous (refer to the Learning-based Collaboration section in Chapter 1).

The majority of the silviculture treatments for the study prescriptions (site preparation, tree planting, vegetation control, PCT) will be implemented through the DNR Olympic Region silviculture program. Researchers may supplement this with prescription-specific regeneration or other surveys. The planting material will be supplied by DNR Webster Forest Nursery.

Monitoring, Modeling and Data Management

The key questions and associated monitoring described in Chapter 2-6 of this document and in the Riparian Study Plan (Martens et al. 2020) helped the principal investigators identify monitoring indicators (Table I-2) and spatial and temporal sampling designs, and to develop monitoring protocols. One to three years of pre-treatment field monitoring took place in stream, riparian and upland portions of the experimental watersheds starting in 2020. The start of post-treatment monitoring depends on the completion of the harvests in the treatment areas and the timing of silvicultural activities such as tree planting and vegetation control. Since the 13 timber sale implementing the study are sold and harvested at different time and the units for individual prescriptions fall in two or more timber sales, a fully-replicated prescription may take several years to implement. As a result, the post-treatment monitoring for this prescription is likely to start in different calendar years. DNR has committed to 10 years of no action in the designated control watersheds starting in 2018. Accordingly, the postharvest monitoring is expected to continue at least until then and may continue long-term depending on DNR management plans and available resources. The field and remote-sensing monitoring is led and coordinated by DNR and ONRC with participation of principal investigators and partners

Databases are currently being built in Microsoft Access for all pre-treatment environmental monitoring data (Table I-2.) and associated metadata. As needed, the functionality of the Access databases will be enhanced using R programing language (R Core Team 2020). Each dataset is assigned a data steward. Data management procedures including quality control, archival, and generation of data summaries are being developed. Data will be managed separately, with processes yet to be determined, for remote sensing (e.g., drone, LiDAR, and satellite images), economics (e.g., operational cost of treatments), and social (e.g., interviews).

The project team is working through various data management challenges stemming from the broad scope of the project. The large volume of data, particularly remote sensing and acoustic data, requires adequate storage and involved back-up process for the longevity of the project. The variety of datasets—field environmental data, remote sensing, social, and economics—requires diverse data management expertise and effort to maintain consistency across the databases. The participation of multiple partnering institutions presents a data sharing challenge. Dual GIS systems and long-term data storage are required given the restricted access and the already established data management procedures for DNR corporate data such as forest inventory and timber sales planning. The project staff is currently working to identify data repository(s) and data sharing processes convenient for all participating organizations.

Table I-2. Pre-treatment environmental indicators sampled during T3 watershed experiment

Monitoring Indicator (Aquatics)	Year Collected*	Monitoring Indicator (Upland and Riparian)	Year Collected
Fish density	2020, 2021, 2022	Avian habitat	2020, 2021, 2022
Fish biomass	2020, 2021, 2022	Avian acoustics	2020, 2021
Water temperature	2020, 2021, 2022	Upland overstory vegetation	2021, 2022
Air temperature	2020, 2021, 2022	Upland understory vegetation	2021, 2022
Stream Habitat	2020, 2021, 2022	Riparian overstory vegetation	2021
Canopy cover	2020, 2021, 2022	Riparian understory vegetation	2021
Water chemistry	2021, 2022	Soil in EDVP units	2022
Fish stomach content	2020, 2021, 2022	Drone LiDAR data	2021, 2022
Drift invertebrates	2020, 2021		
Benthic invertebrates	2020, 2021		
Fine sediment	2021		
Stream flows	2021		
Periphyton & Seston	2020, 2021		
Leaf litter	2022		
PAR	2022		

*Additional pre-treatment sampling may occur in 2023

Several ecological and economic modeling efforts are underway as part of the stuy. Their goal is to produce quantitative projections of the post-treatment environmental conditions, to estimate economic returns and the optimal set of prescriptions across the OESF landscape, and to evaluate the uncertainties associate with these projections. The modeling outcomes will be used as testable hypotheses about the treatment responses -such hypotheses are difficult to formulate given the multiple biotic and abiotic interactions and feedbacks that occur in the ecosystems and the uncertainties associated with markets, policy changes, and other factors.

Forest growth and yield. The development of stands after treatments is modeled using the forest vegetation simulator (FVS; Dixon 2002) used by DNR, with its Pacific Northwest variant (Keyser 2008). A parallel effort, using a distance-dependent model to simulate forest growth, will be used for comparison. Results are expected by July 2023.

Net present value (NPV). Economic projections for entire lifespan of each prescription are developed using the forest growth and yield projections and all activity revenues and costs. Results are expected by July 2023.

