T3 Watershed Experiment in the Olympic Experimental State Forest

2016-2023 Implementation Report

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Acronyms

AVDT – Accelerated Variable Density Thinning (an experimental silvicultural prescription)

BA – Basal Area

CES – Complex Early Seral (an experimental silvicultural prescription)

DBH – Diameter at Breast Height

DNR – Washington State Department of Natural Resources

EVDP – Ethnoforestry Variable Density Planting (an experimental silvicultural prescription)

EVRP – Ethnoforestry Variable Ratio Polyculture (an experimental silvicultural prescription)

GIS – Geographic Information System

GPS – Global Positioning System

HCP – Habitat Conservation Plan

LiDAR – Light Detection and Ranging (a remote sensing method)

LBC – Learning-based Collaboration

LG – Learning Groups

NOAA – National Oceanic and Atmospheric Administration

ONRC – Olympic Natural Resources Center

OESF – Olympic Experimental State Forest

PI – Principal Investigator

T3 – Type 3, referring to the smallest fish-bearing streams and their watersheds

TPA – Trees Per Acre

USDA – United States Department of Agriculture

USFS – USDA Forest Service

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

UW – University of Washington

VRH –Variable Retention Harvest (one of DNR's standard silvicultural prescriptions)

VDT –Variable Density Thinning (one of DNR's standard silvicultural prescriptions)

Executive Summary

This implementation report summarizes the activities of the T3 Watershed Experiment during the period 2016-2023, the rationale behind major decisions, and the lessons learned so far.

The T3 Watershed Experiment is a collaborative study initiated and led by Washington State Department of Natural Resources (DNR) and the University of Washington Olympic Natural Resources Center. It is partially funded by the Washington State Legislature and is implemented on DNR-managed state trust lands in the Olympic Experimental State Forest on the western side of Washington's Olympic Peninsula. This project is a landscape-scale management study designed to assess the ecological, economic, and social impacts of standard and novel management approaches in upland and riparian forest ecosystems. The study aims to expand DNR's toolbox of management practices to increase the sustainability of forest management and to build capacity for finding innovative solutions and for responding to changing ecosystems.

The study takes place in 16 Type 3 watersheds (500-2,000 acres each), the classification for the smallest fish-bearing streams on DNR-managed lands. Four management strategies, each replicated in four watersheds, include standard DNR operations, no-action control, and two alternative strategies for integrating ecological and community wellbeing objectives. The corresponding upland and riparian treatments (i.e., experimental forest management prescriptions) are implemented at an operational scale through DNR forest management operations. A diverse group of researchers and natural resource practitioners developed the vision, study plans, ecological models, and monitoring plans and currently coordinate the study's implementation. Close and timely coordination among these participants was key for finding the best solutions while maintaining the integrity of the experiment.

The experiment is implemented through 13 timber sales covering 2,124 acres within the experimental watersheds. All timber sales were auctioned in the 2022-2023 fiscal years and logging is ongoing. The planning of silvicultural activities such as site preparation and tree planting is underway. Pre-treatment monitoring data has been collected since 2020 and includes sampling in aquatic, riparian, and upland areas as well as bioacoustics and drone LiDAR.

Active engagement of stakeholders and tribes has been a main tenet of the T3 Watershed Experiment. A unique and very successful form of engagement called learning-based collaboration was used to gain insight and feedback through the study design process. It continued with eight T3 Learning Groups where people with diverse backgrounds and expertise are collaborating on specific topics such as carbon, cedar, or invasive species. The T3 study has enormous education potential for graduate and undergraduate students due to the variety of research topics and implementation activities, the opportunities for hands-on experience in environmental monitoring, and the large well-documented datasets. More than a dozen students have completed or are working on T3-related research.

The biggest challenge and, concurrently, the biggest success of the T3 Watershed Experiment during the first seven years of development and implementation has been building understanding, acceptance, and trust across vastly different cultures and knowledge domains: land managers, scientists, regulators, foresters, beneficiaries, environmental groups, and the local community. We see the increasing value of this project as a demonstration of our collective ability to envision bold forest management strategies, implement complex novel prescriptions, learn together, and engage meaningfully with stakeholders and tribes. This is a much-needed example for building adaptive capacity in a fast-changing world.

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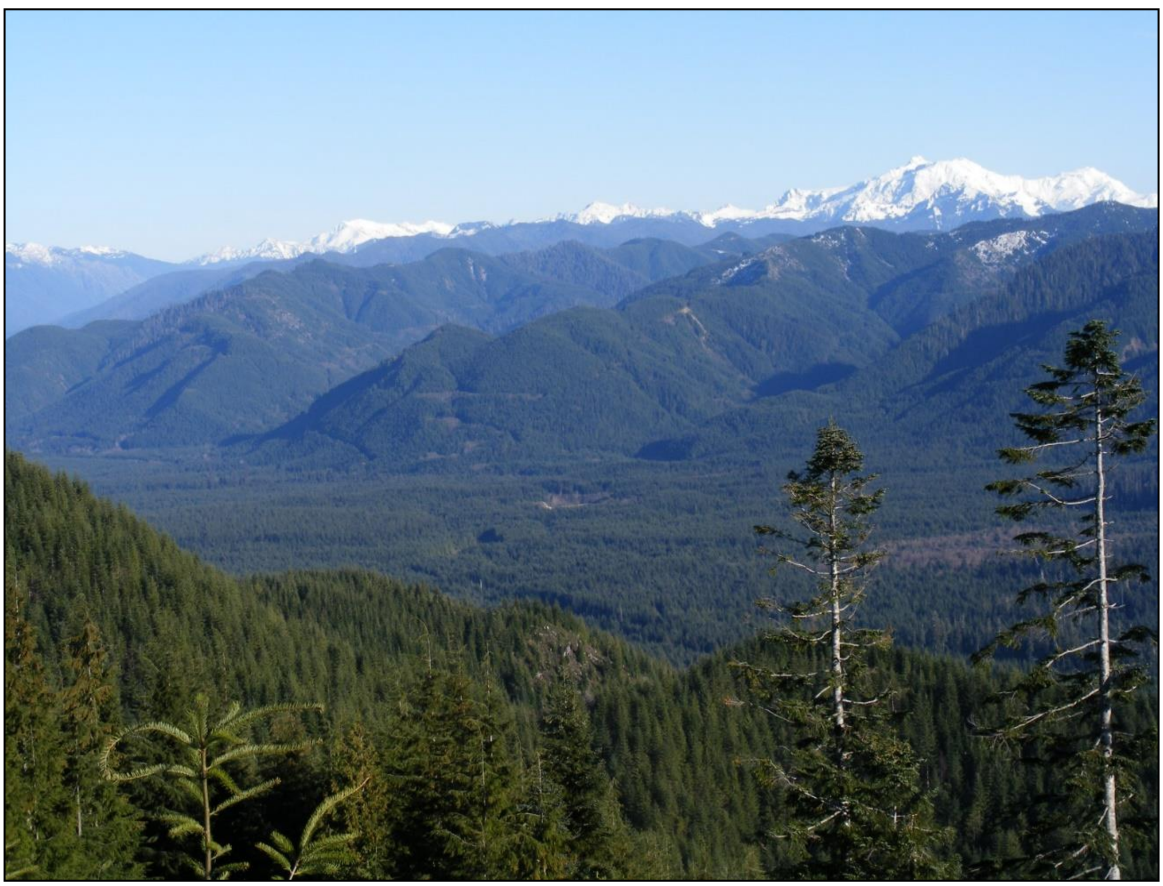
Introduction

The purpose of this implementation report is to summarize the activities of the T3 Watershed Experiment that took place during the period 2016-2023 and the rationale behind major decisions made during the implementation process. This recap is needed due to the long duration of the study (at least 10 years) and the large number of participants from different organizations. The report will also serve as a communication tool and will help account for the funds and staff time used in the project during the reporting period.

The intended audience is Washington Department of Natural Resources (DNR) managers; DNR practitioners implementing the study, such as foresters and silviculturists; study researchers (current and prospective); stakeholders; and other land managers and researchers considering similar projects.

The implementation report is organized in sections according to the major study components. Additional project information, such as study plans and monitoring protocols, is available from previously published documents available online. These are cited throughout the report and are accessible through hyperlinks in the text.



View of the Olympic Experimental State Forest, where the T3 Watershed Experiment takes place.

Study Overview

The T3[1] Watershed Experiment is a collaborative study initiated and led by DNR (Forest Resources Division and Olympic Region) and the University of Washington Olympic Natural Resources Center (ONRC) on DNR-managed state trust lands in the Olympic Experimental State Forest (OESF) located on the western side of Washington's Olympic Peninsula. It is a landscape-scale management experiment designed to assess the ecological, economic, and social impacts of standard and novel management approaches in upland and riparian forest ecosystems in the Coast Range Ecoregion of the Pacific Northwest.

Need, Goals, and Philosophy

Many of the current forest management commitments, policies, and regulations on public lands in the Pacific Northwest were developed in the 1990s in response to declining populations of northern spotted owl (*Strix occidentalis caurina*), marbled murrelet (*Brahcyramphus marmoratus*), and salmonids. These were developed from the best available science at the time and negotiations between stakeholders. Since the 1990s, much of the research and monitoring on these lands has focused on the forest management issues that arose during that era. But the limited amount of innovation and regulatory flexibility in forest management practices, the increasing knowledge of ecological processes, and the rapidly changing social and environmental conditions during the past quarter-century raised the question: Can a broader range of activities be implemented to improve forest management?

DNR's forest management on state managed lands in western Washington are guided by the 1997 state lands Habitat Conservation Plan (HCP; DNR 1997). The HCP outlines how DNR manages state trust lands to protect habitat for at-risk species, such as the northern spotted owl, while carrying out forest management and other revenue-producing activities. The HCP calls for an adaptative management approach with research and monitoring focused on the OESF.

The OESF was established in 1992 as a place to experiment with innovative silvicultural techniques and to use these new techniques as tools to integrate habitat conservation and commodity production (DNR 1997, p. IV.83). The T3 Watershed Experiment addresses a number of research priorities in the state lands HCP by exploring new forest management approaches and also meets a number of HCP monitoring commitments by evaluating current practices. It also addresses the need for adaptive capacity, which we define as the ability of key participants (land managers, regulatory agencies, stakeholders, researchers, and tribes) to work individually and collectively to consider needed social and environmental changes, seek innovative solutions, and implement new approaches to forest management.

The study aims to expand the toolbox of management practices in upland and riparian forests in order to increase the sustainability of forest management and to build capacity for finding innovative solutions and for responding to changing ecosystems. A basic premise of this study is that diversification of the land management tools available for application at small to large scales is key to

[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 the name T3 in the study title.

resilience given the many uncertainties DNR and other land managers face – uncertainties related to climate change, biodiversity loss, and social dynamics.

The study approach can be broadly described as a management experiment using adaptive-management and ecosystem-wellbeing frameworks.

The **adaptive management framework** (Minkova and Arnold 2020; DNR 1997, p. B.10) means that the study is designed to address forest management uncertainties and the findings will be formally considered for improvement of management practices. Because the intention is to test experimental forest management techniques, called "prescriptions," that can potentially expand the toolbox available to managers, these prescriptions are implemented at an operational scale—the scale of typical timber sale units (average size is 25 acres)—so that realistic costs and benefits are demonstrated and can be better understood. DNR has adopted an administrative procedure for the adaptive management process in the OESF (DNR 2016, p 4-9) that describes how DNR managers and scientists identify priority research questions, report project findings, and consider related management implications.

The **ecosystem-wellbeing framework** (Bobsin et al. 2023) refers to the understanding that people (community) and natural environment are interconnected parts of an ecosystem that ought to be managed as a whole (Figure 1). To truly achieve ecosystem wellbeing, both community and environmental wellbeing need to be considered simultaneously and with equal seriousness. Therefore, this study integrates ecological, economic, and social objectives for forest management – all experimental prescriptions are designed to simultaneously provide benefits to people and the environment, while meeting the legal requirements of the trust mandate and the state lands HCP (DNR 1997). To understand and address the wellbeing of local communities, we use the process of learning-based collaboration (LBC), where natural resource managers and practitioners, researchers, stakeholders, and tribes engage with one another focusing on asking and answering questions about options and effects of management choices through scientifically valid comparisons. This collaborative process helps to meet community needs, enrich research, and build collective trust and goodwill to explore innovative management solutions and adopt management adjustments. Elements of this framework are described in the state lands HCP (DNR 1997, p. IV.81-86) and are implemented by DNR as part of its integrated management approach to production and conservation and the OESF learning objective. Expansion of these elements through the ecosystem-wellbeing framework will be evaluated during the T3 Watershed Experiment.

Figure 1. Ecosystem wellbeing framework focusing on the inherent interactions between two elements where learning occurs.

Research Design

The research approach is to compare the current DNR forest management practices to novel prescriptions by tracking ecological, economic, and social responses. The comparisons are done at different spatial scales because the ecological processes of interest, such as aquatic productivity and tree regeneration, unfold at different spatial scales, and DNR land management decisions, such as riparian conservation and sustainable harvest level, are also applied at different spatial scales. Therefore, to link research to DNR decisions holistically, the final study design includes three scales of nested experimental units: (1) watersheds (500 to 2,000 acres) (Figure 2); (2) individual timber sale units (often 20-60 acres) where individual prescriptions are applied; and (3) more typical research plots (4-5 acres) or stream reaches (300 feet), to test specific silvicultural and ecological relationships.

Although this is an experimental study, it is designed as a management experiment – the treatments are implemented through DNR forest management operations at large spatial scale – and for this reason it needs to comply with the trust obligations of state lands and the agency's implementation procedures.

The T3 Watershed Experiment officially began with the designation of the 16 experimental watersheds in 2018. The study will continue for at least 10 years, after which DNR and T3 researchers will discuss potential extension. DNR committed to implement only the T3-planned harvest activities in the experimental watersheds for the initial duration of the study.

Teodora Minkova, DNR

Figure 2. Landscape view of a typical watershed in the study area. The watershed is dominated by second-growth forest containing a mix of western hemlock and Douglas-fir with a patch of old growth forest in the background and a recent harvest in the foreground.

Four watershed-level management strategies guided the development of riparian and upland prescriptions. They influence the prescriptions' makeup, placement within watersheds, and size. The four strategies are:

- **Control (no-action).** The Control Strategy consists of no harvest at the watershed scale for the duration of the study. This strategy serves to document changes due to natural processes, thus helping discern the management effects of the other three strategies. It is not possible for DNR to apply watershed-scale no-action management on a widespread basis on state lands given the current legal interpretation of the trust mandate.
- **Standard.** The Standard Strategy implements the current best practices as set forth in the OESF Forest Land Plan (DNR 2016), including integrated management for revenue and habitat objectives. This strategy serves as a control to which to compare alternative prescriptions and provides opportunity to evaluate current DNR practices. For the purpose of the study, our application of standard management in these watersheds avoids any riparian harvest, although thinning and limited regeneration harvest is permitted in the riparian management zone under the OESF Forest Land Plan.
- **Alternative-1 Integration.** The Alternative-1 Integration strategy seeks greater integration of current habitat mandates and additional ecological concerns (such as increasing early-seral habitat and active restoration of riparian functions) with continued revenue generation by applying the latest environmental science knowledge.
- **Alternative-2 Integration.** The Alternative-2 Integration strategy seeks greater integration of community wellbeing concerns by combining perspectives and local knowledge from diverse collaborators, stakeholders and tribes with social and environmental science developments. This includes increasing culturally significant understory plant species, elk populations, western redcedar, red alder, and fish populations. We refer to this approach as ethnoforestry[2] and define it as people-focused forest management (Bobsin et al. 2023).

The study takes place in 16 Type 3 watersheds (500-2000 ac each) on approximately 20,000 acres of DNR-managed state trust lands in the OESF on the western Olympic Peninsula (Figure 3).[3] These watersheds are located within the drainages of the Clearwater River, the Hoh River, and Kalaloch Creek. Refer to the study proposal (Bormann and Minkova 2017) for a description of the initial pool of potential experimental watersheds in the OESF and the process of selecting the final 16 watersheds. The study was designed to compare the four watershed strategies using a complete randomized-block design with four blocks. Watersheds were grouped into blocks based on similarity, and management strategies were assigned randomly within blocks. Specific prescriptions and sub-study treatments were applied in riparian and upland units based on assigned strategy (Figure 4).

[2] Ethnoforestry involves 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.

[3] GIS data on the environmental conditions of the study area are available at the DNR GIS portal at https://data-wadnr.opendata.arcgis.com.

