

Studying Working Landscapes: Non-Timber Forest Products, Climate Risk, and Watershed
Restoration in Washington State

Alec Solemslie

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

Doctor of Philosophy

University of Washington

2026

Reading Committee:

Kent Wheeler, Chair

Gregory Ettl

Sergey Rabotyagov

Program Authorized to Offer Degree:

School of Environmental and Forest Sciences

©Copyright 2026
Alec Solemslie

University of Washington

Abstract

Studying Working Landscapes: Non-Timber Forest Products, Climate Risk, and Watershed
Restoration in Washington State

Alec Solemslie

Chair of the Supervisory Committee:

Kent Wheeler

School of Environmental and Forest Sciences

Washington State is a mosaic landscape of different working lands that support a wide range of communities economically, culturally, and environmentally. The studies presented examine the relationships of working lands and communities under the lens of forest economies through the non-timber forest products (NTFPs) industry, climate risk to resources, and watershed restoration decisions made on private lands. The studies employ qualitative case-study research, climate-risk analysis, and stated preference methods to understand how working landscapes intersect and stand to benefit those within the state.

The first study presents a qualitative case study of the NTFP greenery and bough industry through interviews and archival evidence to understand how the industry is organized, sustained, and constrained. The industry is a multi-layer system that operates with many different parties, from landowners, harvesters, processors, brokers, wholesalers, and retailers,

that is built and sustained on developed trust and mutual gain. The industry is largely supported by a greenery export market to Europe and a strong Christmas greenery and bough market domestically. However, the industry faces challenges with decreased exports to a weakening European market, declining harvest opportunities on National Forest lands, changing consumer preferences, land-use change, immigration policies, and the uncertainty of climate change. Nevertheless, the industry does have opportunities in the form of integrated NTFP management with timber production, forest farming development, improved connection and education, and the development of new products.

The second study evaluates the risk to bough production associated with climate change affecting seasonal heat, cooling, and snow conditions. The bough industry presents a unique product that is seasonally constrained by physiological processes of evergreen trees and the cultural importance of the Christmas holiday in the United States, serving an important product in rural economies in Western Washington. Ensembled, downscaled climate models under moderate climate conditions from 2015 to 2100 were used to develop operational indicators based on observable weather conditions representing late summer and early fall heat, timing of the first frost, and snowfall. Indicators were developed for Western Washington and Oregon across forest ownership types and ecoregions. Results indicate a shrinking post-frost quality window with the probability of frost by November 15th declining by 11.5 to 15.8 percentage points across private forest lands by the end of the century. Coastal and lowland forests are projected to have less reliable frost events compared to montane and federal forests, suggesting

a possible spatial shift where managers may look to for reliable frost-conditioned boughs during the early and mid-harvest season.

The third study employs stated preference methods to understand incentives and barriers to private landowner willingness to engage in watershed restoration in the Stillaguamish River watershed. Landowner willingness-to-accept and engage in conservation programs and landowner willingness-to-pay for conservation funding were estimated through a split-sample survey design using mixed logit models. Results indicate that landowners were less likely to engage in conservation programs under longer contracts and more frequent monitoring from the program sponsor. Overall, individual environmental identity, age, and length of residency helped explain stated enrollment preference. For willingness-to-pay, landowners were more willing to pay for salmon habitat enhancement and water quality improvement purposes compared to recreation enhancement or increased sport fishing purposes. Higher fees also deterred willingness to engage in the funding program. Individuals' prior experience in restoration, environmental identity, and acreage holdings explained variance in individual decisions. Modeled results were used to create pseudo-policy scenarios to explore policies and programs that landowners would support through a majority referendum style simulation. Results indicate that feasible revenues from the within the local watershed may not be able to support all those who are willing to enroll acres for restoration.

These studies explore the working landscape through different methods and different settings.

The NTFP industry has long supported rural economies in Washington State and

faces several different challenges, along with many opportunities, but remains a relatively unknown industry to scientific literature. A changing climate introduces uncertainty to the NTFP industry and a culturally significant product to the region. Restoring the lands that support these industries, ecosystems, and mitigate against climate change requires collective action across private ownerships that may not have the capacity to support those willing to engage in restoration. The research gaps highlighted across these studies point to where more work is needed in the regional context.

Table of Contents

Acknowledgements	12
Introduction	1
Dissertation Framing	3
Chapter I: Organization, Persistence, and Constraints in Washington’s Non-Timber Forest Product Greenery Industry: A Case Study	6
Abstract	6
Introduction	7
Research Question	9
Literature Review	10
History and Products.....	10
Economics and Markets	13
Labor and Relations	15
Regulations, Policy, and Governance	17
Sustainable Ecology and Management	18
Methods.....	20
Interview Methods.....	20
Document and Archival Analysis.....	26
Results	28
Descriptive Results	28
Thematic Results	32
Other Challenges and Opportunities	40
Climate Change	41
New Products	42
Discussion.....	42
Data Convergence, Divergence, Absence	44
Management Implications	46
Further Research Needs.....	46
Limitations.....	47
Conclusions	49
References.....	51
Supplemental I-I: Interview Questions	56

Chapter II: Climate Change and Shifting Seasonal Harvest Windows for Evergreen Boughs in the Pacific Northwest	57
Abstract	57
Introduction	58
Research Questions.....	61
Literature Review	62
Evergreen Bough Literature	62
Incorporating Climate Literature.....	65
Methods	66
Data Availability and Sources.....	67
Climate Indicator Creation	70
Sensitivity Analysis	72
Climate Ensemble Indicator Creation	73
Analysis Unit Creation	74
Data Issues	76
Results	77
Overall Climatic Indicators	77
Climatic Metrics by Ecoregions	81
Climatic Metrics by Ownerships	84
Climatic Metrics by Ownerships within Ecoregions.....	88
Probability of Frost Across Ownerships and Ecoregions.....	91
Sensitivity Analysis	95
Discussion.....	97
Climatic Impact	97
Phenology Considerations	98
Management Impacts	98
Limitations.....	101
Scale	101
Extreme Weather	102
Conclusion.....	103
References.....	105
Supplemental II-I: Bough Grading System Adapted by Schlosser and Blatner (2004).....	111
Supplemental II-II: Data Descriptions	112

Climate Data.....	112
Topography.....	113
Ecoregions	113
Landownership.....	113
Landcover	114
Study Area Mask	114
Supplemental II-III: Existing Vegetation Types included for Bough-Potential Forest Coverage from USDA LANDFIRE.....	115
Supplement II-IV: Tables of Climatic Indicators for Ownerships	117
Supplement II-V: Tables of Climatic Indicators for Ecoregions.....	121
Supplement II-VI: Tables of Climatic Indicators for Ownership-Ecoregion Intersection	125
Supplement II-VII: Graphical Representation of Climatic Indicators for Ownerships.....	137
Supplement II-VII: Graphical Representation of Climatic Indicators for Ecoregion	140
Chapter III: Paying for Restoration: Landowner Preferences, Public Support, and the Feasibility of Watershed Restoration in the Stillaguamish	143
Abstract	143
Background	144
Research Questions.....	145
Study Area and Context	147
Selected Literature Review	149
Willingness-to-Accept and Other Conservation Adoption Literature.....	149
Willingness-To-Pay and Valuation Literature	153
Study Design and Methods	155
Study Population and Survey Design	155
Conceptual and Theoretical Framework and Instrument.....	157
Willingness-to-Accept Model Framework	157
Willingness-To-Accept Instrument Design	160
Willingness-to-Accept Experimental Design	161
Willingness-to-Pay Model Framework.....	165
Willingness-to-Pay Instrument and Experimental Design	166
Willingness-to-Accept and Willingness-to-Pay Analysis	169
Results	173
Survey Sample Demographics.....	173