Management decision support. The forest growth and yield and the economic projections ranges will be used to extrapolate potential impacts of individual prescriptions to the entire OESF. The goal is to simulate sustainable harvest volume and to produce optimal set of prescriptions needed to maximize NPV within HCP and other constraints. Planned for 2024.

Aquatic trophic productivity. A dynamic food web simulation model that estimates the capacity of stream ecosystems to sustain fish and is explicitly tied to transfers of organic matter between different components of a simplified stream-riparian food web (Bellmore et al. 2017). The model outputs will show short- and long-term aquatic food web responses to each riparian treatment. Results are expected by July 2023.

Budget and Project Management

Funds for monitoring, modeling of treatment effects, research coordination, and stakeholder outreach come primarily from Washington State Legislature proviso funding to ONRC and DNR (so far for biennia 19-21 and 21-23). Additional funding has come in the forms of grants such as a 3-year research support for acoustic monitoring from The Earthwatch Institute and McIntire-Stennis grant for the economics sub-study. The timber harvest portion of all prescriptions is implemented through DNR Olympic Region timber sale program which is funded by DNR management fees. Most of the silviculture activities for the prescriptions will be implemented through DNR Olympic Region silviculture program which is funded by DNR management fees. All participating organizations, and particularly DNR and UW-ONRC, provide substantial in-kind support in the form of researchers' time, field and lab equipment, and technical support.

The project is managed jointly by DNR and UW-ONRC. The study leads, identified on the cover page of this plan, are responsible to:

- Define overall project objectives and intended outcomes;
- Coordinate that various sub-studies align with the project objectives and implementation schedule and do not impede each other;
- Evaluate project performance and advise (and sometimes decide) on changes in project design and implementation schedule;
- Seek funding and manage the Legislature budget or other general project funding;
- Oversee the stakeholder engagement;
- Advise and coordinate outreach activities (presentations, media materials, etc.)[27];
- Foster positive and constructive communication between project participants;
- Communicate with DNR managers, funding entities, and research collaborators

Stakeholders, including DNR beneficiaries, local tribes, and DNR managers, are important partners in this project. As described in the learning-based collaboration section of Chapter 1, they have been engaged together with researchers from the start of the study in identifying key questions and designing treatments, reviewing study plans, adding sub-studies and monitoring. The goal of this collaboration is to build collective adaptive capacity to find innovative solutions quickly enough to positively respond to the rapidly changing, complex world in which we live.

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[27] The project updates are posted on UW-ONRC website (https://www.onrc.washington.edu/t3-watershed-experiment/) and on DNR webpages for the Olympic Experimental State Forest (https://www.dnr.wa.gov/oesf).

Appendix 1. Current DNR Forest Management Policies and Practices

Through its Policy for Sustainable Forests (WDNR 2006), the Washington State department of Natural Resources (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*." (WDNR 2006). Environmental and other benefits are to be integrated with sustainable trust income through decisions such as temporary and permanent reserves, sustainable harvest calculations, access to state lands, recreation development, secondary economic benefits, land exchanges, and riparian and upland silviculture. The guidance with the most impact on degree and types of integration are: (1) the DNR's State Trust Lands Habitat Conservation Plan (WDNR 1997, WDNR 2019b) and (2) the decadal sustainable harvest calculations (WDNR 2006, WDNR 2019a) and (3) the forest land plans that provide foresters and managers practical guidance through specific implementation procedures (e.g. WDNR 2016). The HCP is an agreement between DNR and Federal Services (US Fish and Wildlife and NOAA Fisheries) allowing DNR to actively manage forest lands for revenue within the range of federally listed threatened and endangered species, while remaining in compliance with the Endangered Species Act. DNR is permitted specified levels of incidental take but must manage the forested landscape to meet habitat objectives for northern spotted owls, marbled murrelet, salmonids, and other species, listed and non-listed.

Uncertainties in how to best achieve integration led to the establishment the Olympic Experimental State Forest (OESF) in 1992, to "gain and apply knowledge in order to better integrate management for forest commodities and ecological values." In particular, the OESF was designated to study an "unzoned" alternative to the permanent, fixed-reserve model applied on other state trust lands and on Forest Service lands under the Northwest Forest Plan. This science-based alternative to the fixed-reserve model was based on disturbance ecology rather than conservation biology. The OESF approach uses a shifting mosaic of management activity that mimics natural disturbance patterns and ecological processes by achieving and maintaining a fixed distribution of stand structures through time. This approach spatially shifts habitat through time was thought to better meets the needs of the full array of species adapted to these patterns and processes. Fixed boundaries were unavoidable for the initially rare patches of existing structurally complex old forest, a few areas of unique habitats, and for most riparian zones.