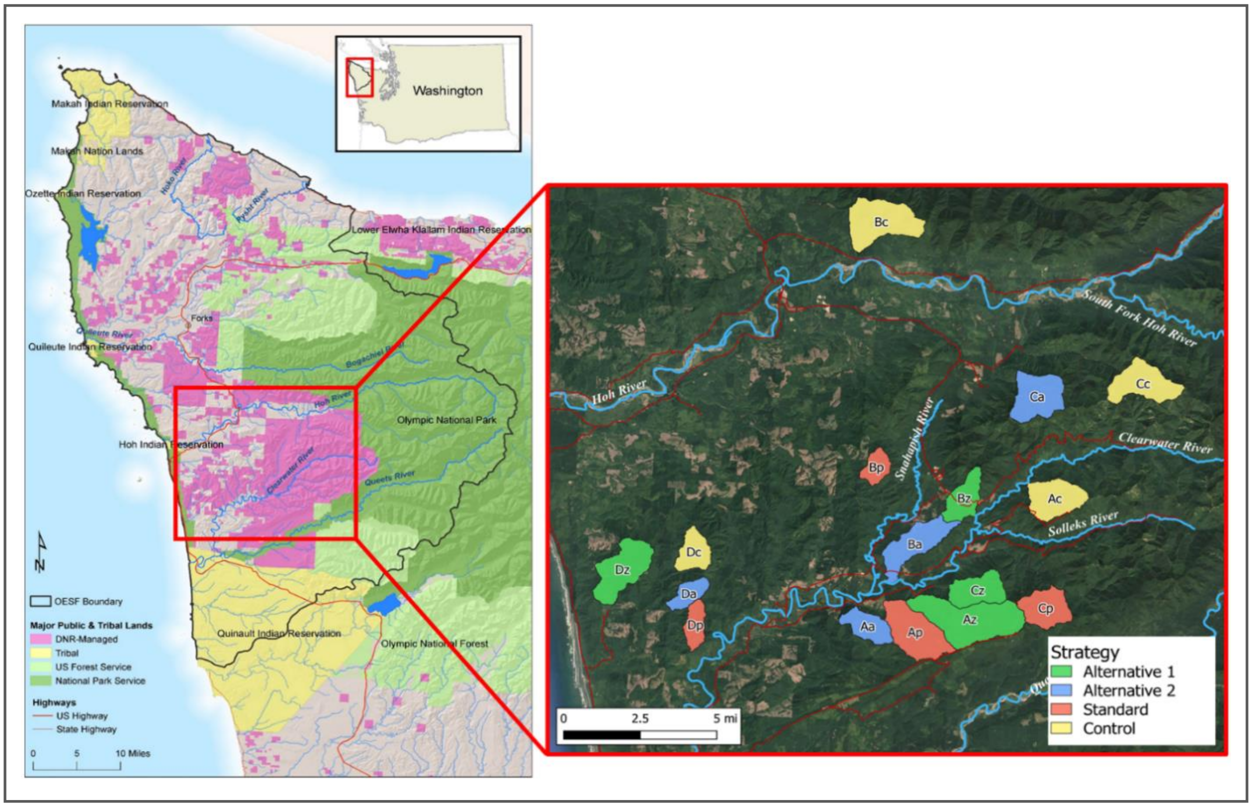


Figure 3. The T3 study area on the western Olympic Peninsula. The 16 experimental watersheds were grouped based on similarity into four blocks (capital letters A, B, C and D) and management strategies were assigned randomly within blocks. Specific prescriptions and sub-study treatments (not shown on this map; refer to Figure 4) are applied in riparian and upland units based on assigned strategy.

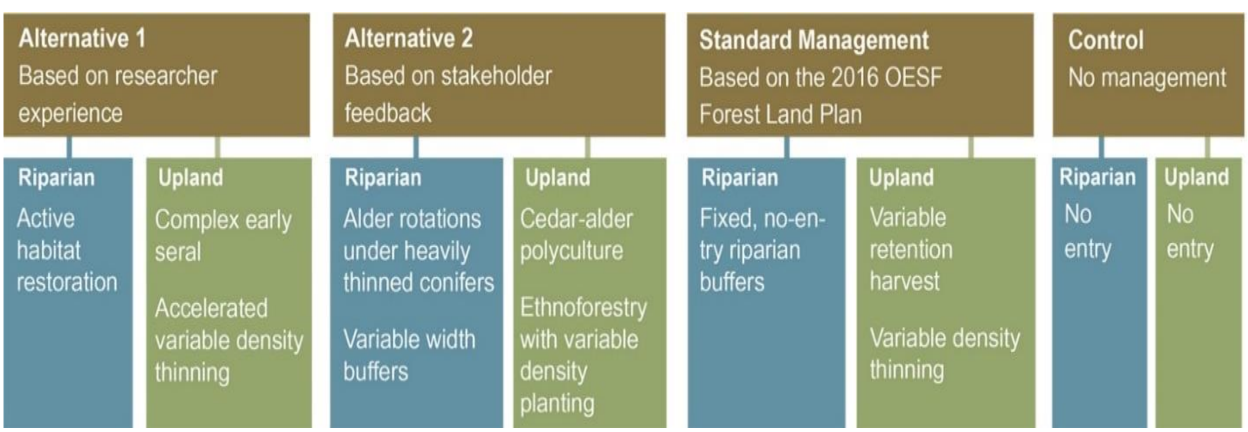


Figure 4. The riparian and upland prescriptions grouped by management strategy. Each strategy is implemented in four watersheds and therefore each prescription is replicated at least four times.

The experimental management prescriptions tested in this study are all tools designed to diversify plant and animal communities and forest stand structures. Increasing heterogeneity across the landscape is a key approach to building forest resilience under a changing climate. The study does not explicitly address climate change through research questions, experimental treatments for adaptation or mitigation, or the potential interference of changing climate with treatment responses. However, because this is a long-term experiment, the outcome of these management tools will be evaluated in the context of climate change. The study monitors climate through a weather station established centrally among the watersheds and numerous temperature loggers located in streams and in riparian forests.

Study Planning

After initial discussions between UW and DNR in 2016, a study concept (Bormann and Minkova 2017) was proposed to DNR managers and stakeholders in 2017 (Table 1). It included study rationale, spatial scales, research approach, and potential experimental watersheds. As the project took shape, it came to be called the T3 Watershed Experiment. To implement this complex enterprise, three study plans were developed: an overview plan, a riparian plan, and an upland plan.

The Overview Study Plan (Bormann et al. 2021) describes the overall context, goals, and philosophy of the T3 Watershed Experiment as well as management strategies. The plan introduces Learning-based Collaboration as a stakeholder engagement strategy.

The T3 Riparian Study Plan (Martens et al. 2021) describes the riparian component of the T3 Watershed Experiment, including riparian prescriptions designed under the four management strategies, and the environmental monitoring approach. The director of the Forest Service Pacific Northwest Research Station coordinated peer review of the plan in 2021.

Table 1. Chronology of study planning activities for the T3 Watershed Experiment.

Activity	Year
Study proposal to DNR	2016-2017
Review of the study proposal by stakeholders	2017
Coordination between DNR and ONRC on experimental management strategies, spatial scales, and the selection of 16 experimental watersheds	2017-2018
Random assignment of the four experimental strategies to the experimental watersheds – official start of the T3 Watershed Experiment	2018
Conceptualizing riparian and upland experimental prescriptions by project researchers in cooperation with DNR Olympic Region staff	2020-2022
Development of the T3 Overview Plan	2020-2021
Development of the T3 Riparian Study Plan; peer reviews	2020-2021
Development of the T3 Upland Study Plan; peer reviews and stakeholder reviews	2020-2022

The T3 Upland Study Plan (Bormann et al. 2022) describes the upland component of the T3 Watershed Experiment, including timber harvest and silvicultural prescriptions designed under the four management strategies, their implementation and analyses, and the modeling and monitoring approach. The dean of the Oregon State University College of Forestry coordinated peer review of the plan in 2022. Prior to peer review, the study was shared for stakeholder review and input.

Additional study plans have been developed for T3 sub-studies such as acoustic monitoring, cedar browse, and harvest productivity. They are described in the section *Affiliated Research* later in this document.

Experimental Prescriptions

A summary of upland and riparian experimental prescriptions follows. A detailed description, rationale, and research questions for each can be found in the T3 Upland and Riparian study plans. Prescriptions that include harvesting are applied through DNR timber sales on approximately 2,100 acres in the study watersheds (10 percent of the total watershed area) (Figure 5; see *Timber Sales and Silviculture* section below). This harvest level was determined by applying the average decadal sustainable harvest level (DNR 2019b) for the OESF (approximately 10 percent of OESF forested land) to the individual experimental watersheds in this study. The four Control watersheds' harvest level anticipated over the next decade was redistributed equally among the other 12 experimental watersheds, resulting in 13.3 percent harvested area per watershed during the initial decade of the study.

UPLAND PRESCRIPTIONS

In the uplands of the T3 watersheds, experimental forest management approaches were developed in support of the goals of the two Alternative Integration strategies. Two experimental prescriptions were developed under each of these strategies. The outcome of these experimental management prescriptions will be evaluated through a series of comparisons that include the conventional VRH and VDT prescriptions of the Standard Strategy.

The Alternative-1 Integration strategy seeks greater integration of current habitat mandates and additional ecological concerns. Its Complex Early Seral prescription addresses the problem of declining early-seral habitat in coastal Pacific Northwest ecosystems, which has resulted from the fact that land managers tend to focus on either efficient timber production or late-seral habitat conditions. As a result, complex early-seral habitat that is structurally and biologically diverse is among the rarest habitat stages in coastal Pacific Northwest forests (Franklin et al. 2018, Phalan et al. 2019, Donato et al. 2020). This prescription examines the possibility of including an early-seral habitat stage at the beginning of a production forestry rotation.

The second Alternative-1 experimental prescription, Accelerated Variable-Density Thinning, aims to accelerate the development of late-seral habitat in second-growth stands. Although thinning of second-growth forests to hasten late-seral habitat development has been tested on public lands in the Northwest during the past three decades (Carey 2003, Harrington 2005), the accelerated approach thins stands to a lower residual density with greater spatial variability. This more aggressive tactic contrasts with some of the more conservative habitat thinning approaches applied in the past (Anderson and Ronnenberg 2013).

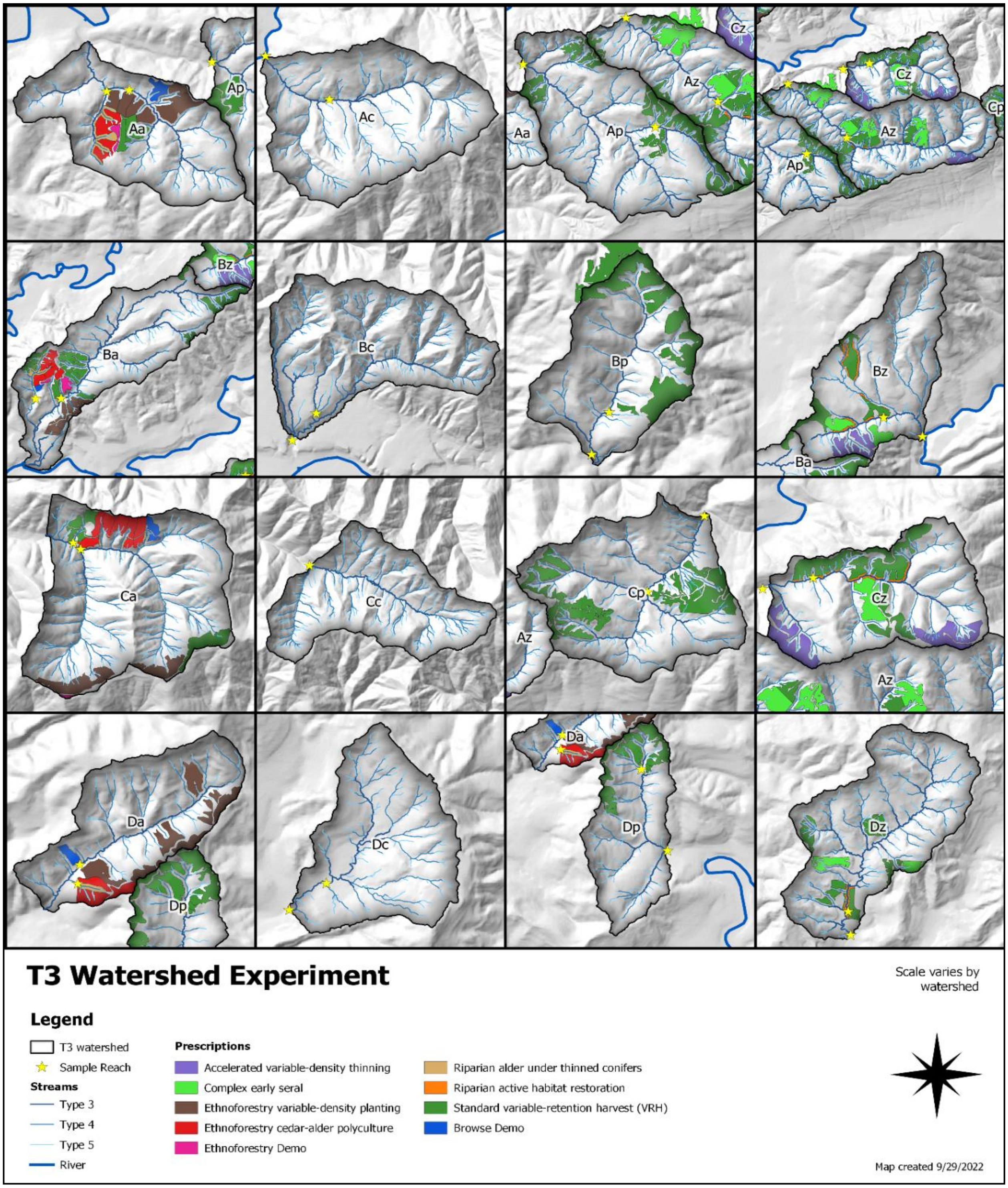


Figure 5. Allocation of study prescriptions across the 16 experimental watersheds. The watersheds in the second column are four replicates of unharvested control. The watersheds in the third column replicate the DNR standard upland and riparian management. The first and last columns are the two alternative management strategies with four replicates each.

The Alternative-2 Integration strategy seeks greater integration of community wellbeing concerns by applying community perspectives and knowledge with social and environmental science developments. The first experimental prescription, Ethnoforestry with Variable-Ratio Polyculture, tests spatially integrated establishment of tree species that have cultural or potential economic benefits: western redcedar and red alder. In the second- and third-growth forests of the coastal Washington, western redcedar is occurs much less frequently today than it once did, due to past reforestation practices. Increasing its presence on the landscape has both cultural importance to local tribes as well as economic benefits (Johnson et al. 2021). Red alder will be established as a hardwood timber species and is also expected to increase soil productivity through nitrogen fixation (Binkley et al. 1992).

The second Alternative-2 Integration strategy is Ethnoforestry with Variable-Density Planting. This prescription seeks to increase early seral habitat (but in a different way than the Complex Early Seral prescription) and to introduce structural heterogeneity in the forest stands. It will test different clumped planting arrangements and the space between clumps will support a variety of early seral native species.

A full list of the upland prescriptions follows:

Control Strategy

No-Action Control (Control). No timber harvest within the Control watersheds for the duration of the study. These watersheds would have been managed by DNR if not designated as controls; thus, no activity is considered an experimental prescription.

Standard Strategy

Standard Variable-Retention Harvest (VRH). This prescription is currently the predominant upland harvest prescription in the OESF and serves as a standard to which experimental upland prescriptions are compared. Its simplest description is a regeneration harvest with retention of 8 trees per acre and other biological legacies such as dead down wood. This prescription includes environmental protections such as riparian management zones and no harvesting on unstable slopes or near wetlands. Planting (mainly Douglas-fir; *Pseudotsuga menziesii* (Mirb.) Franco) and tending of conifers in a 40-to 60-year rotation[4] follows. Timber sale units implementing this prescription are located in the Standard-strategy watersheds and in some Alternative-1 and Alternative-2 watersheds. It is implemented in the Alternative-1 and Alternative-2 watersheds to meet the experimental requirement of a uniform amount of upland harvest across the 12 actively managed watersheds.

Standard Variable-Density Thinning (VDT). This is another standard practice applied on DNR-managed lands since 2006. The current sustainable harvest level for the OESF (DNR 2019b) calls for about 2 percent of the OESF to be harvested using VDT and about 9 percent to be harvested using VRH per decade. Only one harvest unit in the experimental watersheds was of an appropriate stand developmental stage to apply this prescription. Two units in nearby watersheds in which VDT was previously applied will be examined retrospectively.

[4] DNR extends rotations on some stands to better meet northern spotted owl habitat concerns at the landscape scale.

Alternative-1 Integration Strategy

Complex Early Seral (CES). This prescription inserts a complex early seral stage into the beginning of a production forestry rotation by leaving more trees and down wood from the previous stand, avoiding site preparation with herbicides and allowing natural tree regeneration. Relative to EVDP (described below under Alternative 2), this prescription takes a more passive approach by using natural regeneration to extend the duration and quality of the early-seral stage. The goal is to eventually provide a fully stocked stand available for future management options.

Accelerated Variable-Density Thinning (AVDT). To accelerate late-seral habitat development, this prescription modifies standard variable-density thinning by thinning to a lower residual density and increasing spatial variability, leaving larger gaps and skips. After AVDT, the experimental units may be either harvested 20 years later by VRH or added to the designated late-seral-structure pool of stands. This long-rotation prescription will be evaluated for its effects on carbon sequestration and other benefits to the trust.

Alternative-2 Integration Strategy

Ethnoforestry with Variable-Ratio Polyculture ("**Polyculture**"**).** This prescription tests the planting of a species mixture—western redcedar and red alder—at various ratios after a VRH. Stakeholders and tribes raised concerns about the supply of red alder and western redcedar wood for mills and for cultural uses of these species. Additionally, these species have potential ecological benefits: red alder is known to benefit soil productivity, and western redcedar contributes to long-lasting, late-seral forest structure. Planting these species will add spatial heterogeneity to the landscape, which is expected to provide increased resiliency to climate changes and other uncertainties.