Willingness-to-Accept Model Results	173
Willingness-to-Pay Model Results.....	177
Pseudo-Policy Scenario Development: Funding Projections and Estimated Restoration- Willing Acres	182
Discussion.....	188
Considerations from the Willingness-to-Accept	188
Considerations from the Willingness-to-Pay	192
Pseudo-Policy Scenarios Significance.....	197
Management Implications	199
Limitations.....	200
Conclusions	202
References.....	204
Supplemental III-I: Near-Bayesian Efficient Experimental Design Blocks for the Willingness-to- Accept Experiment.....	209
Supplemental III-II: Near-Bayesian Efficient Experimental Design Blocks for the Willingness-to- Pay Experiment	210
Supplement III-III: Sample Structure of the Willingness-to-Accept Survey Instrument	211
Supplemental III-IV: Sample Structure of the Willingness-to-Pay Survey Instrument.....	215
Supplemental III-V: Results from the WTA MNL Model.....	218
Supplemental III-VI: Results from the WTA Structural Mixed Logit Model I.....	219
Supplemental III-VII: Results from the WTA Structural Mixed Logit Model II.....	220
Supplemental III-VIII: Results from the WTA Interaction Mixed Logit Model III.....	221
Supplemental III-IX: Results from the WTA Interaction Mixed Logit Model IV.....	222
Supplemental III-X: Results from the WTA Interaction Mixed Logit Model V.....	223
Supplemental III-XI: Results from the WTA Interaction Mixed Logit Model VI.....	224
Supplemental III-XII: Results from the WTA Interaction Mixed Logit Model VII.....	225
Supplemental III-XIII: Results from the WTA Interaction Mixed Logit Model VIII.....	226
Supplemental III-XIV: Results from the WTA Interaction Mixed Logit Model IX.....	227
Supplemental III-XV: Results from the WTA Interaction Mixed Logit Model X.....	228
Supplemental III-XVI: Results from the WTA Interaction Mixed Logit Model XI.....	229
Supplemental III-XVII: Results from the WTA Interaction Mixed Logit Model XII.....	230
Supplemental III-XVIII: Results from the WTA Interaction Mixed Logit Model XIII.....	231
Supplemental III-XIX: Results from the WTA Interaction Mixed Logit Model XIV.....	232

Supplement III-XX: Results from the WTP MNL Model	233
Supplement III-XXI: Results from the WTP EC Model I	234
Supplement III-XXII: Results from the WTP Structural Mixed Logit Model II	235
Supplement III-XXIII: Results from the WTP Structural Mixed Logit Model III	236
Supplement III-XXIV: Results from the WTP Structural Mixed Logit Model IV	237
Supplement III-XXV: Results from the WTP Structural Mixed Logit Model V	238
Supplement III-XXVI: Results from the WTP Structural Mixed Logit Model VI	239
Supplement III-XXVII: Results from the WTP Interaction Mixed Logit Model VII	240
Supplement III-XXVIII: Results from the WTP Interaction Mixed Logit Model VIII	241
Supplement III-XXIX: Results from the WTP Interaction Mixed Logit Model IX.....	242
Supplement III-XXX: Results from the WTP Interaction Mixed Logit Model X.....	243
Supplement III-XXXI: Results from the WTP Interaction Mixed Logit Model XI.....	244
Supplement III-XXXII: Results from the WTP Interaction Mixed Logit Model XII	245
Supplement III-XXXIII: Results from the WTP Interaction Mixed Logit Model XIII	246
Supplement III-XXXIV: Results from the WTP Interaction Mixed Logit Model XIV	247
Supplement III-XXXV: Results from the WTP Interaction Mixed Logit Model XV	248
Supplement III-XXXVI: Results from the WTP Interaction Mixed Logit Model XVI	249
Supplement III-XXXVII: Results from the WTP Interaction Mixed Logit Model XVII	251
Supplement III-XXXVIII: Map of Response Rates by Subwatershed.....	252
Discussion.....	253
Alignment of Working Landscapes.....	253
Heterogeneity and Scale in Working Landscapes	256
Implications.....	257
Limitations.....	258
Future Research	259
Conclusion.....	259
References for Introduction, Discussion, and Conclusion	262

Acknowledgements

This dissertation and degree would not be possible without every person I met along the way. First, a deep and everlasting thank you to my family: Keith, Marilyn, and Ryan Solemslie who have been a steady foundation throughout the years and always willing to listen to whatever I have to celebrate, complain, or scheme about. I would be remised to not also acknowledge and thank my partner, Kelvin Close-Kung, for supporting me during my lowest points and celebrating me during the best of times. I would be nowhere close to what I have accomplished thus far without my mentors along the way: Dr. Sadie Trush, Dr. Meggie Callahan, and Dr. Christina Bjarvin. My colleagues and labmates were also vital in finding innovation and motivation to continue, through late talks to coffee walks: Lieke Droog, Sarah Pollack, Hemalatha Velappan, Lily Yang, and Karisha Hariadi. A shoutout to my supervisory committee who supported and mentored me along the way: Dr. Kent Wheeler, Dr. Gregory Ettl, Dr. Sergey Rabotyagov, Dr. Clare Ryan, and Dr. Isabelle Cohen. Finally, to all of my friends that kept me sane, I could not have done this without you.

To those who passed on, I remembered you all while I worked, hoping to honor your memories and serve you proudly. I am sorry you are not here to see this, though I know you never had any doubts.

This work was not possible without the financial support of the McIntire-Stennis Cooperative Grant and funding by the Washington State Department of Fish and Wildlife.

Introduction

Working landscapes occur as human-modified landscapes that are supporting multiple objectives including conservation, economic, and cultural values. These landscapes often provide more value in ecosystem services than industrialized landscapes, such as conventional agriculture (Kremen & Merenlender, 2018). As multiple objectives are introduced to the landscape, so are competing interest and objectives. This means that the landscape has many institutions (i.e., industries, governments, communities, and societies) and agents (i.e., individuals who act on the landscape) that represent those multiple objectives. Those institutions and agents have varying levels of rights and responsibilities, creating a complexity to how the landscape is managed and the conflict that occurs therein (Kremen & Merenlender, 2018; Sayer et al., 2013).

To this end, these working landscapes become some of the most complex settings to understand as they support multiple and competing objectives under many different ownership and interest groups. These aspects must be understood together, as the working landscape serves as a heterogeneous place where these aspects of production, conservation, and recreation are inter-connected and support one other, to provide a landscape with multiple outcomes (Kremen & Merenlender, 2018; Sayer et al., 2013). The very human-modified nature of working landscapes leads to these landscapes being under multiple dimensions, including economic, ecological, cultural, institutional, and political constraints (Arts et al., 2017).