Special provisions were established in the 1997 HCP for the OESF to examine some of its underlying assumptions through research and monitoring. The OESF was identified as a place to research additional topics such as watershed processes and aquatic habitats, timber harvesting systems, and landscape management (WDNR 1997, V.8). In addition to the learning objective, the OESF has important adaptive management objective to incorporate research and monitoring results into management.

In the OESF Forest Land Plan (DNR 2016, Chapter 2), DNR describes specifies the processes it uses to implement integrated management today, with the understanding that DNR's approach may change again in the future as DNR continues its intentional learning in the OESF. Below, we describe the current landscape and stand-scale approaches.

Managing from a landscape perspective involves multi-disciplinary planning for the entire land base at different spatial scales to balance multiple objectives for revenue and ecological values, including the objectives of the four major habitat conservation strategies. Operable (available for harvest) and deferred areas are identified. Areas deferred from harvest include permanent deferrals, for example natural area preserves, and areas deferred from harvest per current DNR policies, management practices, and guidance, such as old-growth forests and unstable slopes. Habitat managed under HCP conservation strategies, such as spotted owl old forest habitat, riparian management zones, and marbled murrelet habitat patches have different levels of deferral. It can be partially deferred - for example, thinning is allowed in spotted owl habitat and small amount of regeneration harvest is allowed in riparian zones. The habitat can be subject to shifting across the landscape such northern spotted owl habitat and long-term forest cover for marbled murrelet. It can also have more permanent deferral status such as marbled murrelet occupied sites.

Variable density thinning

Variable Retention Harvest in the OESF

Variable Retention Harvest in the OESF

Figure A-1. Example applications of DNR standard practices on the OESF.

Silviculture is the principal tool by which DNR introduces and maintains structural diversity within and across forest stands sustainable trust income for the people of Washington. The primary harvest techniques currently used by DNR are variable retention harvest (VRH) and variable-density thinning (VDT)[28]. These along with other silvicultural practices such as planting, vegetation control, and pre-commercial thinning (PCT) form the prescriptions used to meet DNR objectives.

VRH is the most common harvest technique applied to upland, even-aged, second- and third- growth stands, which has not changed much since the adoption of the 1997 HCP (Fig. A-1). VRH is a type of regeneration, or stand-replacement harvest where key structural elements of the existing stand are maintained while the commercial forest stand cohort is re-initiated. Retained elements include structurally unique and

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[28] Before the 2006 sustainable harvest calculation, in 1997 to 2006, thinning was more conventional commercial thinning lacking the focus on adding variability in density.

other leave trees (minimum 8 trees per acre, clumped or dispersed), snags, down wood, and other elements. VRH is not applied in designated riparian zones, spotted owl or marbled murrelet habitat, wetlands, old growth, or on unstable slopes or other unique habitat types (WDNR 2016, Chapter 2).

VRH facilitates regeneration and optimized growth of tree species of intermediate or low shade tolerance, notably Douglas-fir, but also Sitka spruce (*Picea sitchensis* (Bong.) Carrière) and red alder, with the principal goal of producing future revenue. More shade-tolerant species, including western hemlock, Pacific silver fir (*Abies amabilis* (Douglas ex Loudon) Douglas ex Forbes), western redcedar, or big-leaf maple (*Acer macrophyllum* Pursh) can often regenerate naturally after VRH in the maritime climate for the OESF. The current practice on the OESF is to apply PCT when trees are 15-25 ft (6-8 m) in height (Pers. Comm., Matt Perry, DNR silviculturist who runs the PCT program), although funding issues sometimes delay this. PCT is applied to reduce competing species and reduce conifer densities so individual trees will achieve harvest size more rapidly.

VDT is a commercial activity used to accelerate stand development towards a stated objective which can be structurally complex habitat or future VRH. VDT is also typically applied to even-aged stands. Variability is achieved by including gaps (usually between 0.1 to 1.0 ha; ¼ to 2 acres), skips without harvest, and evenly thinned patches [*cite more original work—Carey?*]. Gaps are generally required to increase habitat and plant biodiversity for a prolonged period as tree crowns close back up quickly. VDT is often applied to promote the growth of residual trees in stands where a final VRH is planned or to meet habitat distribution targets (40% of the landscape) for growing stands with older forest structure.[29] Similar to a conventional thinning, a variable density thinning must have revenue objectives and financial thresholds to be operationally feasible.