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-level and landscape-scale spatial heterogeneity to provide increased resilience against disturbance. To accomplish these objectives, Douglas-fir is planted in a variety of clumped arrangements rather than at a uniform spacing.

RIPARIAN PRESCRIPTIONS

The T3 Watershed Experiment's riparian component serves a dual purpose: to evaluate DNR's existing riparian management practices and to assess three alternative riparian management prescriptions associated with Variable Retention Harvests. In general, riparian forest management is designed to protect both stream and riparian forest habitat for the various species that rely on it. In the Pacific Northwest, where the majority of actively managed forests have a history of riparian harvest, effective riparian management needs to address not only current upland harvesting impacts, but also restore riparian processes disrupted by past management. Since the 1990s, the prevailing approach to riparian restoration in managed forests has been a hands-off, passive approach. However, with improved understanding of riparian processes, alternative approaches are being explored, such as those incorporating active habitat restoration.

Monitoring efforts in the OESF, such as Riparian Status and Trends Monitoring and Riparian Validation Monitoring programs (Martens et al. 2019; Devine et al. 2022; Martens and Devine 2023), along with other studies (McHenry et al. 1998; Warren et al. 2013; McMillian et al. 2022) have revealed concerning signs in small fish-bearing streams in second- and third-growth forests. These streams appear to have diminished fish populations, reduced instream wood, and excessive canopy shading. Reduced instream wood negatively impacts fish habitat (Tschaplinski and Pike 2017), and very high canopy cover has been linked to reduced productivity of streams (Kaylor and Warren 2017). Moreover, under passive management, conditions in these mid-successional riparian forests may not improve for centuries (Martens et al. 2020). The potential decline in physical stream habitat, lower stream productivity (food for salmon), and the long timeline for recovery highlight the need to evaluate current riparian management practices and explore alternative approaches. In response, the riparian component of the T3 Watershed Experiment was developed to compare five prescriptions.

Control Strategy

No-Action Control (Control). No timber harvest within the Control watersheds for the duration of the study. The uplands of these watersheds would have been managed by DNR if not designated as controls; thus, no activity is considered an experimental prescription.

Standard Strategy

Fixed, no-entry riparian stream buffer. The most common riparian management approach currently conducted in the OESF is associated with variable-retention harvests and starts with a fixed-width 100-ft buffer around DNR Type 3 and Type 4 streams (small fish-bearing and non-fish-bearing streams, respectively). The no-harvest buffer is expanded to include wetlands and unstable slopes and landforms. An additional 80-foot buffer is added where there is a high potential for severe endemic windthrow in the riparian buffer.

Alternative-1 Integration Strategy

Active Habitat Restoration. This prescription is designed to address existing stream habitat concerns, such as a low amount of in-stream wood and excessive shading reducing the productivity of aquatic species, primarily salmon. Second-growth riparian forests will be thinned, 0.22-acre gaps will extend from nearby VRH units to the stream, and trees will be felled into the streams to increase in-stream wood.

Alternative-2 Integration Strategy

Variable-width Riparian Buffer. This prescription recognizes that overly simplistic regulations with fixed-width buffers are inefficient and counter to integrating community and environmental wellbeing. This no-entry buffer starts with a default width less than the standard buffer and varies in width along the length of the stream depending on the watershed harvest history, stream habitat conditions, and fish presence.

Alder Rotation under Riparian Wide Thinning. This prescription is applied to 100 percent of the riparian buffer in a designated sub-catchment in each of the four watersheds representing the Alternative 2 strategy. It will grow repeated rotations of red alder between widely spaced large conifers. Red alder is expected to produce revenue and added manufacturing benefits. Riparian benefits of red alder are expected to include faster growth of the large conifers, leading to faster production of large in-stream logs and increased food supply to fish through more soil nutrients, higher-quality litter, and terrestrial insects.

DNR Support

The DNR support for the study was built gradually starting in 2016 when Bernard Bormann (ONRC) and Teodora Minkova (DNR) proposed the idea to DNR managers. The study is based on an initial agreement between ONRC and DNR that the project will provide three kinds of plausible benefits to meet the trust mandate and other DNR commitments: 1) high (but not necessarily maximum) net revenue[5]; 2) science-based learning focused on trust land management issues; and 3) increased public support for management of trust lands.

DNR has committed to 10 years of no action in the control watersheds, which ensures the study duration to at least 2028. The project team plans a thorough 10-year review to assess costs and benefits of the study and potential continuation. Per the researchers' request, DNR randomly assigned management strategies to the 16 selected experimental watersheds (details in the T3 Upland Study Plan). Given the operational scale of the experiment and the need to evaluate the feasibility of planning and implementing the prescriptions, DNR committed to implement the timber sale and silvicultural operations through standard work processes and funding in the agency's Olympic Region. This includes planning and laying out timber sales, timber sale auctions, timber sale compliance and contract administration, silvicultural planning, and implementation of silvicultural activities such as site preparation, tree planting, and regeneration surveys.

DNR staff from the OESF Research and Monitoring Program, including scientists, field technicians, and research coordinators have been committing substantial amounts of time and effort since 2016 to ensure the scientific credibility, operational feasibility, monitoring efficiency, and stakeholder engagement in the study. Similarly, DNR staff from Olympic Region, including foresters, silviculturists, and managers have been heavily involved in the planning and implementation of the research designs, compliance of the forest management activities, and communication with the other project participants. Coordination amongst these programs was necessary to develop the prescriptions and implementation scheduling.

Research Partnerships

The broad scope of the study, spanning biophysical, social, and economic fields, the complex ecological interactions to be tracked in riparian and upland ecosystems, and the operational scale of the treatments require partnerships with a diverse group of researchers and natural resource practitioners. The collaborating institutions include University of Washington, USDA Forest Service Pacific Northwest Research Station, University of Washington, NOAA Fisheries, Oregon State University, Washington State University, Yale University, University of California San Diego, University of Alaska Southeast, and Omfishient Consulting. The principal investigators (PIs) and key partners are listed in Appendix A.

The T3 PIs are responsible for:

- Developing research questions, hypotheses and study designs;

[5] The initial planning of the novel upland prescriptions was constrained only by theoretical consistency with the DNR trust mandate to produce net revenue +/-15 percent of the current sustainable harvest projections (DNR 2019b) and/or by their ability to address broad state lands HCP (DNR 1997) and agency requirements.

- Writing study plans and responding to peer reviews and stakeholder reviews;
- Designing and consulting on monitoring protocols and overseeing data collection;
- Overseeing the implementation of the prescriptions' research components;
- Managing and analyzing research data;
- Reporting and interpreting the study results, communicating the T3 science through conferences, seminars, scientific and popular articles, field tours, and other forms of outreach;
- Attending T3 monthly coordination meetings.

The T3 Watershed Experiment is jointly led by DNR and ONRC. Study leads Teodora Minkova (DNR) and Bernard Bormann (ONRC) are responsible for:

- Defining overall project objectives and intended outcomes;
- Coordinating that various sub-studies align with the project objectives and implementation schedules and do not impede each other;
- Evaluating project performance and advising (and sometimes decide) on changes in project design and implementation schedule;
- Seeking funding and managing the funding from Washington State Legislature, DNR, and UW;
- Overseeing the stakeholder and tribal engagement;
- Advising and coordinating outreach activities (presentations, media materials, etc.)[6];
- Fostering positive and constructive communication between project participants; and Communicating with DNR managers, funding entities, and research collaborators.

Local tribes and stakeholders, including DNR beneficiaries, environmental groups, and local communities, are important partners in this project. Their participation is described in the *Stakeholder Engagement* section.

Ally Kruper, UW

Researchers and DNR staff implementing the T3 Watershed Experiment discuss logging and silviculture experimental treatments in the upland study units during a field tour on November 3, 2023.

[6]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).

Funding

The financial support for T3 monitoring, modeling of treatment effects, research coordination, and stakeholder outreach comes primarily from Washington State Legislature proviso funding to DNR to coordinate with ONRC (Table 2). The Legislature provided additional funding to DNR for the 2023-25 biennium for monitoring and silvicultural activities in the experimental prescriptions. Project funding has come also in the form of research grants to project scientists.

The timber harvest portion of all prescriptions is implemented through the DNR Olympic Region timber sale program, which is funded by DNR management fees. Most silvicultural activities for the prescriptions will be implemented through the DNR Olympic Region silviculture program, which is funded by DNR management fees and supplemented with Washington State Legislature funding.

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. For example, DNR field technicians funded through management fees help with T3 riparian monitoring.

Table 2. Chronology of funding for the T3 Watershed Experiment.

Activity	**Fiscal Year[1]**	**Amount**
Funding from Washington State Legislature for the 2019-2021 biennium provided to DNR to coordinate with the ONRC to implement the study	2019-2021	$374,000
Grant from Earthwach Institute awarded to Teodora Minkova to work with volunteers to implement passive acoustic monitoring	2020-2022	$183,000
McIntire-Stennis grant awarded to UW for the economics sub-study	2021-2023	$219,000
Grants secured by ONRC including the 1) UW Campus Sustainability Fund grant used to implement the ethnoforestry field trials which informed the T3 prescriptions and monitoring; and 2.) the UW EarthLab grant that supported stakeholder and tribal engagement and interviews	2019-2022	$100,000
USDA Forest Service, Pacific Northwest Research Station support to ONRC	2021 2022 2023	$27,000 $20,000 $20,000
Funding from Washington State Legislature for the 2021-2023 biennium provided to DNR to coordinate with ONRC to implement the study	2021-2023	$896,000
Funding from Washington State Legislature for the 2023-2025 biennium provided to DNR to coordinate with ONRC to implement the study; additional funding provided to DNR for OESF research	2023-2025	$625,000 $375,000

[1] The state fiscal year starts on July 1 and ends on June 30 of the following year (e.g., FY 2019 starts on July 1, 2018).

Implementation Status

The implementation of the T3 Watershed Experiment has largely followed the initial study proposal presented to DNR and the upland and riparian study plans (Bormann and Minkova 2017, Bormann et al. 2021, Martens et al. 2021). A timeline of key implementation events is listed in Table 3.

Table 3. Timeline of key events during implementation of the T3 Watershed Experiment.

Activity	Year	Relevant Section in Report
Study proposal to DNR, with review by stakeholders	2016 - 2017	Study Planning
Building research partnerships and start of systematic stakeholder and tribal engagement	2018 - 2020	Research Partnerships Stakeholder and Tribal Engagement
Funding from Washington State Legislature	2019 - 2025	Funding
Conceptualizing riparian and upland experimental prescriptions by project researchers in cooperation with DNR Olympic Region staff	2020 - 2021	Research Design
Study plan development: T3 Overview Plan, the T3 Riparian Study Plan, and the T3 Upland Study Plan	2020 - 2021	Study Planning
Planning, layout, and auction of the 13 T3 Watershed Experiment timber sales by DNR Olympic Region staff	2020 - 2023	Timber Sales and Silviculture
Pre-harvest environmental monitoring of riparian and upland experimental areas	2020 - 2024	Pre-Treatment Monitoring
Learning groups begin to meet regularly, facilitated by DNR	2021 - ongoing	Stakeholder and Tribal Engagement
Negotiations with WA Forest Practices and the Federal Services (USFWS and NOAA) regulating the state lands HCP to approve experimental prescriptions	2021 - 2023	This section[1]
Implementation of treatments by loggers, with compliance monitoring by DNR Olympic Region staff and project personnel	2023 - 2026	Timber Sales
Silvicultural planning by DNR Olympic Region staff to implement all prescriptions	2023 - ongoing	Silviculture

[1] A DNR Memo regarding WA Forest Practices Rules and the variance letter from the Federal Services regarding the state lands HCP requirements are on file with DNR.

Study Plan Modifications

As the study planning and implementation planning process unfolded, the researchers and DNR practitioners and managers reconsidered some research and operational aspects of the T3 Experiment.

The adjustments were made in an iterative fashion to promote agreement among the various components of the study (e.g., aligning the actively managed riparian areas below the upland timber harvest units), to ensure regulatory compliance such as avoiding old growth forest patches and unstable features identified in the field, and/or to meet operational constraints such as road access. Three departures from the initial research design deserve noting:

Constraints of the Marbled Murrelet Long-Term Conservation Strategy

The random allocation of the four management strategies within each of the four blocks of experimental watersheds suffered a disruption in 2019 when, after watershed strategy designations were already made, 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 (DNR 2019a). Although the study never planned to harvest in older forests, this still precluded our ability to apply riparian treatments in that experimental watershed. After exploring different options with the upland PIs, the desire to retain four replicate watersheds won out over the consequences of modifying the original randomization. Strategy assignments for Cz and Ac watersheds were switched, moving the control strategy to (former) Cz (now assigned Ac) and the Alternative-1 strategy to (former) Ac (now assigned Cz). Future analyses have several ways to handle this disruption.

Reduced Harvest in Riparian Management Zones

When the timber sales implementing the experimental riparian prescriptions were laid out on the ground, unstable slopes and landforms, and old growth riparian forest were encountered in a number of areas. Therefore, segments of the experimental riparian prescriptions in these areas were removed from the study, reducing the area receiving those prescriptions. Each instance was reviewed by the riparian study lead, Kyle Martens, to minimize the impact on the study design.

Maintaining balanced replication within the riparian prescriptions of the Alternative-2 watersheds.

Initial sampling revealed that two of the watershed areas (Blocks C and D) dedicated for the *Alder Rotation under Riparian Wide Thinning* prescription had no fish. This indicates a Type-4 (non fish-bearing) rather than Type-3 as envisioned in the study design. If the study followed original implementation plans, that prescription would have only two replicates in Type-3 streams. After an initial discussion among the riparian PIs, it was determined to be better to distribute the Type- 4 watersheds between the two prescriptions. This necessitated switching prescription locations in the Block C watershed, with both Alternative-2 prescriptions being implemented in three Type-3 streams and one Type-4 steam.

Close and timely coordination among practitioners and researchers was key to finding the best solutions while maintaining experiment integrity. The fact that the study research coordinator and some of the project PIs were at DNR was particularly helpful as they had easy access to operational data and to the decision-makers and foresters implementing the prescriptions.

Next Steps

The next steps until the 10-year study evaluation in 2028 are listed in Table 4. The post-harvest monitoring is expected to continue at least until then and may continue long-term depending on DNR management plans and available resources.

Table 4. Next steps for the T3 Watershed Experiment.	
Activity	**Year**
Completion of logging and timber sale compliance	2023-2026
Collecting information on operational feasibility (costs and productivity) of harvest operations	2023-2026
Processing of samples and analyses of pre-harvest environmental data and operational feasibility data	2024-2028
Post-harvest environmental monitoring of riparian and upland experimental areas	2024-2028
Silviculture activities implementing the study (site preparation, planting, regeneration surveys, etc.)	2024-2028
Stakeholder engagement through learning groups, field tours, meetings, etc.	Continuous
Growth and yield and economic analyses to compare model projections to actual outcomes	2024-2028
Management decision support: building decision support tools and quantifying the economic feasibility of the alternative prescriptions.	Starting 2024 or 2025
Comprehensive 10-year review to assess costs and benefits of the study	2028

Timber Sales and Silviculture

The experimental prescriptions in both the upland and riparian portions of the T3 study are implemented by the Olympic Region through their timber sale and silviculture programs. Since 2020, T3 PIs and coordinators from the Forest Resources Division have been working closely with Olympic Region personnel to develop strategies to integrate the T3 experimental prescriptions into the Region's timber sales. Beginning in 2023, T3 PIs have worked with the Olympic Region silviculture program to plan the post-harvest silvicultural activities—primarily planting and control of vegetative competition—that are needed to establish the experimental treatments.

Timber Sales

DNR operates under long-term sustainable harvest targets that specify the volume of timber to be removed from each planning area (e.g., the OESF) in each planning decade. Under the concurrent objectives of meeting DNR's OESF harvest targets while also implementing the T3 Watershed Experiment, the Olympic Region developed a plan to temporarily concentrate the Region's timber sales in and around the study watersheds.

To reflect realistic DNR harvest rates, the cumulative area harvested across the 16 T3 study watersheds during the study was set equal to the OESF-wide rate of harvest. (Among the 16 watersheds, the harvest area was adjusted to account for the fact that no harvest occurred in the control watersheds.) After calculating the area of harvest to occur study-wide, the Olympic Region Planning Forester then evaluated the study area to find merchantable stands that would meet T3 research needs and provide economically viable timber sales. Economic viability is determined by having merchantable timber of sufficient value to attract bids, given anticipated operational costs, especially road construction and the haul distance to the mill. The development of timber sales is also constrained by large-scale planning directives and regulatory constraints that effectively preclude timber harvest on 40 to 50 percent of DNR-managed forestlands west of the Cascade Range.

Ultimately, the Planning Forester determined that the timber harvest needed to implement the T3 Watershed Experiment could be achieved through 13 timber sales. Many of these timber sales included harvest areas within and outside of the experimental watersheds. This was necessary because the experimental watersheds often lacked sufficient merchantable stands in close enough proximity to constitute a sale, without adding harvest units from adjacent non-experimental watersheds.