As working landscapes are complex systems, these landscapes must be understood so that these ecological and social systems are coupled together. Each interaction between these dimensions vary through spatial, temporal, and organizational scales will present different and

so need understood through an interdisciplinary lens (Liu et al., 2007). These coupled socio-ecological systems then need to be studied as such, understanding that different interactions fall under different resources, governance, actors, and outcomes (Ostrom, 2009).

With the plurality of dimensions, objectives, and interactions, and how these aspects need to be studied, the context to which what is studied must be understood. To this end, rights and governance varies across the landscape, depending on the resource, context, and agents (Lemos & Agrawal, 2006). This governance can also take on informal structures made by those working with the resource rather than an authority, such as a governmental entity (Ostrom, 1990). Even in the case of working landscapes, systems driven by economic behavior are too intertwined with social systems (Granovetter, 1985). These aspects highlight that research in the subject of working landscapes must consider these levels of governance, including the social and economic systems that have created what is observed on the landscape.

To understand working landscapes, a modified approach to Ostrom (2009) can be used to define the different dimensions of a working landscape. First, there are the ecological processes, the natural phenomena that allow for conditions on the landscape to exist, such as soils that support agriculture or native ecosystems that have harvestable edibles. Second, there is the agent capacity, or the willingness of individuals to engage in the working landscape as workers, consumers, managers, etc. Third, there is institutional capacity, or the existence of institutions, such as industry and governments, that can act on the organization of multiple outcomes on the working landscape. Finally, there is the economic demand, or the desire for a product to be traded or the existence of a value to an outcome. The alignment of these four dimensions results in the existence of a working landscape for multiple objectives (Figure I).

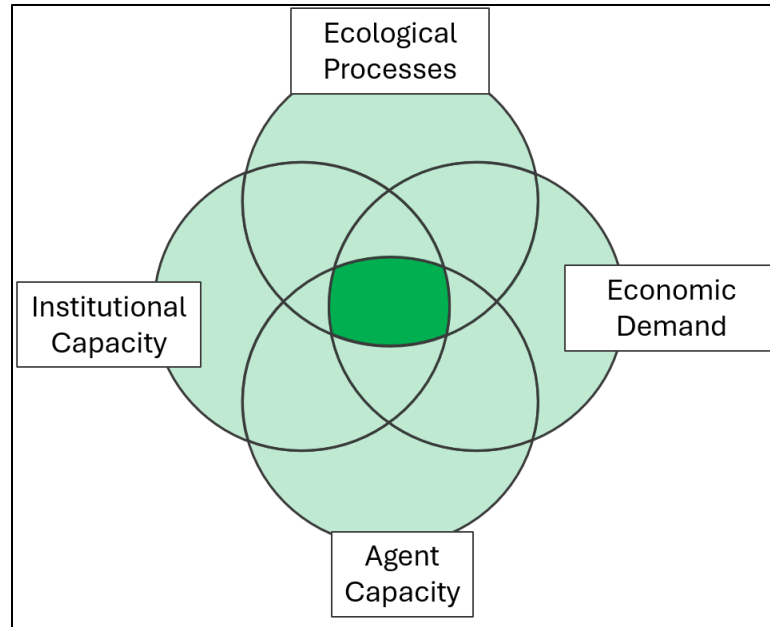


Figure 1: A conceptual framework for understanding working landscapes as the alignment of ecological processes, institutional capacity, agent capacity, and economic demand.

Dissertation Framing

The purpose of this dissertation is to examine the use, management, planning, and restoration of working landscapes using Washington State as a setting. Through three studies, the systems of rights, boundaries, agents, economies, and risk will be examined. These studies demonstrate the multi-faceted aspects of working landscapes, especially the multiple objectives these landscapes support. With this, this dissertation is framed with the research question:

- *How do ecological processes, institutional capacity, agent capacity, and economic demand interact to shape the management of working landscapes?*

Through the framing that socioecological systems cannot be fully understood through one lens, this dissertation employs several different methods across the studies. The multiple method research presented here underscores the difficulty to understand working landscapes and presents the argument for further interdisciplinary research.

The first chapter of this dissertation is a case study that investigates the non-timber forest product greenery industry of Washington State. The study seeks to understand how the industry is organized, sustained, and constrained. The study is framed as an exploratory case study that uses semi-structured interviews and publicly available data. The study describes how the industry is organized and the system that the industry presents.

The second chapter is a spatial climate-risk analysis using the evergreen bough portion of the non-timber forest product greenery industry as the study unit. Understanding that evergreen boughs are an important aspect of the Christmas holiday season but have physiological limitations around their harvest, the study works to understand how a future changing climate may impact the harvest season through how long hot days extend into the operational season, how frost dates that frame a quality operational window change, and how different expected snow dates limit access. The results describe the potential risks and impacts of climate change on a culturally relevant product that supports rural industry.

The third chapter investigates the incentives and barriers to conservation engagement and support for private landowners in the Stillaguamish Watershed. Through a split-sample discrete choice experiment, willingness-to-accept and willingness-to-pay is estimated and used to create pseudo-policy scenarios to describe local willingness to engage in conservation programs and the local willingness to support that engagement. The study provides evidence for participation and policy support across a heterogeneous landscape with many different landowners.

These three chapters demonstrate the mixed methods approach needed to understand working landscapes. The first chapter relies on a case study founded on qualitative interviews

supported by quantitative data where available. The second study uses climatic modeling outputs to understand the climatic connection to an industry and a fixed cultural economic demand. The third study employs a quantitative survey to conduct environmental economic modeling to highlight policy scenarios. These are very different methods to be employed in understanding one overarching subject. Nevertheless, these multiple methods highlight the need for interdisciplinary work and researchers, so that the context in which research and the environment exist can be fully understood rather than considered alone.

Additionally, these three chapters will explore the conceptual four dimensions of a working landscape previously defined, highlighting the alignment of these dimensions. The NTFP greenery industry is an industry founded on the harvesting of wild native plants for economic trade domestically and abroad, built on informal connections and willing laborers. Evergreen bough harvesting relies on a climatic indicator that will shift with climate change, suggesting that other dimensions will need to adapt in order for the alignment of a working landscape to continue. Understanding residential restoration demonstrates how to align many different individuals to achieve one goal in conserving an ecological process through revealed valuation. These three chapters present the highly dynamic nature of working landscapes and their dimensions.