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[29] In a 2006 settlement to a lawsuit (Washington Environmental Council vs. Sutherland et al.), DNR agreed to apply VDT to half of the area harvested in the OESF. This agreement ended in 2019. Pressure to thinning practice continues across the state, but is difficult for DNR to implement when reduced net revenue calls into question its fiduciary responsibility to trusts for sustained revenue.

Appendix 2. The T3 Watershed Experiment at the Landscape Scale

Geographic and Historical Setting

The study is located on the western Olympic Peninsula in the temperate rainforest zone of the Pacific Coastal Ecoregion. The maritime climate receives heavy precipitation, estimated at 137 inches per year for the study area, with the majority falling as rain between October and April. The climax vegetation zones in the study area, in order of increasing elevation, are Sitka spruce, western hemlock, and Pacific silver fir (Franklin and Dyrness 1973; Henderson et al. 1989). The most prevalent tree species are western hemlock, Douglas-fir, Sitka spruce, Pacific silver fir, and western redcedar. Red alder is the most prevalent hardwood, establishing as an early-seral species in disturbed areas and near waterways, and bigleaf maple is also present. Stand age distribution is heavily weighted to the 30 to 60-year-old class, reflecting; (1) extensive harvesting 1960 to 1990; (2) retention of older forest patches, many dating to a 1921 windstorm; and (3) only recent re-entry into second and third growth stands (Fig. A2-1).

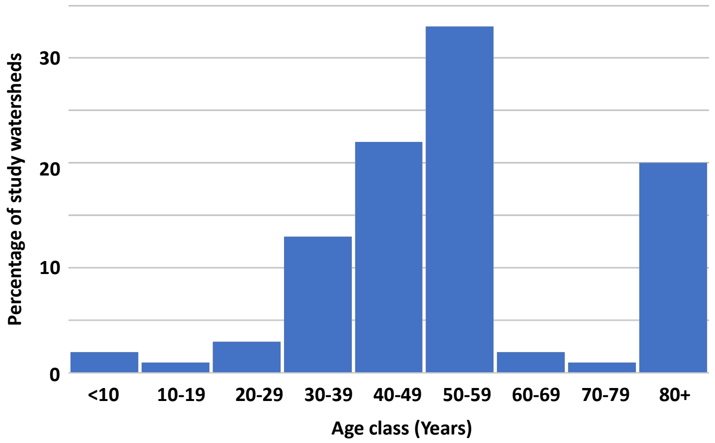

Figure A2-1. Age distribution for stands in the study watersheds (calculations were made using the DNR inventory model predicting stand age, on 24 February 2020).

The study area is in the OESF planning unit, which contains more than 273,000 acres of state trust lands in Clallam and Jefferson Counties on the western Olympic Peninsula, WA. The study watersheds are located within Jefferson County. For planning purposes, the OESF is divided into 11 landscape units ranging from 9,000 to 57,000 ac (WDNR 2016a). The T3 Management Experiment watersheds fall into four of these landscapes: Clearwater (7 watersheds), Coppermine (3 watersheds), Kalaloch (3 watersheds), and Willy Huel (3 watersheds).

The 16 study watersheds consist predominantly of DNR-managed trust lands (79 to 100 percent of total watershed area; Table A2-1). A preliminary analysis indicated that, among the 12 non-control watersheds, the percentage of each watershed's area that meets economic, regulatory, strategic, and ecological criteria for harvest at this time ranges from 11 to 63 percent. Areas not harvestable under the marbled murrelet Long-Term Conservation Strategy adopted December 2019 consist of marbled murrelet occupied sites, occupied site buffers, metered P-stage habitat, and special habitat areas. Combined, the marbled murrelet habitat areas not available for experimental manipulation account for 2% to 48% of watershed area among the 16 study watersheds.

Table A2-1. Summary of the 16 study watersheds, including harvestable area

Experimental block	Strategy	Total watershed *acres*	State trust Lands *acres*	State trust Lands *% total*[2]	Harvestable area[1] *acres*	Harvestable area[1] *% total*[2]
A	Alt-1	2,660	2,660	100%	540	20%
	Alt-2	844	844	100%	245	29%
	Standard	1,803	1,803	100%	364	20%
	Control	1,120	1,120	100%		
B	Alt-1	931	931	100%	276	30%
	Alt-2	1,470	1,470	100%	530	36%
	Standard	532	532	100%	198	37%
	Control	1,922	1,871	97%		
C	Alt-1	1,337	1,337	100%	470	35%
	Alt-2	1,505	1,505	100%	581	39%
	Standard	1,159	920	79%	412	36%
	Control	1,483	1,483	100%		
D	Alt-1	1,660	1,457	88%	188	11%
	Alt-2	561	529	94%	353	63%
	Standard	600	526	88%	153	26%
	Control	801	778	97%		

[1] This is an early approximation based on a GIS analysis by Planning Forester Kevin Alexander. It is a work in progress; the values in this table are from 5 February 2020. The final harvestable area is expected to be smaller than the values in this table.