Timber sales were initially drafted as rough polygons in GIS and then were subject to many revisions over time as Olympic Region foresters and other personnel reviewed the sites in the field, collected GPS data, and made considerations for factors such as unstable slopes and operational limitations. These limitations were particularly common in riparian areas. The steep slopes common near small streams in the OESF are often unstable and thus forest harvest cannot occur on them without specific exemptions. There are also operational challenges to harvesting in riparian areas because these areas are typically farthest from the landings and therefore cable yarding (often required in the study area due to the steep terrain) is complicated and difficult (Figure 6).

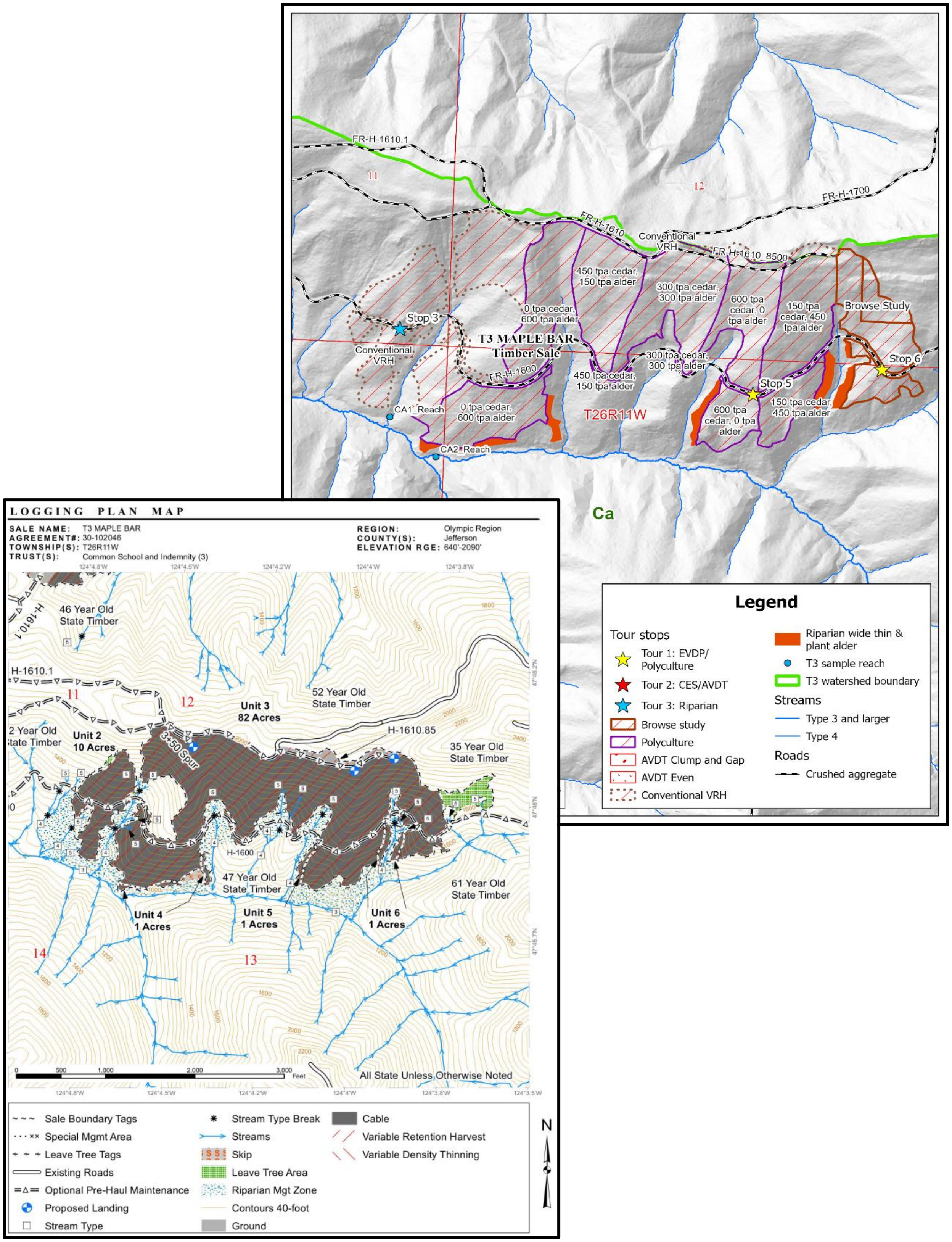


Figure 6. Example of the spatial layout of T3 prescriptions (top) and the timber sale logging map implementing the logging part of the prescriptions (bottom).

Cumulatively, the 13 T3 timber sales included 2,124 acres within the experimental watersheds (Appendix B)—1,934 acres of regeneration harvest and 190 acres of thinning—and approximately 816 acres outside of the experimental watersheds. Total estimated volume of timber in these sales is 74 MMBF (Appendix C). The crosswalk between the timber sales and the T3 prescriptions is in Table 5.

Table 5. Allocation of experimental prescriptions (acres) by timber sale and watershed.

Timber sale	Water-shed	Upland prescriptions (acres)				Riparian prescriptions (acres)		
		AVDT	CES	EVDP	Poly-culture	Variable-width buffer	Active restoration	Wide thinning w/ alder
T3 Snap To It	Bp							
T3 Camp Run	Bz		13.4				15.0	
T3 Backwater	Cp							
T3 Maple Bar	Ca				61.1	Present		3.2
T3 C-1300	Ap, Az						2.0	
T3 C-1200	Aa, Ap			66.3	24.8	Present		5.2
T3 H-1500	Ca			64.7		Present		
T3 C-1400	Az, Cz	85.4	199.5				3.9	
T3 C-2800	Ba	32.0	13.3	42.3		Present		
T3 Upper Manor	Cz						1.0	
T3 Kalaloch East	Da, Dp			52.4	18.2	Present		1.2
T3 Kalaloch West	Dz		34.2				4.3	
T3 Douglas	Ba				35.7	Present		4.1

The foresters' time required to plan, lay out on the ground, and comply the timber sales implementing the experimental prescriptions was expected to be different from the time required for conventional prescriptions. Capturing this implementation cost and the foresters' experiences implementing the experimental prescriptions is important because it would be part of a cost-benefit analysis of the prescriptions as well as part of the discussion of adopting these prescriptions later. This was done through an in-person forum with DNR foresters and T3 researchers on November 30, 2022, in Forks and in a subsequent survey. See the Economics section for more details.

The first of the 13 timber sales was sold at auction on May 25, 2022, and the last was sold at auction on October 25, 2023. Logging began in January 2023 and is ongoing as of the date of this document (Figure 7). The first contract to end (i.e., completion of harvest) is the T3 Maple Bar sale, which ends

September 30, 2024. The last contract to end is the T3 C-1400 sale, which ends July 31, 2026. Timber harvests will continue, likely through the first half of 2026. After the loggers' work is completed in a given sale, the Olympic Region forester assigned to the sale will do final compliance checks to verify that the contract was followed correctly. The next step is to implement silvicultural activities.

Kyle Martens, DNR

Figure 7. A 100-by-100-foot gap created in the riparian canopy, adjacent thinned riparian forest and logjams created in the stream as part of the T3 active habitat restoration prescription. The upland variable retention harvest is visible in the background.

Silviculture

T3 project personnel in the Forest Resources Division coordinate with the Olympic Region silviculturist to ensure that the T3 study areas receive the desired vegetation control treatments where applicable and are planted with the desired seedling stock. The Olympic Region silviculturist orders the tree seedlings from DNR's Webster Nursery and administers contracts for planting, chemical site prep treatments, and other vegetation control treatments. The silviculturist also coordinates regeneration surveys to ensure successful establishment of seedlings. All silvicultural activities (and all other forest management activities that have a spatial component, from timber sales to regeneration surveys) are scheduled using DNR's Land Resource Manager (LRM), which is a data system that includes a GIS component.

The bulk of the T3 silvicultural planning and scheduling began in spring 2023. The first step was to verify that all experimental prescription areas were correctly delineated and labeled in LRM. This required ensuring that prescriptions with multiple treatments, such as EVDP, had each treatment area correctly represented by a polygon in GIS. The second step was to review all of the scheduled site prep and planting activities for all of the individual T3 treatment units in LRM. Forest Resources Division T3 personnel and the Olympic Region silviculturist completed this iterative process by early August 2023. An overview of silvicultural activities is shown for each prescription in Appendix D. (This does not include individual treatment units.)

In August 2023, the Olympic Region silviculturist used this information in LRM to calculate all of the seedling stock needed for planting in early 2026; he then placed the seedling order with DNR's Webster Forest Nursery. Seedling orders must be made 2.5 years prior to when they are to be delivered. Thus, seedlings to be planted in early 2027 will be ordered in August 2024, using the planning data from LRM.

For units that include chemical site preparation as part of their experimental prescription, this is the first silvicultural activity, often occurring in July or August of the first or second growing season following harvest. Timing of application depends on on-the-ground conditions: It is desirable for as much competing vegetation as possible to germinate prior to spraying, as this maximizes treatment efficacy. Planting occurs early in the calendar year following the site prep treatment. After planting, subsequent surveys are conducted to evaluate seedling survival and competition from other vegetation. Post-planting vegetation control is likely to be necessary, and interplanting may be planned if seedling survival is insufficient.

Pre-Treatment Monitoring

Collection of pre-treatment monitoring data in the T3 Watershed Experiment has been ongoing since 2020 (Table 6). This monitoring can be categorized as riparian, upland, remote sensing, and soil mapping and is described in the following subsections. Research staff developed the monitoring protocols, which are available from T3 Data Management Coordinator Warren Devine (DNR) upon request.

Table 6. Chronology of pre-treatment monitoring activities for the T3 Watershed Experiment.

Activity	Year
Pre-harvest environmental monitoring of riparian areas	2020-2023
Pre-harvest environmental monitoring of upland areas	2020-2023
Drone LiDAR flights to record pre-harvest conditions in all T3 experimental units	2021-2023
Development of databases and management system for environmental monitoring information	2022-2023
Soil mapping	2022-ongoing

Upland Prescriptions

COMPLEX EARLY SERAL

A key response variable in the Complex Early Seral experiment is the presence of songbirds that are known early-seral associates or early-seral obligates. To evaluate treatment effects on these species, it is necessary to first document potential pre-treatment presence across the complex-early seral prescription units and across the control harvest units (i.e., conventional VRH and regeneration). In each of these two treatments, 16 permanent monitoring stations were established in 2020 for a total of 32 stations. At each station, pre-treatment songbird presence was sampled through passive acoustic monitoring (PAM). Acoustic recorders were deployed for 10 days at each site during the breeding season (in spring and early summer) of 2020 through 2023.

To understand the effects of the Complex Early Seral prescription on vegetation and to link vegetation impacts to songbird presence, a set of nested habitat plots was established at each of the 32 PAM stations. These plots are used to sample the forest overstory as well as the shrub layer, the understory, and down wood. Pre-treatment data were collected at the 32 plots between 2020 and 2022 with the help of volunteers provided through a grant from Earthwatch.

Because the various harvest units associated with the treated and control prescriptions will be harvested in different years, the post-treatment data will also be collected in different years, beginning in summer 2023. The first post-treatment PAM data were collected in two control sites in the summer 2023 immediately after the harvest of Unit 3 of T3 Snap To It timber sale.

POLYCULTURE

Long-term changes in soil fertility, specifically changes in soil nitrogen, are of interest in the Polyculture study because treatments include planting of red alder. Thus, pre-treatment soil sampling is necessary to measure treatment effects. In July 2022, interns from the University of Washington assisted with T3 research sampled soils (Figure 8). Samples were collected from the two pure species treatments and from the 50:50 mixture in each of the four blocks, for a total of 12 treatment areas sampled. In each of the 12 treatment areas, samples were collected from 10 random locations determined in advance by using GIS. Volumetric soil samples (to determine bulk density) and mineral soil samples were both collected from two depth intervals: 0-20 cm and 20-50 cm.

Teodora Minkova, DNR

Figure 8. University of Washington interns collect soil samples in polyculture experimental units.

Riparian Prescriptions

FIELD SAMPLING

Pre-treatment sampling started in the summer of 2020 and continued through 2023 (Table 7), primarily conducted by DNR technicians under the guidance of Kyle Martens. Sampling took place within two stream reaches in each watershed. With the exception of the Alternative-2 watersheds, these two sampling reaches were typically established at: (1) the most downstream prescription site, and (2) immediately upstream of the watershed's outlet, also called the "pour point" (Figure 9).

Alternative-2 watersheds contain two prescriptions—Heavy Thinning with Alder Underplanting in the most downstream tributary and Variable-Width Buffer on the mainstem stream above the most downstream tributary—and were sampled at the prescription sites only.

Before the 2022 field season, it was determined that the prescription site in Block C designated for the Active Habitat Restoration prescription was not practical for implementing gaps and wood jams due to unstable slopes. Consequently, a new prescription reach site was established less than a kilometer upstream of the previous location.

Initially, most sampling, excluding water temperature, was limited to the summer season. In 2022, seasonal sampling was initiated at the Active Habitat Restoration, Heavy Thinning with Alder Underplanting, and Standard prescriptions sample reaches. Seasonal sampling takes place in the spring (March), late spring (July), summer (September), and fall (November).

Table 7. Sampling for the riparian component of the T3 watershed experiment.

Method	Season	Year			
		2020	2021	2022	2023
Fish Surveys	Summer	X[a]	X[b]	X[c]	X[d]
Stomach Contents	Summer	X	X	X	X
Habitat Unit Surveys	Summer	X[a]	X[b]	X[c]	X[d]
Cross Sectional Surveys	Summer	X[a]	X[b]	X[c]	X[d]
Stream Temperature	Year-round	X	X	X	X
Macroinvertebrates	Summer	X	X[e]		
Light Survey	Summer			X	X
Riparian vegetation[f]	Summer		X		
Leaf litter[g]	Spring, late spring, summer, fall			X	X
Periphyton 1	Summer	X			
Periphyton 2[g]	Spring, late spring, summer, fall				X
Water chemistry 1	Summer		X		
Water chemistry 2[g]	Spring, late spring, summer, fall			X	X
Stream discharge 1	Summer		X		
Stream discharge 2[g]	Spring, late spring, summer, fall				X
Leaf decomposition	Summer			X	X
Gap stream temperature	Summer				X

[a] All sites sampled except C block pour point control site.

[b] All sites sampled except for the B and C block pour point controls sites.

[c] The A block pour point standard and control, B block pour point standard and control, C block pour point active habitat restoration, standard and control, and D block pour point control were not sampled due to unexpected staffing issues.

[d] All sites were sampled except the D block pour point control site.

[e] Only two benthic samples were collected

[f] This sampling was only done on the reach sites

[g] This sampling is restricted to the active habitat restoration, standard, and alder underplanting treatments.

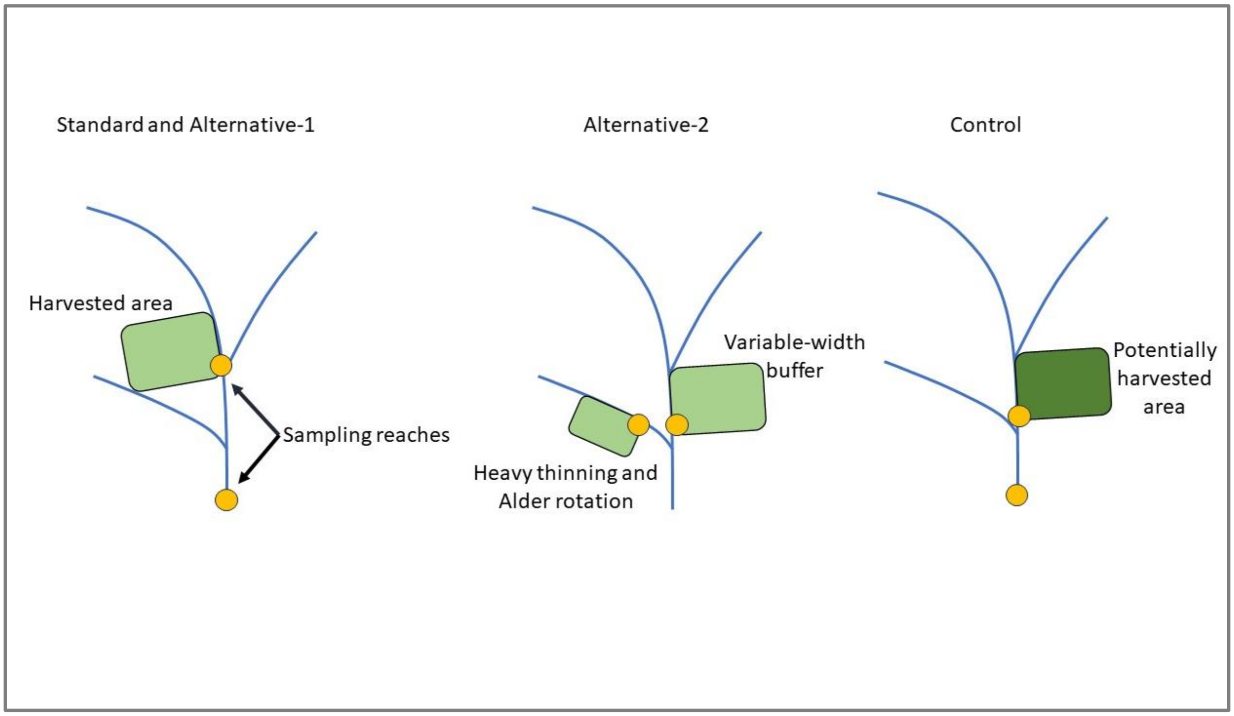


Figure 9. Sampling design for riparian monitoring of the T3 Watershed Experiment. Standard and Alternative-1 watersheds are sampled near the most downstream harvet sites and pour points, Alterntaive-2 watersheds are sampled at the most downstream harvet sites for the two prescriptions (Varible-width buffer and Heavy thinning and Alder rotations), and Control watersheds are sampled at the site of potential harvest locations and pour points.