Chapter I: Organization, Persistence, and Constraints in Washington's Non-Timber Forest Product Greenery Industry: A Case Study

Abstract

Washington State has a decorated history of non-timber forest products (NTFPs) being used in markets and trade. Notably, the commercial NTFP greenery industry, has a strong domestic and international market, supporting rural economies and immigrant workers in the Pacific Northwest. However, the industry has not been studied intensively since the 1990s, leaving several decades unaccounted for an industry that is known for secrecy and distrust in institutions. The exploratory case study used semi-structured interviews and publicly accessible data to provide an update on the industry. The industry is described as regional, centered in Washington State that supports export markets to Europe, domestic holiday markets, and the notable Christmas season. Salal, the largest traded and harvested NTFPs in volume, makes up most international trade. Evergreen boughs drive the domestic Christmas season market. Findings demonstrate that long-term relationships and trust are foundational for access to land and cooperation between landowners, harvesters, and processors, especially in an industry where regulation and enforcement is limited. The industry has largely been supported by immigrant labor and by a reliance on the European market outside of the domestic Christmas season. The reliance on the European market and the immigrant workforce of the industry have created institutional vulnerabilities as the industry now faces declining trade from Europe, attributed to conflict, tariffs, and decreased consumer purchasing power, and domestic immigration policies creating uncertainty for the workforce.

Introduction

Non-timber forest products (NTFPs) are abundant and hold a historic importance to the Pacific Northwest. There are at least 250 documented products being used historically for a variety of purposes such as food, medicine, decoration, and cultural reasons (Kuhnlein & Turner, 1991; Turner & Cocksedge, 2001; Winkler, 2023). These products, derived as mostly parts of plants and fungi (Chamberlain et al., 2018), continue to provide communities in the PNW through personal use and as economic commodities (Arnett & Crawford, 2007; W. Schlosser & Blatner, 1995b, 1997; W. E. Schlosser et al., 1991). Notably, the PNW is known for wild floral greens (e.g., salal, beargrass, huckleberry, evergreen boughs and Christmas trees, and swordfern), food products (e.g., huckleberries, various edible mushrooms), and drug derivatives (e.g., yew, cascara) (Shaw, 1949).

Of the greater NTFP industry in the Pacific Northwest, the NTFP greenery industry, including floral greens and evergreen boughs, provides significant support to rural economies through domestic and international markets, and provides culturally important products to the region and beyond (W. E. Schlosser et al., 1991). While the NTFP greenery industry supports rural economies and cultural products for the region, little is known about the industry. In the Pacific Northwest, researchers have documented that there is a degree of distrust and wariness towards outsiders for various reasons, including the informal economies, protecting trusted harvesting locations, fears of retribution or deportation, and existing weak regulations and enforcement (Love & Jones, 1997, 2001; Lynch & McLain, 2003; McLain, 2000). Distrust and secrecy from within the industry toward regulators and researchers has made the industry difficult to study and understand and likely has prevented further development of monitoring

for products, the economy, and labor. During the height of the NTFP research in the Pacific Northwest between 1990 and 2005, the most extensive studies were conducted on the NTFP greenery industry, documenting its multi-million dollar economic contribution, the industry network, and the thousands of employed as harvesters or in processing centers (H. L. Ballard & Huntsinger, 2006; Lynch & McLain, 2003; W. Schlosser & Blatner, 1997; W. E. Schlosser et al., 1991).

Since the 1990s and early 2000s, little research has been conducted on the NTFP greenery industry. Similarly, no monitoring schemes have been implemented to collect data on employment or economic contribution of the industry. Rather, the industry has only been documented in sporadic news stories documenting mergers, labor tensions, and illegal harvesting (*Continental Floral Greens Acquires The Hiawatha Corporation* / *Produce News*, n.d.; Welch, 2006). Much has happened in the past 20 years that may have affected the industry, ranging from technological advancements, changing foreign relations, and several economic recessions. Given the importance of the industry to the local economy, it is relevant to reassess the industry, provide a contemporary account, and begin laying the framework of understanding a hard-to-observe industry in a developed economy.

This study focused on Washington State as the processing center of the NTFP greenery industry of the Pacific Northwest, producing floral greenery and boughs for domestic and international markets. While the entire NTFP industry, including edibles, Christmas trees, and medicines, is interconnected through the sharing of harvesters, using the same lands for product acquisition, and some processors operating with products from each category (e.g., floral greens, edible berries and mushrooms, medicinal), these products are not included to

narrow the scope of research. These products, however, do provide context for the how the NTFP greenery industry operates in the Pacific Northwest.

Research Question

With nearly three decades since the last major research into the NTFP industry of the Pacific Northwest, little is known about the state of the NTFP industry in Washington State. The lack of regulation and monitoring of the industry leaves little information to pull upon in developing a deeper understanding of the industry that could help address important issues such as sustainable harvesting practices, migrant labor rights, rural economic development, and job creation. Additionally, the issues of secrecy and trust hamper inroads for data gathering. This case study addressed the NTFP industry through a case study framed around the research question:

- How is the NTFP greenery industry organized, sustained, and constrained in Washington State?

The study focused on the NTFP greenery processors and landowners in Washington State, serving as the processing center of the NTFP greenery industry of the Pacific Northwest. This case boundary acknowledges that Washington is the center of the processing industry but the supply-chain extends throughout the Pacific Northwest, from southern British Columbia and south through Oregon. Through case study methods of interviews and document analysis, the study provides a contemporary account of the NTFP greenery industry, highlights core relational patterns in the industry, discusses opportunities and challenges, and identifies existing information gaps and research needs for the industry.

Literature Review

History and Products

Washington State, and the Pacific Northwest in general, has a long history of NTFPs being used for economic benefit. First descriptions of economic systems around NTFPs date to before pre-colonial times with the Indigenous nations and communities (Turner & Cocksedge, 2001). In post-colonial times, Washington State has a decorated history of producing many special forest products, including, but not limited to, Christmas trees, salal floral greens, beargrass floral greens, huckleberry floral greens, huckleberry berries, many species of edible mushrooms, distilled pitch from softwood species, and drug derivatives, including Cascara since the early 1900s (Shaw, 1949). In the latter half of 20th century into the current century, floral greens from salal, Christmas trees, huckleberry berries, evergreen boughs, and mushroom species are significant contributors to the industry (Arnett & Crawford, 2007; W. Schlosser et al., 1991; W. Schlosser & Blatner, 1995b).

Notable NTFP greenery species include salal (*Gaultheria shallon* Pursh), two huckleberry species, including red huckleberry (*Vaccinium parvifolium* Smith) and evergreen huckleberry (*Vaccinium ovatum* Pursh), beargrass (*Xerophyllum tenax* (Pursh) Nutt), western swordfern (*Polystichum munitum* (Kault.) C. Presl), deer fern (*Struthiopteris spicant* (L.) Weiss), Oregon grape (*Berberis aquifolium* Pursh), and various moss species. Additionally, invasive species have previously been harvested in the Pacific Northwest, scotch-broom (*Cytisus scoparius* (L.) Link) and baby's breath (*Gypsophila paniculata* L.) (W. E. Schlosser et al., 1991).

The notable evergreen boughs include the species Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Douglas ex D. Don) Lindley), incense cedar (*Calocedrus*

decurrens (Torrey) Florin), lodgepole pine (*Pinus contorta* Douglas ex Loudon), noble fir (*Abies procera* Rehder), pacific silver fir (*Abies amabilis* Douglas ex J. Forbes), ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), western juniper (*Juniperus occidentalis* Hook.), western red cedar (*Thuja plicata* Donn ex D. Don), and western white pine (*Pinus monticola* Douglas ex. D. Don). Of these, producers spent the most on the acquisition of noble fir, western red cedar, subalpine fir, and western white pine (W. E. Schlosser et al., 1991). See Table I-I for more details on selected economically important floral greens.