[2] Percentage of total watershed area.

At the whole-study level, harvest will occur at a rate commensurate with the sustainable harvest calculation (SHC) for the OESF for the decade 2015-2024. The harvest volume under the SHC is 739 MMBF, which includes 200 MMBF arrearage from the prior decade (WDNR 2019c). On an estimated area basis, the harvest for the same decade is projected to be 25,028 acres, assuming that, averaged across the decade, approximately 75% of the harvested acreage is VRH and 25% is VDT. Thus, on an area basis, approximately 10% of the DNR-managed lands on the OESF (excluding Natural Area Preserves and Natural Resource Conservation Areas) is planned for harvest in the current (2015-2024) decade of the SHC.

The T3 Management Experiment was scheduled to begin with as a 10-year study, which aligns with the decadal planning timeframe of the SHC. To calculate harvest in the T3 Management Experiment, the OESF's estimated 10% decadal rate of harvest is applied to the total area of the 16 study watersheds (20,388 ac), resulting in a harvest target of 2,039 ac for the decade of the study.30 However, because the four no-action control watersheds in the study will not be harvested, the other 12 watersheds will need to be harvested at a higher rate than 10% to achieve the 2,039-ac target for the entire study. Raising the harvest rate in the 12 watersheds from 10% to 13.3% compensates for the control watersheds that are not harvested. Thus, after accounting for the unharvested control watersheds, the total harvested area across the entire study will remain at the approximate 10% per decade rate that is equivalent to the rate of

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[30] For study implementation, it was preferable to plan harvest initially by area, and then estimate volume.

volume in the sustainable harvest calculation. These harvest rates apply only to the uplands. Some riparian harvest from interior-core stream buffers (WDNR 2016a) adjacent to upland harvest units will occur in the Science and Community strategies, as described in the riparian study plan.