METHODS

Water temperature loggers were deployed at all sites in 2020 and have been continuously monitored year-round. Annual summer fish surveys used multiple-pass removal population estimates, providing information on species composition, fish density and biomass. Additionally, a selection of 0-5 individual fish per species and age class were preserved for fish diet analyses, led by Dr. Peter Kiffney of NOAA Fisheries.

Habitat Unit, Cross-sectional, Macroinvertebrate, Fine-sediment, and Light surveys were conducted simultaneously with the summer fish surveys. Habitat Unit surveys involved the identification and measurement of habitat units, counts of instream wood within the bankfull width, and the determinization of pool formation. Cross-sectional surveys measured bankfull width, substrate, and canopy coverage. Stream gradient measurements were also included until 2021. Macroinvertebrate sampling, conducted by graduate student Elsa Toskey from Washington State University's Vancouver campus, took place in 2020 and 2021 to assess drift and benthic insect composition and periphyton. The 2020 samples included 5 benthic and 2 drift samples per site, while the 2021 samples included two benthic samples. Fine sediment sampling conducted at three pools measured at the tail of the pool was added in 2021. Water Chemistry and stream flow were also collected during the summer of 2021, but this monitoring switched to seasonal sampling in 2022. In 2022 and 2023 light surveys were conducted at 5-meter increments along the stream reaches.

In 2021, riparian vegetation surveys were conducted at the 20 reach sites on the side of the stream where the experimental prescription was planned. For overstory trees, this survey included identification of species, measurement of diameter at breast height (DBH), and measurement of distance from stream for all living and dead trees on a 10-by-30-meter plot oriented perpendicular to the stream. Five such plots were located, equally spaced, along each sample reach. Additionally, estimates of shrubs and counts of small trees and downed wood were taken along the plot midline.

For the seasonal sampling initiated in 2022 at the 12 reach sites in the Active Habitat Restoration, Heavy Thinning with Alder Underplanting, and Standard prescriptions, sampling included measurements of fallen leaf litter, water chemistry, periphyton, and stream flow. Water chemistry data was collected for Dr. David Butman at the University of Washington.

Other less routine riparian sampling included under-canopy drone surveys that were conducted opportunistically since 2020. This sampling was done to document stream size and instream wood locations. In 2021, 2022, and 2023, leaf litter stream decomposition monitoring that included DECOTAB deterioration, sediment core samples, dead and live leaf collection, and microbial water column sampling was collected at the leaf litter sites for Dr. Sara Jackrel of University of California San Diego. In 2022, the University of Washington contracted with West Fork Environmental (Tumwater, WA) for drone lidar data surveys over most reach locations.

Additional stream loggers were placed along the planned gaps within the Active Habitat Restoration prescriptions in 2023. This deployment included loggers positioned above, below and within the planned gaps. Also in 2023, 10 PAR loggers were installed in the Active Habitat Restoration, Heavy Thinning and Alder Underplanting, and Standard prescriptions (excluding Bp reach and Da1 reach).

Remote Sensing Monitoring

In addition to field sampling, described in the previous sections, the project team is using remote sensing techniques to assess 100 percent of the treated areas of the 16 experimental watersheds pre- and post-harvest. The sampling of entire treatment areas avoids some sources of bias related to the sampling approach with monitoring plots. Researchers can use remote sensing data to address landscape-oriented questions such as the effects of topography and forest edge not possible with ground plots alone. Four types of remote sensing are used in the study: aerial photography, airplane-based LiDAR, drone-based LiDAR, and drone-based photography.

DNR LIDAR DATA AND AERIAL PHOTOGRAPHY

DNR has full aerial LiDAR coverage of the study area and a number of LiDAR derivatives, including a digital elevation model, vegetation height, and modeled streams. DNR's LiDAR data and the major derivative datasets are available online.[7] This LiDAR data was collected by airplane, and because flights are infrequently repeated (e.g., some areas have only been flown once as of 2023), detecting change over time using this method will likely prove challenging.

DNR has digitized aerial photos of the T3 watersheds from the USDA National Agricultural Imagery Program (NAIP). From the past 10 years, T3 watershed coverage is available from 2013 (3-ft resolution), 2015 (1-ft resolution), 2017 (1-ft resolution), 2019/2020 (half flow each year at 1-ft

[7] DNR's GIS Open Data at https://data-wadnr.opendata.arcgis.com

resolution), and 2021/2022 (half flow each year at 6-inch resolution). Many other digitized aerial photos are available online from federal sources. T3 researchers have also scanned and georeferenced aerial photos from 1950 and 1967 covering the T3 study area. DNR has many additional historical aerial photos that have not yet been digitized. The older photos were used to reconstruct the forest harvest history of the study area (Figure 10).

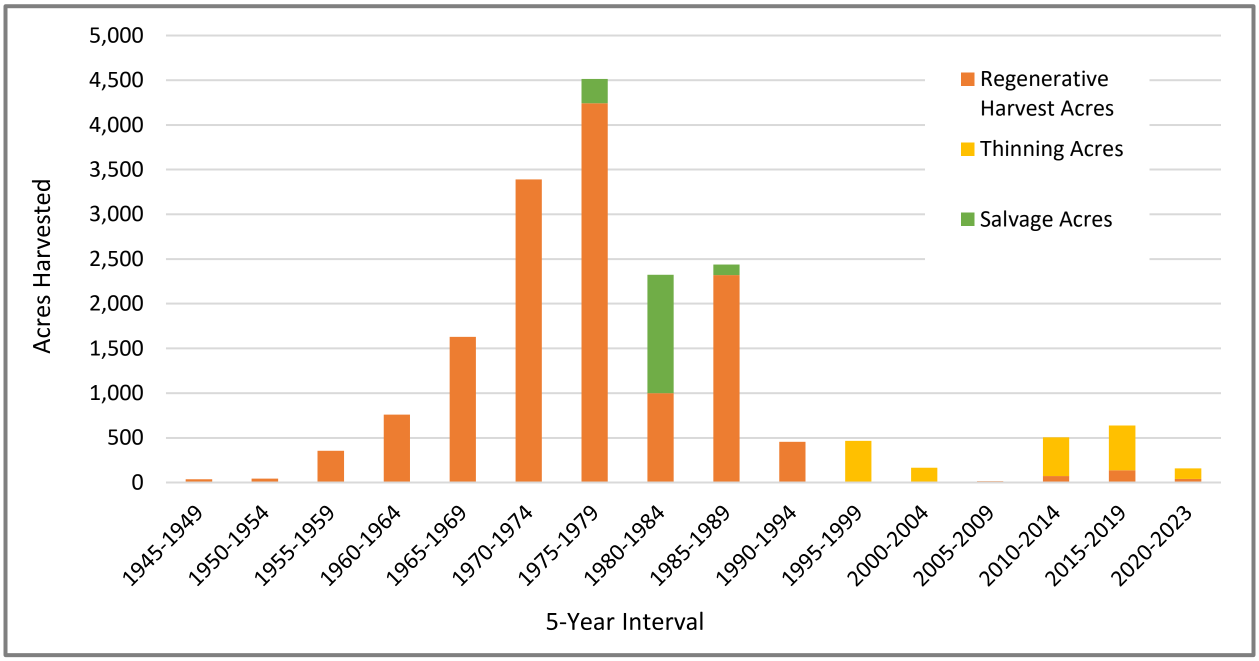


Figure 10. Reconstructed forest harvest history for the 16 T3 experimental watersheds.From: undergraduate capstone project by Karena Iliakis.

DNR has a remote-sensing-based forest inventory system (RS-FRIS) that uses a combination of aerial photo analysis and ground plots to model various attributes of the forest overstory. At present, this data represents conditions in 2019-2020, though an updated dataset will likely be produced in the future.

T3 DRONE LIDAR DATA

This monitoring approach is a private-public partnership between West Fork Environmental Inc. (provides the drones, sensors, and software; flies the T3 study area; and provides the error-checked products), ONRC researchers and students, and USDA Forest Service Pacific Northwest Research Station (Dr. Robert McGaughey). The ONRC and PNW RS contributions include ground-truthing plots and innovative analyses including new locational and interpretive models. Potential metrics derived from the drone LiDAR include species composition (Figure 11), stem density, gap frequency and size, canopy cover, and tree clump characteristics (stem count, DBH/height distribution, and species composition).

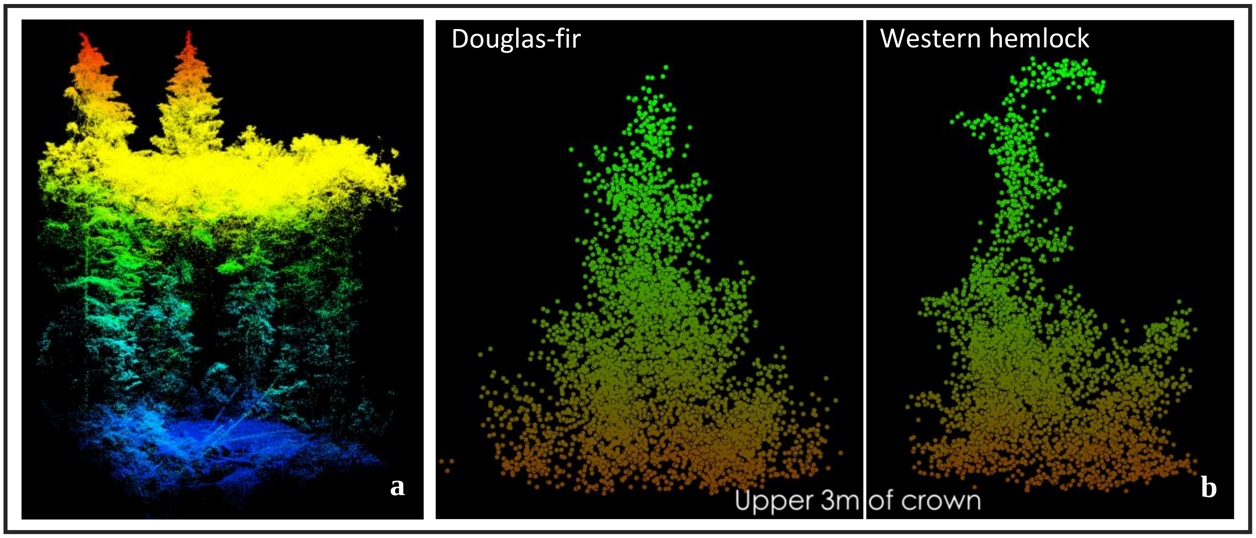


Figure 11. Drone LiDAR point clouds from the T3 study used to characterize the forest structure (a) and to identify tree species based on the crown leader morphology (b). (source: R. McGaughey)

T3 DRONE IMAGERY

Drone-photography approaches are being developed by DNR's Unmanned Aerial Vehicle (UAV) program. Flights has been flown along a portion of the study stream reaches and the riparian team is exploring their utility for riparian measurements and monitoring (Figure 12).

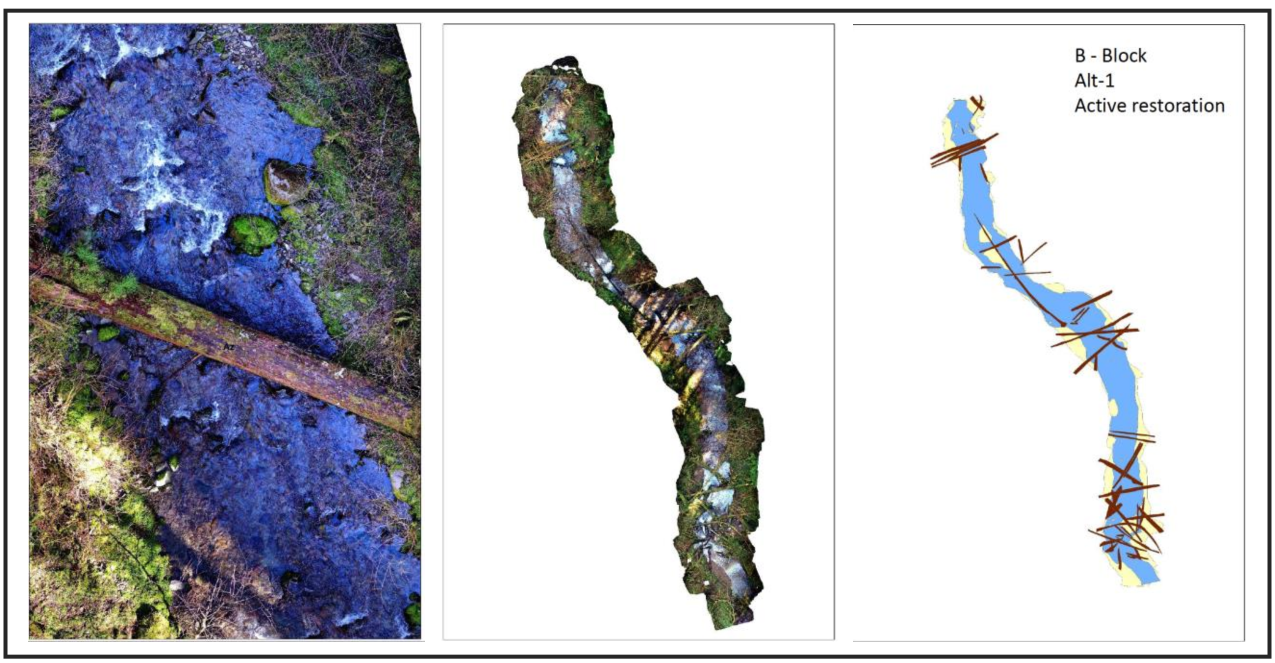


Figure 12. Drone photo image, photo mosaic, and resulting spatially explicit map of a studied T3 stream reach (left to right). (source: K. Martens)

Soil Mapping

The USDA Natural Resources Conservation Service soil series maps published for the western Olympic Peninsula were created at a scale too coarse to be useful for research conducted at the scale of individual timber sale units (i.e., <100 ac). Thus, higher-resolution soil mapping would be very useful for research in T3, as it would allow us to interpret treatment response in the context of local soil conditions.

In November 2022, T3 PIs began discussions with Jerome Barner, a soil scientist from Olympic National Forest, on potential collaboration to map soils in the T3 watersheds at a higher resolution (i.e., a target of approximately 1-acre resolution). The areas prioritized for mapping are approximately 780 acres that contain the timber sale units designated for T3 experimentation. In February 2023, Barner began field work, which he projected would take six to seven weeks. Because this collaborative work for T3 is a lower priority than his primary work obligations for the Forest Service, the mapping field work is expected to extend into the 2024 calendar year.

Reports and Publications

Riparian

The 2021 T3 Watershed Experiment Riparian Study Plan contains the most in-depth information on the riparian portion of the T3 Watershed Experiment. Annual summaries of DNR activities and data from this experiment can be found in the Riparian Validation Monitoring Annual Reports. Furthermore, publications focusing on instream wood and pool formation, and fish composition have incorporated data from the T3 Watershed Experiment. Additionally, two publications addressing periphyton and macroinvertebrates are currently in progress.

STUDY PLAN

Martens, K.D., Bormann, B.T., Minkova, T.V., Olson, D.H., Bollens, S.M., Butman, D., Kiffney, P.M., Alexander, K. and Liermann, M. 2021. Riparian Study Plan for the T3 Watershed Experiment. Washington Department of Natural Resources, Forest Resources Division, Olympia WA. https://live-onrc.pantheonsite.io/wp-content/uploads/2022/11/Riparian-Study-Plan-final.pdf

REPORTS

Martens, K.D. 2022. Riparian Validation Monitoring Program (RVMP) 2020 Annual Report. Washington State Department of Natural Resources, Forest Resources Division, Olympia, WA. https://www.dnr.wa.gov/sites/default/files/publications/lm_oesf_rvmp_2020_ar.pdf

Martens, K.D. 2022. Riparian Validation Monitoring Program (RVMP) 2021 Annual Report. Washington State Department of Natural Resources, Forest Resources Division, Olympia, WA. Available at: https://www.dnr.wa.gov/sites/default/files/publications/lm_oesf_rmvp_2021_ar.pdf

Martens, K.D. 2023. Riparian Validation Monitoring Program (RVMP) 2022 Annual Report. Washington State Department of Natural Resources, Forest Resources Division, Olympia, WA. https://www.dnr.wa.gov/sites/default/files/publications/lm_oesf_rmvp_2022_ar.pdf

Whitney, E. J., J. Ryan Bellmore, J. R. Benjamin. 2023. Modeling Stream Food Web Response to Riparian Treatments in the Olympic Experimental Forest: Summary Report (Revised). https://www.dnr.wa.gov/publications/lm_oesf_food_web_st.pdf

JOURNAL PUBLICATIONS

Martens, K.D., Dunham J. 2021. Evaluating Coexistence of Fish Species with Coastal Cutthroat Trout in Low Order Streams of Western Oregon and Washington, USA. Fishes, 6(1):4. https://doi.org/10.3390/fishes6010004

Martens, K.D., Devine, W.D. 2023. Pool Formation and the Role of Instream Wood in Small Streams in Predominantly Second-growth Forests. Environmental Management 71, 1011–1023. https://doi.org/10.1007/s00267-022-01771-z

Toskey, E., Bollens, S., Rollwagen-Bollens, G., Kiffney, P., Martens, K., Bormann, B. (*In Prep*) Stream algal biomass associations with environmental variables in a temperate rainforest.