Table I-I: Major Floral Greenery and Christmas Greenery Non-Timber Forest Products of the Pacific Northwest

Name	Use	Image
Salal <i>Gaultheria shallon</i> Pursh	Tips of branches are harvested in bunches outside of the growing season. These tips are used for floral arrangements as greenery and filler and are known for their longevity.	 Photo Credit: Continental Floral Greens
Beargrass <i>Xerophyllum tenax</i> (Pursh) Nutt	Stalks of beargrass sheaths are harvested in bunches at maturity. Blades are used in floral arrangements as greenery and filler.	 Photo Credit: Continental Floral Greens

**Red
huckleberry**
*Vaccinium
parvifolium*
Smith

Once the leaves turn red, red huckleberry foliage is harvested for its distinctive color. These are used in floral arrangements as filler and statement pieces.



Photo Credit: Continental
Floral Greens

**Western
Swordfern**
*Polystichum
munitum*
(Kaulf.) C. Presl

Fronds are harvested in the summer after the fronds have set but prior to when reproductive spores form in late summer. These are used in floral arrangements as greenery.

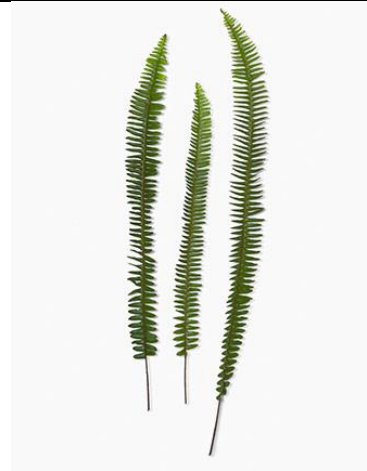


Photo Credit: Continental
Floral Greens

Noble fir
Abies procera
Rehder

Boughs are harvested after the first frost, taking branch tips from the mid-section of trees 10-30 years of age with proper spacing. As such, boughs are generally harvested by hand and transported by truck or helicopter to a processing center. If properly dormant from a hard frost and stored in cool temperatures during transportation, boughs can last upwards of nine weeks. Otherwise, needles brown and fall. The boughs are then used in swags,



Photo Credit: Continental
Floral Greens

wreaths, and other Christmas or winter season-related decorations.

Western red cedar

Thuja plicata
Donn ex D.
Don



Photo Credit: Continental Floral Greens

Western white pine

Pinus monticola
Douglas ex D.
Don



Photo Credit: Continental Floral Greens

The NTFP industry is in part closely tied to the edible NTFP industry, as workers often harvest different species of NTFPs throughout the year (McLain, 2000). The edible and medicinal NTFP industries are not evaluated in this case study.

Economics and Markets

Much of the most recent economic literature on industrial NTFPs in Washington State comes from survey work done in the 1980s and 1990s. The wild NTFP greenery industry was estimated to be \$128.5 million in sales in 1989 (W. Schlosser et al., 1991). In raw material valuation, wild NTFP greenery was valued in 1989 at \$30 million and boughs valued at \$9.5

million, roughly \$80 million and \$25 million in 2026 dollar value respectively (Table I-II; Table I-III) (W. Schlosser et al., 1991; W. Schlosser & Blatner, 1997). Salal, beargrass, and noble fir were the top valued products and greatest in their respective harvest units (W. Schlosser et al., 1991; W. Schlosser & Blatner, 1997).

Table I-II: Valuation of Floral Greenery Bought from Harvesters by Processors in 1989.

Species	Volume	Unit	Raw Value (1989 USD)
Dwarf Oregongrape	99,141	Bunch	59,485
Salal	345,698	Bunch	138,279
Salal tips ²	10,878,589	Bunch	7,641,090
Sword-fern	2,463,092	Bunch	1,527,117
Evergreen huckleberry	2,278,454	Bunch	1,480,995
Evergreen huckleberry (tips ²)	289,521	Bunch	107,123
Red-evergreen huckleberry (red-huck)	173,692	Bunch	112,900
Beargrass	12,781,823	Bunch	11,503,641
Moss	158,510	50 lb/sack	2,060,628
<i>Total</i>			<i>30,070,552</i>

¹Adapted from Schlosser et al. (1991) and Schlosser and Blatner (1997)

²Foliage of a shorter floral length than typical harvested amounts

Table I-III: Valuation of Raw Boughs and Other Tree Greenery Bought from Harvesters by Processors in 1989.

Species	Volume	Unit	Raw Value (1989 USD)
Subalpine fir	900	Tons	575,840
Noble fir	9,310	Tons	6,703,116
Western juniper	283	Tons	141,705
Incense-cedar	176	Tons	133,242
Lodgepole pine	272	Tons	97,856
Western white pine	995	Tons	457,503
Douglas-fir	1,317	Tons	263,393
Western redcedar	2,375	Tons	1,092,385
Other boughs	NA	Tons	59,242
Cones	7,230,871	Number	253,080
Holly	1,908,861	Pounds	2,672,405
<i>Total</i>			<i>12,449,767</i>

¹Adapted from Schlosser et al. (1991) and Schlosser and Blatner (1997)

The industry of the late 1980s relied heavily on the domestic market, with 69% of the product remaining in the United States. Europe was the next dominant market, with 24% of the product being exported to European countries (W. Schlosser et al., 1991).

Some research explored the added value NTFPs provide to landowners. While NTFP harvest is not a primary revenues source, it does supplement landowner forest land revenue (Blatner et al., 2010; W. Schlosser et al., 1991, 1992). Researchers identified that most of the timber lands in Washington State are in forest associations that support the majority of wild NTFP greenery species, allowing for timber landowners the opportunity to capitalize on these products (W. Schlosser et al., 1992). Others found that including bough production on timber units increases the net present worth of the stand, of between \$118.89 to \$1,702.05 per acre or between 4.1% to 5.1% internal rate of return (Blatner et al., 2010).

Labor and Relations

As is the trend in the NTFP literature of the United States, there is little information on the NTFP industry formation and labor. Early work on NTFPs in Washington State estimated that there were about 5,420 harvesters for the wild NTFP greenery industry with upwards of 4,880 processor employees, paying out \$23.8 million to employees at the time (W. E. Schlosser et al., 1991). Generally, the workforce has been largely immigrant labor from Asia and Central America, with a trend towards a Central American dominated workforce from the 1990s to the early 2000s (Hansis, 1996; Lynch & McLain, 2003). Little is known about the harvesters who work in eastern Washington (W. Schlosser & Blatner, 1997). Other studies have focused on harvesters in the mushroom industry (McLain, 2000).