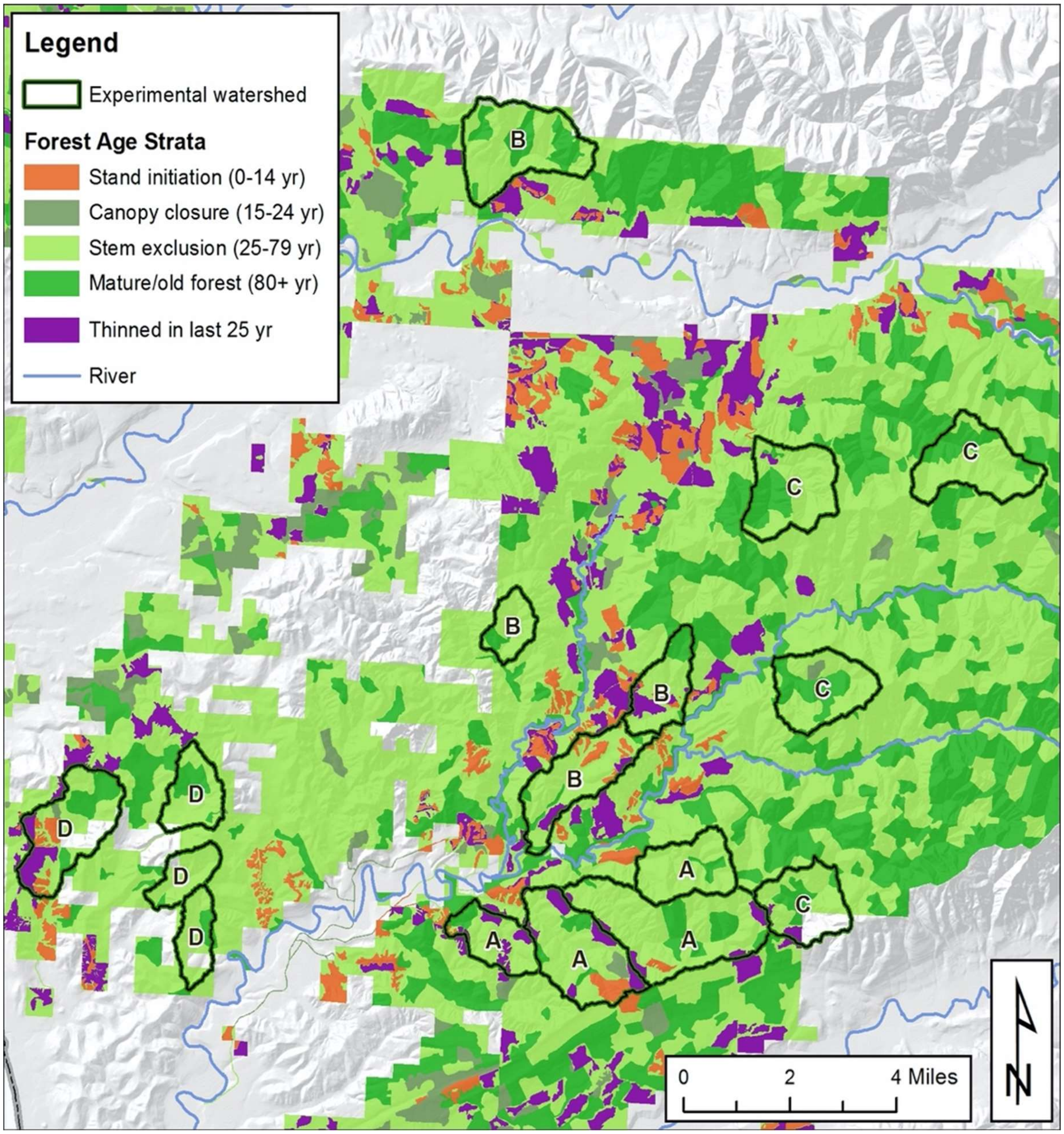

Figure A2-2. Forest age strata for DNR-managed forest lands in the vicinity of the 16 study

Historical Context and Pre-Treatment Variability

An affiliated study led by PIs Bormann, Minkova, Devine, Alexander, Bobsin, along with GIS staff and graduate students (with support from the PNW Research Station) is underway to quantify pre-treatment conditions within operational areas to:

- Establish past historic condition that can be compared into the future;
- Examine similarity of operational and sub-units being assigned randomly; and
- Provide quantitative differences that might be used in future co-variate analysis.

This “history project” has been underway for several years, and has been seeking available evidence before and after the initial wave of harvests. So far, we have uncovered a number of sources of historical data including some with tree species composition. We have geo-rectified all 1967 aerial imagery in the area which predates most harvesting on the watersheds (Fig. A2-3). We also developed a Landsat database to identify when harvest units first show up that will allow us to confirm harvest dates and narrow the search for the best post-harvest photos and other records.