Toskey, E.K., Bollens, S.M., Kiffney, P.M., Martens, K.D., Rollwagen-Bollens G. (*In Prep*) The relative importance of abiotic, biotic, and spatial factors in structuring the stream macroinvertebrate metacommunity in a temperate rainforest.

Upland

The 2022 T3 Watershed Experiment Upland Silviculture Study Plan contains the most in-depth information on the upland portion of the T3 Watershed Experiment. Additional study plans for affiliated studies were developed and scientific publications on stakeholder engagement and remote sensing were published or are in progress.

STUDY PLAN

Bormann, B.T., T. V. Minkova, C. Bobsin, W.D. Devine, D. C. Donato, R. Slesak, G. Ettl, K. Alexander, D. Churchill. 2022. The T3 Watershed Experiment Upland Silviculture Study Plan. Washington Department of Natural Resources, Forest Resources Division, Olympia WA. Available at: https://www.dnr.wa.gov/sites/default/files/publications/lm_oesf_t3_upland_pln.pdf

STUDY PLANS FOR AFFILIATED STUDIES

Minkova, T., L. Kuehne, and D. Donato. 2020. Using Passive Acoustic Monitoring to evaluate sustainability of forest management. Study Plan. Washington State Department of Natural Resources, Forest Resources Division, Olympia, WA. 39 p. http://www.dnr.wa.gov/publications/lm_oesf_pac_sp.pdf

Chung, W. 2022. Assessing Implementation Costs of Alternative Forest Management Treatments in the Olympic Experimental State Forest (OESF). Draft Study Plan. Oregon State University, College of Forestry, Corvalis, OR, 22p. https://live-onrc.pantheonsite.io/wp-content/uploads/2022/11/T3-Operations-Study-Plan-1.pdf

Rose Cornwell. 2023. Regenerating Western Redcedar Under Ungulate Browsing Pressure in the Olympic Peninsula: An Ethnoforestry Approach https://live-onrc.pantheonsite.io/wp-content/uploads/2023/01/Cornwell_Capstone.pdf

REPORTS

Comnick, J., L. Rogers. 2022. Growth and Yield Simulations for the Type 3 Watershed Experiment on the Olympic Experimental State Forest. Draft Report. (The final report, which will include calibrated projections, is expected in February 2024.)

JOURNAL PUBLICATIONS

Kruper, A., R. J. McGaughey, S. Crumrine, B.T. Bormann, K. Bennett, C.R. Bobsin. 2022. Using airborne LiDAR to map red alder in the Sappho long-term ecosystem productivity study. Remote Sensing. Vol. 14, no. 7: 1591. https://doi.org/10.3390/rs14071591

Bobsin, C. R., B.T. Bormann, M. L Miller, B. D. Pelach. 2023. Perspectives: Ethnoforestry, ecosystem wellbeing, and collaborative learning in the Pacific Northwest. Forest Ecology and Management, Vol. 529, 120738. https://doi.org/10.1016/j.foreco.2022.120738

Bobsin, C.R., M.L. Miller, B.T. Bormann, B.D. Pelach, T.V. Minkova, A. Kruper. (*In review*). Learning groups in natural resource management: collaboration on the Olympic Peninsula.

McGaughey, R., A. Kruper, C.R. Bobsin, B.T. Bormann. (*In review*). Tree species classification based on upper crown morphology captured by UAS lidar data.

Stakeholder and Tribal Engagement

Active engagement of stakeholders and local tribes has been a tenet of the T3 Watershed Experiment since its inception. Stakeholders include local rural community members, trust beneficiaries, environmental organizations, forest industry representatives, and other local land managers. In addition, western Olympic Peninsula tribes, including the Makah Tribe, Quileute Tribe, Hoh Indian Tribe, and Quinault Indian Nation have been engaged through this process and are important project partners as well.

The purpose of engaging stakeholders and tribes is to: 1) collaboratively define community and environmental wellbeing; it is important to hear from the communities who will be most affected by this research and its outcomes; 2) bring in different and diverse perspectives, knowledge, and experiences to enrich the research; 3) build trust and broad support for implementing and funding the study; and 4) use learning-based collaboration to build adaptive capacity for future management adjustments. A secondary purpose was to collectively develop new engagement models that may prove useful in other DNR regions and for other collaborative groups.

Levels of Engagement

Stakeholders and tribes are engaged in this experiment in several ways and all participants can choose their involvement level. A large group of stakeholders and tribes who are interested in the T3 Watershed Experiment project are kept informed through biannual update emails, project updates on DNR and ONRC websites, and in the joint OESF-ONRC newsletter, presentations, and publications in media and scientific journals.

A subset of this group is more actively engaged in the project through input for and review of project documents, participation in field tours, and interviews.

In addition, small groups of highly interested individuals actively collaborate with project researchers and DNR staff through a process called learning-based collaboration (LBC; Figure 13). LBC is an iterative process in which natural resource managers and practitioners, biophysical and social science researchers, stakeholders, and tribes engage with one another to address management questions and options. This allows participants to learn from the outcome of the work and the learning process itself. LBC ensures the study meets the needs of local people and uses collaborators' input to inform the study plans and implementation.

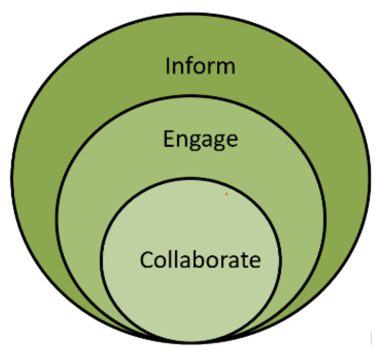


Figure 13. Levels of stakeholder engagement in theT3 Watershed Experiment

The LBC activities and outcomes to date include:

- Semi-structured interviews about community needs conducted by ONRC researcher Courtney Bobsin: Key themes emerged around the changes and reduction in abundance of particular plant species (with beargrass and western redcedar being a common response) and a decline in the population of ungulates over the last several decades, with a lack of appropriate forage material cited as a contributing factor.

- Numerous engagement meetings hosted by DNR and ONRC where the principal investigators presented the novel treatments (two conferences, online sessions focused on individual prescriptions, numerous one-on-one or small group meetings) to gain additional insight: provided opportunities for anyone to listen, comment, or offer feedback.
- Two field tours (in 2021 and 2022) that brought together nearly 40 people representing researchers, managers, tribes, forest industry, business development, environmental groups, and engaged community members, increased the understanding and interest in the project, and brought in new collaborators (Figure 14).
- Creation of 8 Learning Groups (LGs) in early 2022, which brought together people of different backgrounds and interests to address specific portions of the study.

Teodora Minkova, DNR

Figure 14. Stakeholders visiting the T3 study area to discuss planned experimental prescriptions during a 2022 field tour to the study area.

Learning Groups

Learning groups (LGs) are a specific application of the LBC, wherein T3 researchers, forest practitioners and managers, stakeholders, and tribes collaborate around a particular topic and shared goals while learning together (e.g., Reed et al. 2010). As the T3 study plans were finalized, involved stakeholders and tribes expressed interest in continued participation around focused topics, such as cedar or invasive species. The T3 project leads harnessed this interest and enthusiasm by creating LGs to continue collaboration, work toward study goals, and learn together.

The study leads developed a learning group framework in 2021 with the goal to learn together and to continue to inform T3 research questions, implementation, and monitoring effort into the future. The framework allowed groups to set their own goals and develop projects that aligned with those of the T3 Watershed Experiment. Anyone interested is welcome to participate in any group. The LGs were initiated at the 2022 Annual OESF Science Conference. Eight LGs were formed, covering an array of topics, including 1) cedar; 2) invasive species; 3) aquatic responses to riparian forest treatments; 4) carbon considerations; 5) economics and harvest operations; 6) tribal interests; 7) remote sensing; and 8) history of local land management.

Group membership and attendance ranges between LGs, but most have between five and 15 people. Groups typically meet for two-hour online meetings anywhere from two to six times per year. All groups have a DNR facilitator, Tracy Petroske. Refer to Appendix E for more details.

Several factors of success emerged during the first year of the LG existence:

- **Connection to an existing operational-scale experiment**: This allowed support from T3 project leads, access to DNR resource inventory and operational data, and proposed a variety of scientific questions and management uncertainties for the groups to address.
- **Recruiting key participants**: Including several subject matter experts from various organizations whose professional experience aligns with group goals has brought important perspectives that ultimately have made those LGs successful.
- **An enthusiastic leader:** This role is pivotal, providing energy to keep a group moving forward with tangible and realistic plans. In some cases, this leader was a capstone or master's student with time and interest to compel work on a pre-determined timeline.
- **A hired LG facilitator**: This is important to create an environment where everyone's voices are heard, ideas are synthesized, learning is scaffolded to include group members new to the topic as well as subject matter experts. In partnership with the "enthusiastic leader," the facilitator also generally operates as a project manager so groups efficiently move forward with their ideas. Having the same person facilitate all LGs enabled cross-pollination of ideas.

Two main challenges were identified with the LGs so far: 1) the LGs require consistent effort to sustain and 2) the non-linear learning process which occurs in the LGs require time and patience.

Some specific LG activities worth noting include:

- The **Cedar LG** developed a study plan to experimentally test various methods for deterring browse of cedar by elk and deer. This substudy will be implemented as part of the T3 Watershed Experiment with logging and silvicultural activities included in DNR operational plans. It has subsequently grown to consider cedar more broadly, including new research on using remote sensing to find and evaluate cedar trees.

- The **Carbon LG** worked with a diverse collaborative team of UW researchers and nonprofit organizations to submit a grant to the National Science Foundation to develop and evaluate a veteran-oriented workforce model exploring the regenerative, ecological-human wellbeing concept. This project proposes preparing field trials to reduce wildland fuel loads, co-planting alder with cedar, developing options for making biochar from harvest residue to restore fire-degraded soils. In addition, the Carbon LG is working with UW and Peninsula College to develop special topics courses in which LG members act as subject matter experts and students provide a workforce to address a narrowly defined topic.
- The **Invasive Species LG** has been exploring the efficacy of using remote sensing to map the spread of Scotch broom on disturbed landscapes of the Olympic Peninsula. In addition, group members are assisting with efforts to change legislation around biochar kilns, which are unfortunately grouped with other methods of burning harvest residuals that create air quality issues.
- The **History LG**'s primary goal is to collect and organize historical data of disturbances and treatments/practices in the 16 T3 plots. The information on past land use will help to understand the current (baseline; pre-harvest) ecological conditions in the T3 study area and to interpret environmental responses to the experimental manipulations that will occur in these watersheds.

We believe this form of collaboration, although time-consuming, is promising as an effective tool to build trust and buy-in for current and future land management work.

Outreach and Education

The outreach efforts for the T3 Watershed Experiment partially overlap with the stakeholder engagement described in the previous section and with the outreach efforts of the OESF Research and Monitoring Program, which include projects and activities beyond the T3 study. A considerable amount of time and effort was devoted to T3 project outreach to develop awareness about the project's purpose and its scientific contributions and management implications, to gather support and funding, and to bring in collaborators.

The main categories of T3 outreach since 2016 include:

- The OESF and ONRC websites that host the project documents;
- The *Learning Forest* newsletter with feature articles on the study and project updates;
- Presentations, posters and discussions at the OESF annual science conference in 2019-23;
- Articles in local newspapers, magazines, and newsletters;
- Presentations at seminars, conferences, and meetings;
- Scientific publications in peer-reviewed journals on ecological and social aspects of the study.

Citizen science through volunteers, which took place on the acoustic monitoring sub-study in the 16 experimental watersheds in 2021 and 2022, proved to be a powerful communication and outreach tool. For a week, 55 volunteers from across the U.S. surveyed bird habitat and gained a deep understanding of ecological forestry practiced on Washington's state-managed lands. Many of them later shared the experience in their communities through presentations and school lessons (Figure 15).

The T3 study has provided education and research opportunities for graduate and undergraduate students, and this will likely increase given the variety of research topics and implementation activities, the opportunities for hands-on experience in environmental monitoring, and the large well-documented datasets. The list of students working on the project and their research is listed in Tables 8 and 9.

Summer interns from UW, OSU, and other education institutions help with fieldwork while gaining valuable experience and deeper understanding of ecology and

Teodora Minkova, DNR

Figure 15. Volunteers, provided through research grant from Earthwatch, stayed in Forks for a week and helped collect bird habitat data.

Figure 16. Interns from the Doris Duke Conservation Program collect forest habitat data.

natural resource management (Figure 16). These students and interns are the future workforce of natural resource management.

The education value of the T3 study for the DNR staff has also been recognized by agency managers. It has been most impactful for the Olympic Region staff who have collaborated with the study researchers to design, model, and implement the experimental treatments. During the process, they have learned about the rationale behind the research, the ecological relationships, and uncertainties around ecosystems' responses. Undoubtedly, the education went both ways, with the T3 researchers learning about economics and operations. Other forms of DNR staff education have included attending the annual OESF science conferences (and earning Society of American Foresters credits), attending T3 presentations, and joining field tours.

Table 8. Student research completed as part of T3 Watershed Experiment.

Student name	Project type	Project title	Date completed	T3 advisor
		University of Washington		
Roxana Rautu	M.S. thesis	Linking Seasonal and Spatial Stream Carbon Dynamics to Landscape Characteristics in Selected Watersheds on the Olympic Peninsula.	May 2019	David Butman
Therese Kaitis	Undergrad Capstone	The Sound of Science: Acoustic Monitoring and Occupancy Modeling of Songbirds in the Olympic Experimental State Forest.	April 2021	Teodora Minkova, Lauren Kuehne
Levi Casto	Undergrad Capstone	Songbirds as Indicator Species on the Olympic Peninsula: Alternative Selection Criteria.	April 2021	Teodora Minkova, Lauren Kuehne
Ally Kruper	Undergrad Capstone	Using LiDAR to identify red alder in the Sappho long-term ecosystem productivity experiment.	June 2021	Bernard Bormann, Bob McGaughey

Table 8, continued				
Student name	**Project type**	**Project title**	**Date completed**	**T3 advisor**
Xiaoyu Shawree Zhang	Undergrad Capstone	Habitat predictors of bird occupancy in managed forests in the Pacific Northwest Coastal Region.	June 2022	Teodora Minkova
Sarah Crumrine	Undergrad Capstone	Accuracy of RS-FRIS in the Sappho long-term ecosystem productivity experiment.	March 2022	Bernard Bormann, Bob McGaughey
Will Browne	Undergrad Capstone	Conifer species identification in high-density drone LiDAR.	June 2022	Bernard Bormann, Bob McGaughey, Courtney Bobsin
Karena Iliakis	Undergrad Capstone	A history of heavy harvesting: logging through the decades in the T3 experimental watersheds.	April 2023	Warren Devine, Teodora Minkova
Emily Anderson	Undergrad Capstone	Determination of optimal and suitable habitat criteria for coho salmon on the Olympic Peninsula.	April 2023	Kyle Martens, Warren Devine
Courtney Bobsin	Ph.D. thesis	Ethnoforestry and adaptive management: generating new pathways to manage forests on the Olympic Peninsula.	May 2023	Bernard Bormann
Jaren Hutchings	Undergrad Capstone	Comparing LiDAR techniques for use in identifying red alder in the Sappho long-term ecosystem productivity study.	June 2023	Bernard Bormann, Bob McGaughey, Courtney Bobsin
Kyle Yasui	Undergrad Capstone	Using a LiDAR-based model to predict basal area increment.	June 2023	Bernard Bormann, Bob McGaughey, Courtney Bobsin
Washington State University				
Elsa Toskey	M.S. thesis	The relative importance of abiotic, biotic, and spatial factors in structuring the stream macroinvertebrate metacommunity in a temperate rainforest.	July 2023	Stephen Bollens, Peter Kiffney

Table 9. Ongoing student research in the T3 Watershed Experiment.

Student name	Project type	Project title	Estimated completion	T3 advisor
		University of Washington		
Mathew Schmidt	M.S. thesis	Online calculator to examine cashflow consequences of T3 treatments and Swiss Needlecast	2024	Sandor Toth
Ally Kruper	M.S. thesis	Western redcedar on the Olympic Peninsula: Locating this culturally and economically important species using remote sensing and collaboration methodologies	2024	Bernard Bormann
Gio Jacuzzi	M.S. thesis	Applying machine learning methods to explore relationships between avian species, habitat and landscape structure created through management	2025	Teodora Minkova
Josh Kim	Undergrad Capstone	Using drone LiDAR to evaluate edge effects in the long-term ecosystem productivity study on the Olympic Peninsula, WA	2024	Bernard Bormann, Bob McGaughey, Courtney Bobsin
Anna Thario	Undergrad Capstone	Effects of windthrow on forest growth and regeneration	2024	Bernard Bormann, Bob McGaughey, Courtney Bobsin
Paisley Blume	Undergrad Capstone	Scotch broom mitigation: testing new approaches to reduce the spread and growth on the Olympic Peninsula, WA.	2024	Bernard Bormann, Courtney Bobsin

Ecological Modeling

Ecological modeling is a simplified mathematical representation of complex ecosystems. It helps to account for interactions, feedback loops, and dependencies between ecosystem components and is therefore important to understanding and managing ecosystems (Geary et al 2020).