The NTFP industry is a multi-layer network that includes forest landowners, harvesters, producers (processors), wholesalers, brokers, and retailers where product may move back and forth between producers for processing before it reaches the final consumer (Figure II). Generally, the product moves from processor leased forest land or harvesters holding access permits to forest land, where harvesters collect for or sell to processors. Once in the control of the processors, the product is either directly sold to retailers, brokers, and wholesalers or is further processed by the same processor or other processors before continuing on the product chain. Processors sometimes hold complete vertical integration of the industry chain through holding leased land and employing harvesters in backward vertical integration and holding sales agreements with retailers or final consumers in forward integration, removing brokers, wholesalers, and independent harvesters from the equation (W. Schlosser et al., 1991).

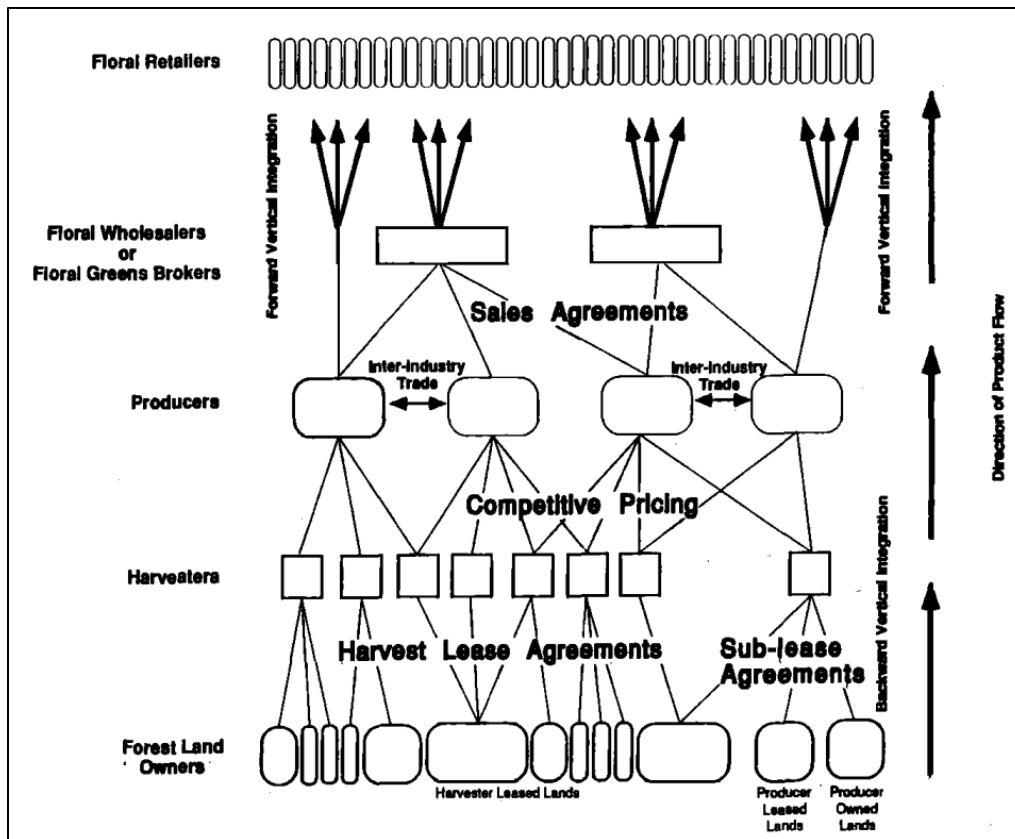


Figure II: NTFP greenery industry formation and connections, with flow of product adapted from Schlosser et al. (1991). The industry has five major player groups, moving from landowners to harvesters, producers, wholesalers and brokers, and finally to retailers.

Regulations, Policy, and Governance

The harvesting of NTFPs in Washington State require a permit and are regulated under Chapter 76.48 of the Revised Code of Washington (RCW). The statute includes definitions of the threshold quantity of NTFPs before the product becomes regulated under the law; 20 pounds in the case of cut foliage for NTFP greenery. The harvesting, possession, and transportation of this amount require a “specialized forest-products” permit no matter the ownership of the land from where the product is harvested. Permittees will also need any additional permissions and permits that the landowner requires for harvesting on their land. Permits are provided by the Department of Natural Resources (DNR) but administered by each county sheriff. Permits are only valid for the property, product, and amount expected to be harvested.

In addition to the specialized forest-products permit, harvesters and processors typically obtain a lease agreement or other permit contract from the landowner. On private forest lands and DNR forest land, internal company or agency policies apply. On National Forest lands, USFS permits must be obtained from the local ranger's district station. Districts are given authority to decide whether permits or special forest products are allowed to be harvested within that National Forest unit. Boughs are considered a timber product and must go through contracting in National Forests.

Sustainable Ecology and Management

Few of the major wild NTFP greenery species have had major research conducted to understand ecological and management considerations related to greenery harvest. Researchers found that most of the greenery species grow in the understory of the western Washington forest zones, especially along the coast and lowlands, with some in the montane regions (W. Schlosser et al., 1992). Boughs are more associated with the tree species that are present in the timber landscape, but general information about the primary tree species has been documented for the USFS in terms of bough production (Vance et al., 2001). The general ecologies and optimal conditions for species have been documented by Vance et al. (2001) and not discussed here.

Salal generally reacts positively to management and thinning operations (H. L. Ballard & Huntsinger, 2006; Cocksedge & Titus, 2006). Quality salal for floral products is associated with partial shaded conditions (H. L. Ballard & Huntsinger, 2006). When harvested for sustainable commercial production, salal produces more biomass the year following a harvest with more suitable stems compared to unharvested salal (Cocksedge & Titus, 2006). However, researchers

warn that continuous yearly harvests may weaken salal over time with harvesters acknowledging that they will let the salal rest to ensure sustainable harvests in the future (H. L. Ballard & Huntsinger, 2006; Cocksedge & Titus, 2006).

Beargrass has also been researched to understand harvest impacts from management (Hummel et al., 2012; Peter et al., 2017; Peter & Harrington, 2023). Researchers found that beargrass has higher commercial quality in shaded areas; however, beargrass has lower reproduction in these shaded areas along with higher chances for mortality (Peter et al., 2017). The study concludes that open stand conditions are necessary for population sustainability (Peter et al., 2017).

For boughs, guidance includes leaving one-third of the green portion of the branch and letting the trees regrow over the course of a few years (Landgren & Freed, 1998; W. Schlosser & Blatner, 2004). Similarly, spacing should allow for adequate bough growth, which may not be the same as for timber harvesting (Buttolph & Jones, 2012; Landgren & Freed, 1998; W. Schlosser & Blatner, 2004).

For salal and beargrass, sustainable management for harvests includes preventing overharvest in a single operation or continuous harvest pressure over time. Studies have reported salal harvests can range from 7.2 g/m² to 112.4 g/m² with regrowth sometimes greater than that of undisturbed sites (H. Ballard, 2004; Cocksedge & Titus, 2006; Fredrickson, 2000). Guides recommend removal of no more than 25% of salal biomass during a harvest and follow a 3-year rotation (Vance et al., 2001). Beargrass is recommended for only 20% of biomass removal in a given area with a research suggesting three years rest between harvests (Baldy, 2013; Peter & Harrington, 2023). Additionally, research suggests that the prime conditions for

floral grade products may not be the same conditions that are required for population growth in NTFP species (Peter et al., 2017).