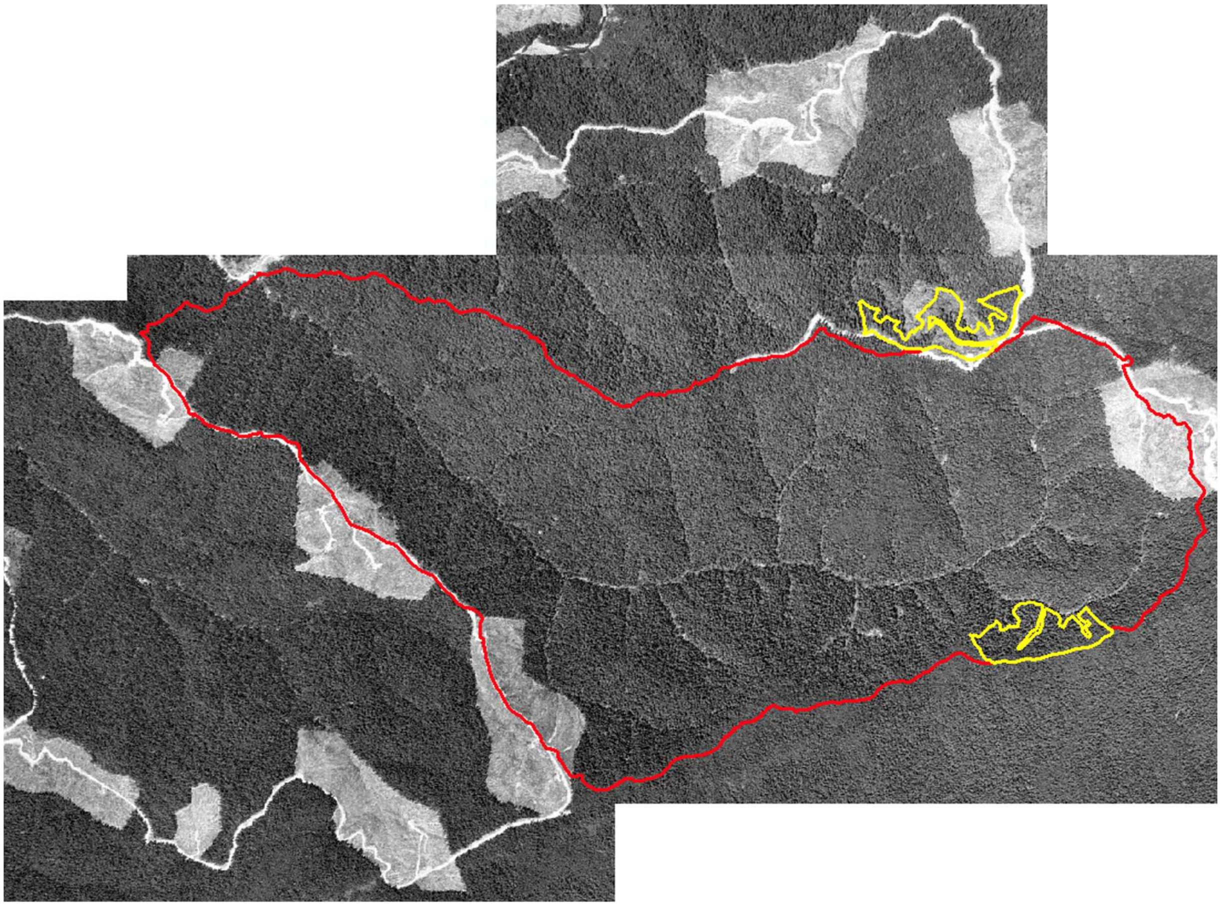

Figure A2-3. The condition in 1967 surrounding watershed Az (red) and Cz just the north. The two AVDT units are shown as yellow polygons.

A pretty clear picture of historical events and current conditions is unfolding with these multiple sources of information. Species composition information from Government Land Office records and a 1930s timber survey suggests a diversity of conifer mixtures were most common, including more cedar and spruce than typically seen today. Pristine stands tended to have large trees about 30 to 60 ft apart (maybe 10 to 50 large trees acre^{-1}), more often on N-facing slopes. S-facing slope stands seemed often to have more numerous, smaller trees, some perhaps dating to the "21-blow" 1921 wind event. The portion of the outer coast of the Olympic Peninsula where the study lies had little harvesting until the 1960s. The first harvests were generally 100 to 150 acres along ridges that allowed for economical construction of the road system (Figure A2-3). About 75% of this area was harvested by the mid 1980s, mostly in the 1970s. In general, taller trees are seen on north and east-facing slopes as south and west slopes are more exposed to Pacific storms. Areas with 40- to 46-year-old stands in 1967 originated in a large windstorm called the '21 Blow. Large 50-to-100-acre harvest units were created in the 1970s and 1980s soon after road segments were completed. Harvest generally started closer to existing roads near the coast and proceeded inland mainly along ridges over following decades. These harvests almost completely ignored current riparian buffers. In some cases, long skyline cable systems were set up ridge to ridge, and there are old photos showing heavy machinery in stream beds. Uncovered timber sale maps show fire lines surrounding most units, and charred logs are seen today in the field, suggesting most units had slash burning. We hope to examine aerial photos taken soon after harvest to confirm harvest practices and possible effects such as planting stock, vegetation management, and slides. Finding folders with documents used in timber sales has proved difficult as the maps describing sale names and locations were destroyed in a fire in the DNR Forks office. Finding and in some cases scanning aerial photos and folders will take time.

Pre-treatment variability at the watershed scale (Figure A2-2) was constrained as much as possible through the choice of watersheds to include within blocks using a similarity analysis (Chapter 6). Characterization of pre-treatment differences are initially made through existing DNR databases and study of past management and can be further assessed with various remote sensing tools. At the scale of operational units, we assessed pre-treatment variability initially using the DNR LiDAR-based inventory (RS-FRIS). These operationally feasible second-growth stands are mostly western hemlock except places where planted Douglas-fir successfully dominated. Silver fir is seen in some stands, mostly further east or at higher elevation. Western redcedar, Sitka spruce, and red alder are scattered at low frequency as well. Similarity of stand conditions (available from RS-FRIS) in operational units is somewhat pre-determined as stand data provided by the was used to identify stands suitable for harvest. Most of the stands chosen were established in the 1970s and 1980s when a large wave of harvest followed construction of roads into the pristine and remote areas of the study. Pre-treatment stand conditions, derived from the DNR LiDAR-based inventory, do not vary greatly both between sub-units and between watersheds (Figure A2-4). We have begun evaluating differences in pre-treatment conditions using drone-lidar and ground measures, which will be far more accurate that RSFRIS based analyses. This work will allow us to identify variation within stands such as the location and extent of small gaps with some understory that might influence seed sources once stands are opened up.