Two ecological modeling projects were completed for the T3 Watershed Experiment: forest growth and yield in upland prescriptions and aquatic trophic productivity in streams. The main goals of these models were 1) to produce quantitative projections of the post-treatment environmental conditions, which can be used to generate testable hypotheses about the treatment responses in short- and long-term; and 2) to identify key uncertainties in the projections and the main factors influencing these uncertainties. The T3 researchers intend to use the models to evaluate empirical data of the actual outcomes as documented through monitoring.

Forest Growth and Yield

The development of forest stands after experimental treatments was modeled by UW Precision Forestry Cooperative modeler Jeffery Comnick, mainly using Forest Vegetation Simulator (FVS; Dixon 2002). This model is currently used by DNR, with its Pacific Northwest variant (Keyser 2008), but refinement is required for the novel T3 prescriptions. A modeling framework was developed for FVS to account for the spatial arrangement of trees by adjusting growth based on solar radiation. The model projections span 80 years and allow to compare the novel prescriptions with the DNR standard ones. The projected tree volume will be used to calculate the net present value of the forest stands at the end of the rotation.

The draft report was submitted in June 2022 and is available from Teodora Minkova upon request. The final report is expected in February 2024. It will include calibrations using DNR regeneration survey data and data from the Silvicultural Options Study implemented on the Capitol State Forest located near Olympia beginning in 1998. The small-tree growth will be modeled with CIPSANON. Additional DNR calibrations will be included to align volume estimates with prior modeling effort.

Aquatic Trophic Productivity

The Aquatic Trophic Productivity model is 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, Whitney et al 2019). Specifically, the model tracks the biomass of periphyton, leaf litter, aquatic invertebrates, and juvenile fish (Figure 17). Model parameters for the T3 study included stream shading, water temperature, nutrients (nitrogen and phosphorus), riparian vegetation composition, substrate size, and stream discharge.

Modeler Emily Whitney (University of Alaska Southeast) convened a workshop with T3 researchers to identify the model parameters and hypothesize how a typical T3 stream reach would be expected to change in response to the riparian treatments. The results of the treatment simulations were presented as a percent change in the average annual biomass of fish, macroinvertebrates and periphyton over a 50-year period after treatments.

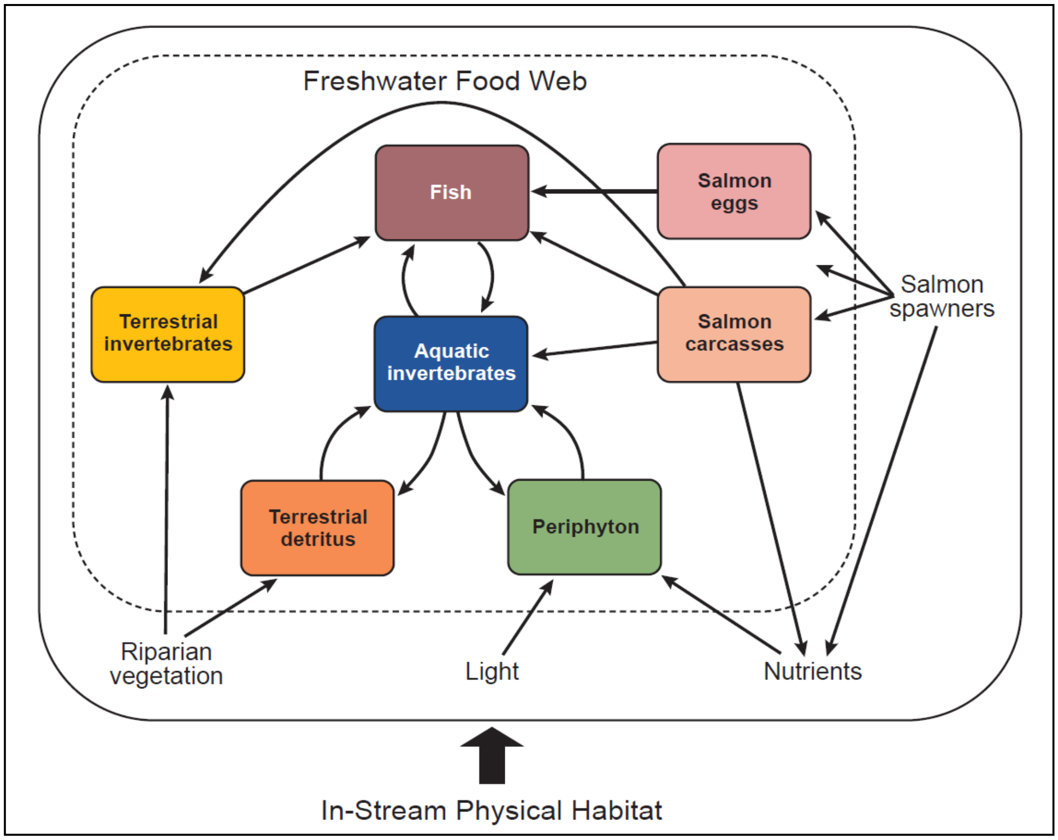


Figure 17. Conceptual diagram of the Aquatic Trophic Productivity model. (Source: Whitney et al. 2019)

The final report is available at https://www.dnr.wa.gov/publications/lm_oesf_food_web_st.pdf

Economic Research

The financial implications of the experimental prescriptions are a key part of the study, given the DNR trust mandate and the need to inform the application of the study findings for future management improvements. The economics of each of the experimental prescriptions will be evaluated relative to conventional prescriptions. Three sub-studies were envisioned in the T3 upland study plan which will flow into each other: 1) implementation costs, 2) projected net present value, and 3) management decision support. The implementation of these sub-studies has been challenging due to a lack of experts in the region who have the available capacity to take on this research.

Implementation Costs

The initial idea of comparing the timber sale auction results (Appendix B) to assess how the novel prescription affected the bids was abandoned because many factors, such as fluctuating market prices, road conditions, distance to the mill, the combination of prescriptions within each timber sale, and purchasers' workload, affect the bids. This makes it difficult to parse out the effect of a given experimental prescription on a bid.

The implementation costs of T3 timber sale planning, layout, and office administration was assessed using DNR staff time. Beyond the necessary training, the time required for novel prescriptions is expected to be different from the time required for conventional prescriptions. Special administrative accounts were set up by DNR to directly record foresters' time, but this tracking proved difficult. Instead, the project staff used an indirect approach to assess potential changes in workload when implementing novel prescriptions. This qualitative approach consisted of an in-person forum conducted in November 2022 and a subsequent survey of eight foresters. Results are summarized in Table 10. The implementation cost report is available from DNR (Warren Devine) by request.

A similar approach will be used for comparative assessments of the costs for timber sale compliance and regeneration surveys. Costs per acre for silvicultural activities such as site preparation, seedlings, planting, control of competing vegetation, and pre-commercial thinning in the experimental prescriptions will be acquired from the Olympic Region.

Harvest productivity, though not a direct cost to DNR, was identified as an important indicator because the type of prescription may influence harvest productivity, which in turn may influence bids for timber auctions containing these prescriptions. The most accurate way to assess differences in productivity is a time study of the logging operations. The data from such a study can be used to identify operational variables that significantly influence operational efficiency and to estimate future implementation costs of prescriptions under various work conditions. A study plan was developed by Dr. Woodam Chung of Oregon State University and a pilot project was conducted in the summer of 2022. It was not implemented because of the combination of the high cost to support a master's student and the logistical challenges to time the student's availability with the logging operations. Instead, qualitative survey methods will be used gather information from the loggers and purchasers.

Table 10. Results from forester survey comparing time spent implementing novel T3 prescriptions with time spent on standard prescriptions.

	Prescription comparison	Phase	Standard prescription: estimated fraction of time spent by phase	Novel T3 prescriptions: difference in time required relative to standard prescription (%) — Difference in time by phase	Novel T3 prescriptions: difference in time required relative to standard prescription (%) — Total difference in time
Upland	CES (vs. VRH)	Planning	0.03	+42%	+61%
		Field Layout	0.69	+71%	
		Admin.	0.28	+37%	
	Polyculture (vs. VRH)	Planning	0.03	+15%	-2%
		Field Layout	0.69	-6%	
		Admin.	0.28	+4%	
	EVDP (vs. VRH)	Planning	0.03	0%	+2%
		Field Layout	0.69	0%	
		Admin.	0.28	+8%	
	AVDT (vs. VDT)	Planning	0.05	+6%	+20%
		Field Layout	0.54	+25%	
		Admin.	0.41	+14%	
Riparian	Rip. Active Restoration (vs. standard buffer)	Planning	0.03	+23%	+60%
		Field Layout	0.69	+61%	
		Admin.	0.28	+61%	
	Rip. Heavy Thinning (i.e., Rip. alder) (vs. standard buffer)	Planning	0.03	+13%	+31%
		Field Layout	0.69	+40%	
		Admin.	0.28	+13%	
	Rip. Variable-Width Buffer (vs. standard buffer)	Planning	0.03	+6%	+3%
		Field Layout	0.69	+4%	
		Admin.	0.28	0%	

Projected Net Present Value

As data on the outcome of the experimental prescriptions are not yet available, economic analyses at this stage must rely on projected outcomes of the prescriptions. The Forest Vegetation Simulator (FVS; Dixon 2002) model was used to project growth and yield for the experimental prescriptions. Future revenues will subsequently be projected based on these yield projections and combined with estimated costs of all silvicultural activities to occur during the rotation. These revenues and costs will then be used to project net present value (NPV) for each prescription.

These economic projections will be used as quantitative hypotheses. The goal is to compare the economics of the experimental prescriptions to DNR's conventional prescriptions under a series of scenarios based on various economic and growth assumptions. The actual costs and revenues will be documented by the study, and—when these deviate from the projections—may be used to re-project lifespan NPV at milestones in the future. This sub-study is led by Dr. Sandor Toth at the University of Washington.

In 2023, a University of Washington master's student developed a tool and accompanying web application to simulate cash flows from forest management activities and to assess the financial trade-offs of the novel T3 prescriptions. The cashflow simulator was presented at a workshop in December 2023 and is available online.

Management Decision Support

Once the NPV ranges for each T3 prescription are projected, a suite of research forest estate model[8] runs might be able to capture potential impacts of the prescriptions if widely applied. 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 to implement them, are made by DNR managers based on a range of management objectives, planning commitments, and regulatory constraints, as well as individual judgement. The study's goal is to provide them with the information and tools to make better informed decisions. This sub-study is led by Dr. Sandor Toth at the University of Washington and will likely not start until 2024 or 2025.

[8] 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 Inc. The model is called Woodstock.

Embedded Studies and Additional Research

A number of studies with stand-alone study plans, and sometimes separate funding and research staff, are affiliated with the T3 Watershed Experiment. These affiliations most often include overlap in the study area and therefore require an exchange of monitoring and operational data. These studies benefit the T3 Watershed Experiment by providing in-depth analyses of certain ecological relationships, such as decomposition of leaf litter, and scientific expertise on specific topics, such as the use of acoustic indices to characterize bird communities.

Using Passive Acoustic Monitoring to Evaluate the Sustainability of Forest Management

The study goal is to evaluate the responses of birds to habitat changes resulting from forest management. The project is organized as a citizen science project, with support from Earthwatch. Principal investigator is Teodora Minkova (DNR) with cooperators from Omfishient Consulting and the University of Washington. The funding is provided by DNR and a grant from Earthwatch. Start date: 2020; study plan developed in 2020 (Minkova et al. 2020); ongoing.

Regenerating Western Redcedar under Ungulate Browsing Pressure in the Olympic Peninsula: An Ethnoforestry Approach

The study goal is to test different silvicultural treatments designed to prevent ungulate browsing and produce replicable, economically feasible results for regeneration at an operational scale. The study plan was developed as a master's capstone by a UW student. Collaborators are UW, DNR, and the members of the T3 Cedar Learning Group. The group has written grants to support the implementation of this work. UW students will assist with the monitoring once the study is underway. Start date: 2021; study plan developed in 2022; ongoing.

Ethnoforestry Trial in La Push

The study goal of this 5-acre study is to determine how to extend the early-seral stage to include understory species that are beneficial to communities and wildlife, while also producing a timber crop. Understory species are planted in varying densities to learn how to actively manage the understory. Plants were selected based on interviews with local community members and tribes. In addition, three wildlife treatments were implemented to better understand how planted species would be used by local wildlife, especially ungulates. Information gained from this pilot study was used to inform the T3 Experiment, especially the EVDP prescription. The ethnoforestry field trials study design as completed in 2020, planting of tree seedlings and understory was completed in Spring 2021, and monitoring of natural regenerating understory, planted understory, and seedlings has occurred in 2021-23. The project is ongoing.

Analyses of Drone LiDAR Data

Drone-based LiDAR appears to provide individual-tree data about all but the most suppressed trees with more than an order of magnitude more returns relative to aerial LiDAR. Connecting returns to individual trees provides many of the traditional growth and yield data needed to evaluate study prescriptions. This includes differentiating among conifer species, which has eluded researchers heretofore. In addition, drone-based individual tree data provides information not possible with ground plots, including more detailed crown characteristics and accurate tree heights, especially on slopes. Further linking to multispectral information has even greater potential for species differentiation and tree health. Far better LiDAR data on understory, downed logs, and fine-scale microsite differences are likely with further study and modeling. Implemented by PNW RS in partnership with ONRC and WestFork Environmental.

Leaf Litter Decomposition in Streams

Leaf litter decomposition is a critical ecological process in the small, shaded streams within the temperate rainforests of the Pacific Northwest because it fuels higher trophic levels, including juvenile salmonids. Research indicates that the successional stage and species composition of the riparian forest affect the decomposition rate. The study goal is to understand the potential impact of land management on leaf litter decomposition. Terrestrial plant phytochemistry and microbial decomposer community composition and function are studied. Field sampling for this project is carried out by DNR staff under the guidance of Dr. Sara Jackrel of the University of California San Diego. The project started in 2021 and is ongoing.

Data Management

Given the long-term nature of the T3 Study and the multiple participating organizations, it is critical to archive and document the diverse T3 datasets and monitoring protocols in a central location so that they can be preserved and easily accessed for research now and in the future.

Data Storage and Quality Control

DNR is responsible for storing all environmental monitoring data and project implementation information. The T3 Data Manager for all datasets managed by DNR is Warren Devine.

ONRC is responsible for managing remote sensing data (e.g., drone LiDAR), economic data (e.g., economic calculations of treatments), and social science data (e.g., interviews). The T3 Data Manager for all datasets managed by ONRC is Courtney Bobsin.

Databases were built in Microsoft Access for all pre- and post-treatment environmental monitoring data and associated metadata including field and laboratory protocols (Table 11). Data management procedures including quality control and archival data storage were developed. For large datasets, data processing workflows were developed using R programing language (R Core Team 2020). Each dataset was assigned a data steward.

Data Ownership and Data Sharing

All T3 data are jointly owned by DNR, ONRC, and the T3 Watershed Experiment's key collaborators. Each user of the T3 study data is required to sign a data sharing agreement (Appendix F). In all publications and presentations that use T3 data, the funding source should be acknowledged, including acknowledging DNR as land manager. For example: "Funding for this research was provided in part by the State of Washington. Research was conducted at the Olympic Experimental State Forest managed by Washington State Department of Natural Resources."

All information and data that is shared with DNR and other state agencies is subject to public disclosure, under the Washington Public Records Act (RCW 42.56). Exemptions to this disclosure policy are made for certain types of information including: personal information of employees, locations of threatened or endangered species, and information on locations of tribal and other sites that have cultural significance.

Table 11. List of T3 databases.

Database name	Datasets within database	Data years	Data steward
	Riparian		
Fish diet	Fish stomach contents	2020-2022	Peter Kiffney
Instream	Fish population and biomass	2020-2023	Kyle Martens
	Stream discharge	2021	Kyle Martens
	Fine sediment in pools	2021-2022	Kyle Martens
	Samples collected (FISH, LIVELEAF, DECOTAB, MICROBIO)	2020-2023	Kyle Martens
	Cross-section (substrate, BFW, gradient)	2020-2023	Kyle Martens
	Habitat surveys (includes in-stream wood)	2020-2023	Kyle Martens
	Above-stream light measurements (PAR)	2022-2023	Warren Devine
	Stream canopy closure (hemi photos)	2020-2023	Warren Devine
	eDNA	2020-2021	Kyle Martens
Vegetation	Riparian vegetation	2021-2022	Warren Devine
Temperature	Water and air temperature	2020-2023	Warren Devine
Temperature_AR	Water temperature in active restoration	2023	Warren Devine
Invertebrates	Macroinvertebrates	2020-2021	Kyle Martens
	Stream flow	2021	Kyle Martens
	Periphyton and seston	2021	Kyle Martens
	Fine sediment	2021-2022	Kyle Martens
Leaf litter	Leaf litter	2021-2023	Sara Jackrel
Water chemistry	Water chemistry	2021-2023	Kyle Martens/ David Butman
	Uplands		
Amphibians	Amphibian survey data	2023	Donald Brown
ONRC Vegetation	Vegetation plot data collected by ONRC[1]	2021-2022	Courtney Bobsin
Polyculture	Pre-treatment polyculture soil samples	2022	Rob Slesak
Drone LiDAR data	Drone LiDAR data	2021-2023	Courtney Bobsin
Passive acoustic monitoring[2]	Habitat data	2020-2023	Lauren Kuehne
	Acoustic monitoring recordings	2020-2023	Lauren Kuehne

[1] DNR stores a copy of this database, but ONRC manages the project, including all data collection.