Methods

A mixed methods case study was employed to understand the NTFP greenery industry. The exploratory and contemporary nature of this study, with the lack of control over the observable events and behaviors, make for a prime singular exploratory case study design to describe the current conditions of the NTFP industry in Washington State. The study then follows the guidelines of case study design and analysis set out by Yin (2017). Through the development of an interview protocol and using relevant publicly available documentation, this is a single-case design using multiple data sources for triangulation and verification of themes presented by the evidence (Yin, 2017).

The case study was designed into two significant data collection and analysis portions. First, experts and those familiar with the NTFP industry were invited to a voluntary semi-structured interview protocol. From there, deductive themes from the interviews were explored, where possible through a document analysis phase to support or counter the presented themes. The study is then presented as thematic results from the interviews with the analysis of public data per theme. Results are presented as a mix of interview themes with public data that supports the theme.

Interview Methods

A semi-structured specialized/elite interviewing approach (after Dexter 2006) was employed. This method allows for interviewers to follow the flow of a conversation rather than

a strict script (Dexter, 2006). Questions focused on opportunities and challenges that the industry faces from each landowners, processors, and federal and state officials perspectives.

The NTFP greenery industry is relatively small with few players and regulators. Interviewing experts helped identify that few participants were expected to agree to the interview process and targeting those with networks and connections was used to help explain the industry with nuance. Additionally, this allowed for the semi-structure interview protocol to deviate from preset questions should interviewees bring up unexpected themes, information, or should an answer need extended clarification. The following parties were interviewed:

- Federal and state officials (2)
- NTFP greenery processors (3)
- Forest landowners (1)

One interview protocol was used for all interviews. The protocol illustrates the basic questions that were asked; however, interviewees were asked about specific products based on their role or industry type. Interviews lasted between 45-90 minutes, being in-person or online depending on the preference of the interviewee. Interviewees were informed that the interviews would be recorded and were asked for their consent to record the interview and use the information in the interview for academic and research purposes. Interviewees were also informed that the recordings would be kept on secure University of Washington servers and recordings would be destroyed after a transcription was created. Transcripts are kept on secure University of Washington servers and may be used for further publications. Given the secretive nature of the industry, interviewees were informed that no quotations would be used in any published report or publication.

Interviews were recorded through a handheld device or the built-in recording feature of Microsoft Teams and transcribed via Otter.ai, reviewed by the interviewer, with any identifiers removed by the interviewer. Interviewees were given the opportunity to review transcripts and remove or modify any statements that they made. If the interviewee requested a transcript, the transcript was not used for analysis until the interviewee approved the transcript. The interview protocol and design underwent IRB approval through the University of Washington IRB, receiving exempt status: STUDY00022285.

The questions in the interview protocol include the following general areas:

- Economic condition of the NTFP industry
- Major challenges for the NTFP industry
- Major opportunities for the NTFP industry
- Workforce
- Regulatory relationships and status
- Unpermitted harvesting and sustainability
- Climate and weather impacts

Sampling was conducted via snowball sampling (Kadushin, 1968) to capture information from key informants in the field. Initial interviewees were determined through web searches of processors, regulatory bodies, and suggestions from those who have previously conducted research in the field. In total, 19 individuals were contacted for the interview process. Thirteen of those contacted either refused, did not reply, or failed to approve the transcript provided of their interview. Any transcripts not approved of were removed from the analysis. Six

interviewees approved their transcripts for analysis. See Supplemental I-I for the interview questions.

Of the interviewees who accepted to be interviewed, the forest landowners represented large industrial forest landowners who commercially harvest timber. Processors were of processing centers that had multiple full-time staff, operating year-round. Officials represented land or had significant knowledge of NTFPs in Washington State.

The coding process was iterative, building expected categories from the literature and expected answers while using descriptive codes as they emerged from the interviews, including recoding when codes were merged, transformed, or redefined. As patterns emerged from the codes, themes were developed to explain these patterns (Saldana, 2009). Here, the coding mechanism was a hybrid of deductive-inductive coding that was informed by the literature and scoping conversations but allowed the flexibility for codes and themes to emerge from the interview text.

Deductive categories were developed prior to coding. These topics included economics, management and sustainability, opportunities, challenges, cultural, and policy and legality. These categories came from broad categories of research conducted in the NTFP field.

Inductive coding was applied within the deductive categories, where codes came from patterns and descriptions from the transcripts themselves. The iterative process of going over the codes led to patterns, eventually turning into themes. All individual codes and themes from this work were inductive.

Coding was conducted manually by the interviewer. In coding, segments (i.e., the parts of the transcripts that were coded, ranging from a few words to several sentences) were allowed

to have more than one code. However, the aim of this process was to limit the number of codes that applied to any segment.

These overarching categories were inspired by the existing literature: economics, management and sustainability, opportunities, challenges, cultural, and policy and legality. The “Economic” category was expected as the interview questions were framed in part to understand the economic nature of the industry and following the existing work on the economics of the NTFP greenery industry (W. Schlosser et al., 1991). “Policy and Legality” stem from the documented tensions between policy-makers and the industry, including the history of illegal and unpermitted harvesting (Lynch & McLain, 2003; McLain & Lynch, 2010). “Management and Sustainability” was developed from the scientific literature that has explored or reported the sustainability of NTFP harvests (H. L. Ballard & Huntsinger, 2006; Cocksedge & Titus, 2006; W. E. Schlosser et al., 1991). Categories were developed for “Opportunities” and “Challenges” as expected from the interview questions. One additional category emerged from the interviews. This “Cultural” theme was unexpected but is mentioned in the existing literature (W. Schlosser et al., 1991).

Coding was an iterative process. As further interviews were coded, some codes were merged with one another, abandoned, or redefined. When codes were transformed, the previous interviews and related coded sections were revisited to consider the newly transformed code. After the first coding effort and initial themes and patterns established, the interviews were coded one additional time. In the end, there were six categories and 38 codes (Table IV). From the codes, themes were developed to represent the interpretation of patterns in the data.

Table I-IV: Code Categories, Codes, and Developed Themes.