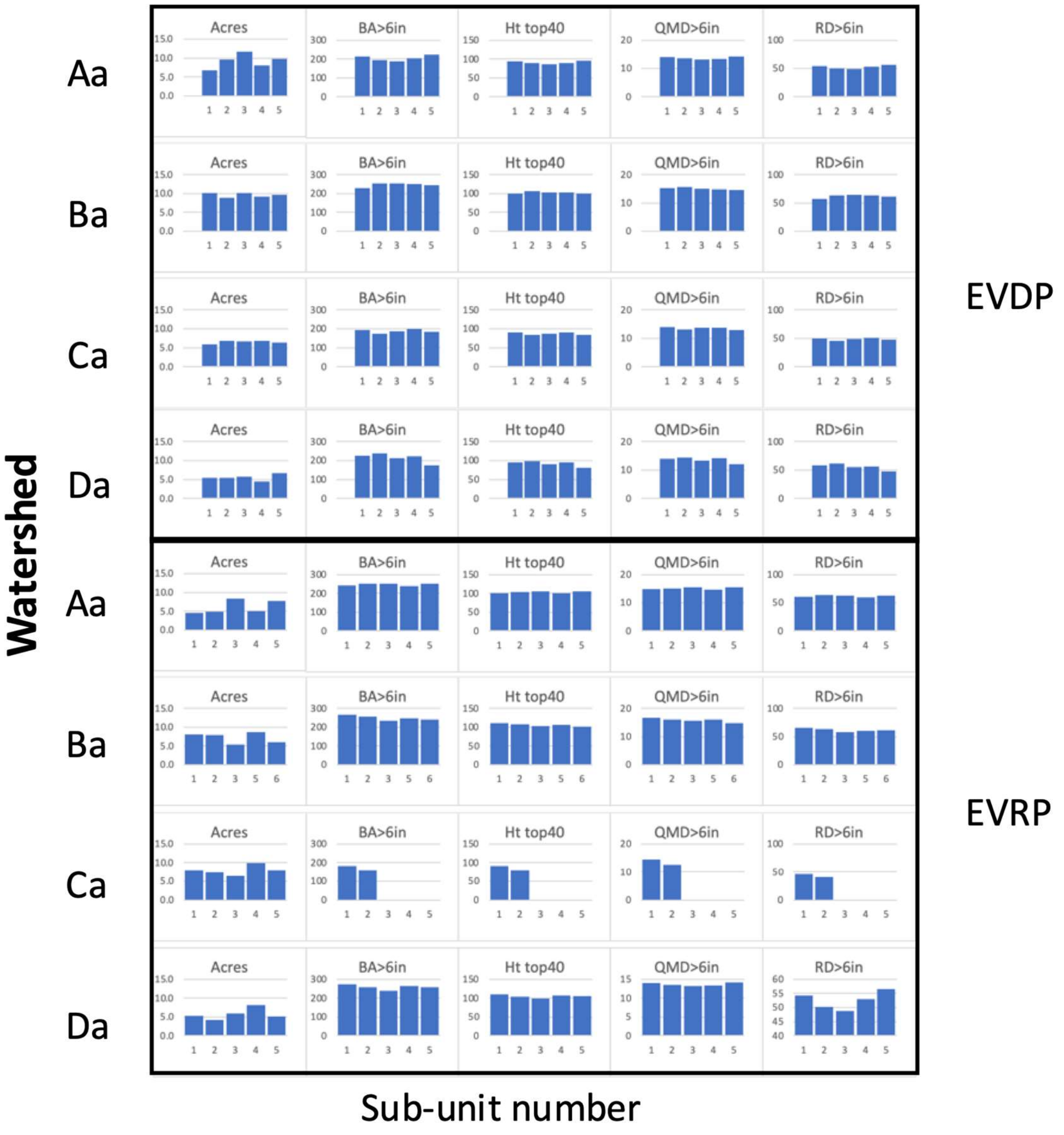

Figure A2-4. Variability in LiDAR-based inventory data for EVDP and EVRP sub-units by watershed, showing substantial similarity within operational units and watersheds. BA>6in is basal area of trees > 6 in. diameter (in.); HT top40 is height (ft) of tallest 40 trees; QMD>6in is quadratic mean diameter (in.); and RD>6in is relative density (% of maximum trees acre^{-1}).

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