[2] These databases include pre-treatment data for the Complex Early Seral prescription. The most current versions of these databases are stored and maintained by Lauren Kuehne. DNR keeps an archived copy of the habitat database and the acoustic recordings.

Lessons Learned So Far

The novel prescriptions in the T3 Watershed Experiment are alternatives to conventional operations with largely unknown consequences. They can be perceived as having higher risk to revenue and the environment. Several factors helped alleviate and manage this risk: availability of recent scientific information, use of predictive tools such as ecological modeling, and commitment from T3 researchers to monitor and evaluate the outcomes and adjust the treatments in order to keep the forest stands in production, mitigate potential environmental impacts, and/or incorporate new research questions.

The successes and challenges listed below summarize the experience of the T3 project staff (T3 researchers and DNR practitioners and managers). Some are specific to the study area (e.g. steep terrain, remote rural area) or the land manager (DNR manages the state trust lands for multiple objectives) and their transferability to other projects should be considered with caution. Other lessons learned, such as project management, can be considered universal.

Greatest Successes

- ✓ Broad support from stakeholders during the planning and implementation phase of the study
- ✓ Strong stakeholder and tribal engagement through involvement of people with diverse backgrounds and expertise in the T3 Learning Groups
- ✓ Securing funding from Washington State Legislature for three biennia in a row and securing ongoing funding for the T3 Experiment provided to DNR
- ✓ Buy-in from DNR managers to implement the experimental prescriptions at operational scale and recognition of the project's learning value
- ✓ Meaningful integration of the research and land management operations in the OESF through involvement of DNR practitioners and managers in all phases of the study and implementing the experimental prescriptions through DNR timber sale and silviculture programs
- ✓ Building a large collaborative team of researchers and subject matter experts who were closely involved in the study planning, implementation and monitoring activities
- ✓ Navigating DNR implementation procedures, and state and federal regulations, to allow the implementation of the experimental prescriptions
- ✓ All 13 timber sales implementing the experimental prescriptions were laid out, approved, and sold with a median overbid of 45 percent
- ✓ Coordinating the timing of the environmental monitoring activities with timber harvest timelines
- ✓ Finding efficient and cost-effective methods to monitor multiple environmental indicators over a large area, including the use of drone LiDAR, bioacoustics, and various aquatic sensors.
- ✓ Proven education value for undergraduate and graduate students and DNR staff

Main Challenges

The large spatial scale, the multitude of experimental treatments and the operational nature of this management experiment presented enormous planning and implementation challenges. They are summarized below in four categories: project management, research design, environmental constraints, and regulatory constraints.

Project Management

- Implementing a large-scale research project when the process for implementation was unclear, the funding was not secured, and the buy-in from all of the needed participants (DNR managers, DNR practitioners, and research partners) was not fully established. This was particularly challenging in the first years of the project.
- Negotiating with DNR managers the acceptable level of risk to revenue for the trust beneficiaries from implementing the experimental prescriptions.
- Changes in DNR leadership slowed implementation and required more effort connecting to the full suite of decision-makers and stakeholders.
- Scheduling 13 timber sales and post-harvest silvicultural activities so that all experimental prescriptions are implemented at approximately the same time; this synchronization is important for reducing the amount of environmental noise in the scientific data.
- DNR contracts with timber purchasers did not require the purchasers to log any particular experimental unit. This resulted in losing at least one 3-acre stream-adjacent unit.
- Ensuring the research designs are properly incorporated in the timber sales' layout and contract, and the logging operations implement the prescriptions as envisioned. This required enormous communication effort with DNR foresters and timber sale purchasers and loggers.
- Maintaining the engagement of research partners after the initial development of study plans and monitoring activities.

Research Design

- Finding 16 watersheds with enough harvestable area for the multiple operational-scale riparian and upland prescriptions.
- Combining multiple upland and riparian prescriptions within the same watersheds created conflicts in the spatial allocation and risked confounding effects. This was partially controlled by implementing same type of upland treatment and percent harvested watershed in the uplands.
- Finding available researchers with expertise in operations research and economics and coordinating operations research with logging activities.
- Establishing monitoring sites prior to finalizing the timber harvest units required close coordination with foresters to ensure manipulated areas include the monitoring sites. In some cases, this was not possible and pre-treatment monitoring data were lost.

Ecological Constraints

- The 16 experimental watersheds were selected without consideration of where in the watersheds the harvestable areas were located, limiting the amount of stream-adjacent harvests.

- The prevalence of young second-growth forests and the difficult access to forest stands made it challenging to find stands within the study watersheds that were both merchantable and in locations that met research requirements.
- Due to the steep terrain, the prevalence of potentially unstable slopes made it difficult to allocate and implement riparian experimental prescriptions. These features also interfered with acoustic monitoring areas, which are supposed to cover only one type of habitat. With the exclusion of unstable slopes from the harvest areas during the timber sale layout , some monitoring areas included unharvested forest patches.

Regulatory Constraints

- Navigating the Washington Forest Practices Application process when the existing rules or the existing crosswalk with the state lands HCP did not include adequate exceptions for the T3 experimentation.
- The Marbled Murrelet Long-Term Conservation Strategy (DNR 2019a), adopted during the planning phase of the study, designated new protected areas which required switching of the randomly assigned strategies in 2 watersheds. It also necessitated obtaining variance from the Federal Services to enter buffers of marbled murrelet protected sites.

The biggest challenge and, at the same time, the biggest success of the T3 Watershed Experiment has been building understanding, acceptance, and trust across vastly different culture and knowledge domains: land managers, researchers, regulators, foresters, beneficiaries, environmental groups, and the local community. Overcoming this challenge has been more successful than anticipated, largely due to the time and effort invested by the project staff. It will continue to be work in progress and a focus of the study. The keen attention to communication and stakeholder engagement distinguishes the T3 study from many other management experiments. Multiple landscape experiments have identified the inadequate communication and stakeholder support as impediment to study implementation or long-term sustainability (Peterson and Anderson, 2009).

By integrating ecological, economic, and social objectives for forest management and by bringing together researchers, land managers and practitioners, stakeholders, and tribes, this study is aiming to meet community needs, and build collective trust and goodwill to explore innovative management solutions and adopt management adjustments.

We see the increasing value of this project as demonstration of our collective ability to envision bold forest management strategies, implement complex novel prescriptions, learn together, and engage meaningfully with stakeholders. This is a much-needed example for building adaptive capacity in a fast-changing world.


Teodora Minkova, DNR

DNR Olympic Region Manager Bill Wells and DNR scientist Daniel Donato discuss the implementation of the T3 Watershed Experiment.

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Appendix A. Principal Investigators and Contributors

Principal Investigator	Institution	Role in the T3 study
Bernard Bormann	UW Olympic Natural Resources Center	Research, UW Study Lead
Teodora Minkova	DNR Olympic Experimental State Forest	Research, DNR Study Lead
Bill Wells	DNR Olympic Region	Manager, DNR Study Lead
Courtney Bobsin	UW Olympic Natural Resources Center	Upland research, Sub-Study Lead
Kyle Martens	DNR Olympic Experimental State Forest	Aquatic Research, Monitoring, Sub-Study Lead
Warren Devine	DNR Olympic Experimental State Forest	Research, Monitoring, Data management, Sub-Study Lead
Gregory Ettl	UW School of Environmental and Forest Sciences	Silviculture research, Sub-Study Lead
Robert Slesak	USFS Pacific Northwest Research Station	Silviculture research, Sub-Study Lead
Daniel Donato	DNR Forest Resources Division	Upland research, Sub-Study Lead
Andrew Bluhm	Oregon State University College of Forestry	Silviculture research, Sub-Study Lead
Sandor Toth	UW School of Environmental and Forest Sciences	Economics research, Sub-Study Lead
Derek Churchill	DNR Forest Health Division	Silviculture research, Sub-Study Lead
Kevin Alexander	DNR Olympic Region	Implementation, Sub-Study Lead
Marc Miller	UW School of Marine and Environ. Affairs	Social research, UW Study Lead
David Butmann	UW School of Environmental and Forest Sciences	Riparian research and monitoring
Peter Kiffney	NOAA Fisheries	Riparian research and monitoring
Bob McGaughey	USFS Pacific Northwest Research Station	Research, remote sensing
Stephen Bollens	Washington State University	Riparian monitoring
Florian Deisenhofer	DNR Forest Resources Division	Silviculture research, Sub-Study Lead

Key Contributor	Institution	Role in the T3 study
Drew Rosenbalm	DNR Olympic Region	DNR administration
Mike Potter	DNR Olympic Region	Timber sales implementation
Mona Griswold	DNR Olympic Region	DNR administration
Emily Gardner	DNR Olympic Region	Research coordination
Allen Estep	DNR Forest Resources Division	DNR administration
Tracy Petroske	DNR Forest Resources Division	Learning groups facilitation
Calvin Ohlson-Kiehn	DNR Forest Resources Division	Silviculture application
Woodam Chung	Oregon State University College of Forestry	Research, harvest operations
Martin Liermann	National Oceanic Atmospheric Administration	Statistical advice
Ryan Bellmore	USFS Pacific Northwest Research Station	Aquatic food web modeling
Emily Whitney	University of Alaska Southeast	Aquatic food web modeling
Matt Perry	DNR Olympic Region	Silviculture implementation
Alex Foster	USFS Pacific Northwest Research Station	Riparian monitoring
Jeff Comnick	UW Precision Forestry Coop	Forest growth modeling
Lauren Kuehne	Omfishient Consulting	Bioacoustic research; data mgmt
Angie Thompson	Environmental Issues Ltd	Outreach and facilitation
John Gordon	Yale University	Research, silviculture
Bryan Pelach	UW School of Environmental and Forest Sciences	Research, social science
Phil Peterson	Westfork Environmental	Drone LiDAR development

Appendix B. Timber Sale Auction Results

Sale name	Volume (MBF)	Min. bid ($)	Winning bid ($)	Winning price / MBF ($)	% over min.	No. of bids	Winning bidder
T3 SNAP TO IT	11,481	2,754,000	3,746,163	326	36%	2	Interfor
T3 CAMP RUN	4,325	1,034,000	1,359,781	314	32%	3	Sierra Pacific
T3 BACKWATER	5,465	1,242,000	1,455,159	266	17%	1	Harbor Timber
T3 MAPLE BAR	7,333	1,514,000	1,678,579	229	11%	2	Willis Enterprises
T3 C-1300	6,684	934,000	2,217,859	332	137%	2	Harbor Timber
T3 C-1200	4,243	444,000	1,238,345	292	179%	3	Sierra Pacific
T3 H-1500	6,160	630,000	631,036	102	0%	1	Alta Forest Products
T3 C-1400	10,847	1,010,000	1,025,000	95	1%	1	Sierra Pacific
T3 C-2800	3,132	339,000	526,651	168	55%	3	Interfor
T3 UPPER MANOR	3,533	543,000	787,855	223	45%	2	Harbor Timber
T3 KALALOCH EAST	4,670	40,000	490,547	105	1126%	3	Alta Forest Products
T3 KALALOCH WEST	2,758	42,000	83,598	30	99%	1	Harbor Timber
T3 DOUGLAS	3,482	222,000	675,886	194	204%	3	Interfor

Appendix C. Timber Sale Timeline

Sale name	Sale date	Contract end date	Total area to be harvested within T3 watersheds (ac)	Total area of experimental prescriptions (ac)
T3 SNAP TO IT	5/25/2022	9/30/2024	103	0
T3 CAMP RUN	6/15/2022	10/31/2024	88	28
T3 BACKWATER	7/27/2022	10/31/2024	174	0
T3 MAPLE BAR	8/24/2022	9/30/2024	95	74
T3 C-1300	10/26/2022	10/31/2024	266	2
T3 C-1200	11/16/2022	10/31/2024	166	104
T3 H-1500	2/22/2023	10/31/2024	94	65
T3 C-1400	3/29/2023	7/31/2026	503	289
T3 C-2800	3/29/2023	10/31/2025	137	88
T3 UPPER MANOR	4/26/2023	10/31/2025	94	1
T3 KALALOCH EAST	6/14/2023	10/31/2025	146	77
T3 KALALOCH WEST	6/14/2023	10/31/2025	127	39
T3 DOUGLAS	10/25/2023	10/31/2025	131	49
Total			2,124	816

Appendix D. Silviculture Timeline by Prescription

EVDP

Watershed	Timber sale and units	2023		2024				2025				2026				2027			
		Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Aa	C-1200 Units 1, 4	Aug. deadline to order 2026 seedlings					TS contract ends 10/31					Plant			Regen survey				
Ba	C-2800 Unit 1	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				
Ca	H-1500 Units 1, 2	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				
Da	Kalaloch East Units 1, 3 & 4	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				

Polyculture

Watershed	Timber sale and units	2023		2024				2025				2026				2027			
		Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Aa	C-1200 Unit 1	Aug. deadline to order 2026 seedlings					TS contract ends 10/31			Site prep		Plant			Regen survey				
Ba	Douglas Unit 2					Aug. deadline to order 2027 seedlings					TS contract ends 10/31			Site prep		Plant			Regen survey
Ca	Maple Bar Unit 3	Aug. deadline to order 2026 seedlings					TS contract ends 10/31			Site prep		Plant			Regen survey				
Da	Kalaloch East Unit 4	Aug. deadline to order 2026 seedlings								Site prep	TS contract ends 10/31	Plant			Regen survey				

AVDT

Watershed	Timber sale and units	2023		2024				2025				2026				2027			
		Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Az, Cz	C-1400 Units 6, 8					Aug. deadline to order 2027 seedlings								TS contract ends 7/31		Plant			Regen survey
Bz	C-2800 Units 6, 7	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				

Riparian Heavy Thin with Alder Planting

Watershed	Timber sale and units	2023		2024				2025				2026				2027			
		Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Aa	C-1200 Unit 2						TS contract ends 10/31	Plant			Regen survey								
Ba	Douglas Unit 3	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				
Ca	Maple Bar Units 4, 5, and 6	Aug. deadline to order 2026 seedlings					TS contract ends 10/31					Plant			Regen survey				
Da	Kalaloch East Unit 6	Aug. deadline to order 2026 seedlings									TS contract ends 10/31	Plant			Regen survey				

Complex Early Seral

Watershed	Timber sale and units	2023		2024				2025				2026				2027			
		Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Bz	Camp Run Unit 6						TS contract ends 10/31	[Natural regen]							Regen survey				
Az, Cz	C-1400 Units 1, 3, 4, 5 & 7													TS contract ends 7/31	[Natural regen]				
Bz	C-2800 Unit 8										TS contract ends 10/31	[Natural regen]							Regen survey
Dz	Kalaloch West Units 1 & 13										TS contract ends 10/31	[Natural regen]							Regen survey

Appendix E. Learning Groups

Activity Type	Group	Number of Members	Meeting Frequency
Research and monitoring	Cedar	17	Every other month
	Carbon	16	Every other month
	Invasive Species	16	Every other month
	History	10	Every other month
Information exchange	Aquatic Responses	20	Quarterly
	Remote Sensing	11	Twice a year
Updates and reviews	Economics and Operations	6	Twice a year
	Tribal	11	Twice a year

Appendix F. Data Sharing Agreement

Type 3 Watershed Experiment Data Sharing Agreement

Last Updated: March 14, 2023

The data referred in this agreement include, but are not limited to, environmental monitoring data, data on land management operations and implementation costs, and social science data. All T3 data are jointly owned by Washington State Department of Natural Resources (DNR), University of Washington Olympic Natural Resources Center (ONRC), and the T3 study's key collaborators. All information that is shared with DNR is subject to public disclosure, under the Washington Public Records Act (RCW 42.56).

1.) I agree to notify the T3 scientists who gathered data if I would like to use those data in any publication. I acknowledge that these data were gathered by T3 scientists because they had already perceived the importance of these data for a variety of scientific and societal issues. I will provide them with formal recognition that, at their discretion, may include co-authorship or acknowledgements on publications. When sharing, presenting or publishing the data and results of data analyses, I will recognize that the data are collected at the Olympic Experimental Sate Forest managed by Washington State Department of Natural Resources.

2.) I realize that the researchers who gathered these data may be using them for scientific analyses, papers, or publications that are currently planned or in preparation, and that such activities have precedence over any that I might wish to prepare. In this case, my preparation of any work may be delayed, at the option of the T3 researchers involved, until their work is completed.

3.) Because it may be possible to misinterpret a data set if it is taken out of context, I will seek the assistance and opinion of those T3 researchers involved as I design my study, collect additional data, and conduct analyses involving the data obtained from the T3 study researchers. To help ensure correct interpretation of data, I will submit publication drafts to T3 researchers for review prior to publication. Moreover, I realize that this data set is not complete, and it may contain errors. The complete data set includes extensive written documentation and metadata, which should be referenced to reduce the chance of errors in data and interpretation.

Printed Name	Organization
Signature	Date