Code Category	Code	Applicable Theme¹
Economic	Tariffs – Foreign Trade Policy	Dependence on Europe
	Conflicts Impacting Trade	Dependence on Europe
	International Trade – Descriptive	Dependence on Europe
	Shifting Demands of Greenery	Dependence on Europe
	Product Value Descriptions	Dependence on Europe
	Domestic Markets	Dependence on Europe
Cultural	European Floral Tradition	Dependence on Europe
	American Floral Tradition	Dependence on Europe
	Floral Tradition - Descriptive	-
Policy and Legality	National Forest Policy	Prioritizing Timber
	Permitting and Leasing	Informal Governance
	State Intervention	Informal Governance
	Illegal/Unpermitted Harvesting	Informal Governance
Management and Sustainability	Workforce/Other Use Conflicts	-
	Timber Management Conflict	Prioritizing Timber
	Workforce – Trust and Relationship Building	Informal Governance
	Workforce Providing Security	Informal Governance
	Workforce - Descriptive	Workforce Vulnerabilities
	Considerations for Family Forest Owners	Prioritizing Timber
	Sustainability	Prioritizing Timber
	Greenery Descriptions	-
	Firewood	-
	Climate Change	-
Challenges	Markets	Dependence on Europe
	Workforce Availability	Workforce Vulnerabilities
	Immigration Policy	Workforce Vulnerabilities
	Customer Relations	-
	Land-use Change	-
	National Forest Lands	Prioritizing Timber
	Education	-
	Emergent Products	-
Opportunity	Culture and Marketing	Dependence on Europe
	Value-Added Processes	Prioritizing Timber
	Network Connections	-
	National Forest Land	Prioritizing Timber
	Forest Farming	-

¹Short names for themes are used in the table. “Dependence on Europe” refers to the titled results “(U.S. Department of Agriculture, Forest Service, n.d.)Dependence on the European Floral Market”; “Informal Governance” refers to “Trust and Relationships as Informal Governance”; “Workforce Vulnerabilities” refers to “An Immigrant Shaped Industry Facing Vulnerabilities”; and “Prioritizing Timber” refers to “Prioritizing the Non-Timber Objectives”

Some interviewees mentioned products that are not part of the strictly NTFP greenery industry, such as mushrooms, big leaf maple (*Acer macrophyllum* Pursh) syrup, and huckleberries. This is expected given the interrelated nature of the industry, especially for landowners. These sections were coded but not included in the case study results.

The interviewees are well established in the field in which they work, both in terms of position and their tenure in the field, being in their field of work ranging from at least 5 years to several decades. While the results may not be completely representative of the industry and may be biased towards those with stronger industry networks and time in the industry, the results from the interviews provide a ground for the current state of the industry. Additionally, disagreement or agreement between interviewees is discussed.

Document and Archival Analysis

Documents and archival materials serve as an additional evidence source for convergence with the semi-structured interviews. The documents and archival materials used are that of government, industry, or other data and reports built from an established institution. Here, analysis follows the guidelines described by Bowen (2009) to assess the quality of the documents and understanding that these documents were created not for the primary purpose of this research, which introduces an innate bias into the documents (Bowen, 2009). Where publicly available data could not be found for triangulation (i.e., to support the findings in the interviews), the technical and scientific literature was referred to instead.

Trade Data

Trade data was used to triangulate interviewee claims on trade and market trends. Monthly export-value data for Washington State as downloaded from the U.S. Census Bureau's

USA Trade Online database (U.S. Census Bureau, n.d.). The Harmonized System (H.S.) (i.e., the system of labeling and coding traded goods globally) code that covers wild NTFP greenery is HS 0604.91 that includes fresh foliage, branches and other plant materials used for bouquets or ornamental purposes. While this is a broad category that is not specific to wild NTFP greenery, it may serve as a proxy to the overall market. Schlosser et al. (1991) found that a large amount of wild NTFP greenery is used for export. This study assumed that changes in the export market could be reflected in the trade data. Predecessor HS codes, from the 2012 revision, were included to reflect the consolidated HS code 0604.91 from 2012 onwards. Commodity quantity was not used as measurements were inconsistent across transportation modes and cargo under certain weights being shipped by truck or rail are not included in USA Trade Online databases.

The monthly export-value data was then converted into real values using a GDP deflator (Federal Reserve Bank of St. Louis, n.d.) and natural-log transformed to stabilize variance. From there, seasonal and trend decomposition via locally estimated scatterplot smoothing (LOESS) was used to develop a long-term trend outside of seasonal variation and irregularities (Cleveland et al., 1990). The developed seasonal and trend decomposition presents archival evidence that can be used for triangulation of economic themed statements from the interviewees.

USFS Cut-and-Sold Reports

Cut-and-Sold Reports from the United States Forest Service (USFS) were downloaded and cut and sold values and quantities were recorded across fiscal years 2008 to 2023 for majority Washington State National Forests in USFS Region 6: Olympic National Forest, Okanogan-Wenatchee National Forest, Mount Baker-Snoqualmie National Forest, Gifford

Pinchot National Forest, and Colville National Forest (U.S. Department of Agriculture, Forest Service, n.d.). Values were adjusted for inflation, using the U.S. Bureau of Labor Statistics Consumer Price Index, to represent 2025 numbers. Prior to 2008, special forest products were recorded in different metrics or were not reported at all. Only years after 2008 were considered for consistency in the data. All special forest products, other than firewood, were considered.

Results

Descriptive Results

Products

Interviewees indicate that the wild greenery NTFP industry is largely based on salal, beargrass, ferns, green huckleberry, red huckleberry, snake rush (*Equisetum hyemale* L.), and then evergreen tree species for the Christmas bough market including noble fir, silver fir, white pine, red cedar, and Douglas-fir. Salal and evergreen boughs make up the majority of the industry, with salal for export and evergreen boughs for the domestic market. Salal, and other greenery, is harvested from southern Oregon up to Vancouver Island, from the Cascades to the Coast, especially in the lower elevations. Few products come from eastern Washington and Oregon but include juniper and cones, particularly ponderosa pine.

Interviewees describe that harvesting greenery, in the case of salal and huckleberry, is done through breaking the stem rather than cutting the stem. This encourages regrowth, mimicking natural processes, which is supported by work that found breaking resulted in higher biomass returns than cutting (H. Ballard, 2004). The product must be of a floral grade, presenting quality length and no defects. Interviewees noted that this means that for greenery species, optimal conditions for floral grade products come from partial shaded plants in forest systems to get a balance of stem length and leaf density. Too sunny of locations result in a tight

short branch of greenery while too closed of a canopy result in plant die-off or leggy branches (i.e., branches that have long spacing between leaf nodes or have weak stem structure).

According to the interviewees, bough harvests vary by tree age, species, and elevation. Higher elevation firs may be harvested between the ages of 12 and 17 years whereas more productive sites for firs may be harvested as young as 6 years. White pine may be harvested in 4 years. Boughs may be harvested again after 2 or 3 years of regrowth. Typically, fir bough harvest should be maintained to the lower two-thirds of the tree and should leave one third of the green area of the harvested branch to allow for the tree to be vigorous and for branches to produce viable boughs in the future. Interviewees disagree whether boughs should experience a freeze before harvesting, with some interviewees noting that a freeze increases the needle retention rate but is not necessarily required.

Extension guidance largely supports interviewee guidance to bough harvesting. Extension guidance recommends a frost event prior to harvesting along with a couple of years for regrowth. However, between extension guidance and interviews, different tree species have different ages and conditions that make them prime for harvest. Survey work conducted in the 1980s found that the bough harvest season was 70 days between October and early December (W. E. Schlosser et al., 1991), suggesting that the bough harvest season has lengthened for some processors who are now harvesting in September or even August.

Economics

Interviewees describe the economic portion of the industry as three major sectors: the greenery export market to Europe, the domestic Christmas evergreen market, and the domestic greenery market. The greenery market in Europe is mostly salal for export, and interviewees

indicate that the market is driven by the general high demand in Europe for floral arrangements. The Christmas market in the United States is largely fueled by the cultural significance of the Christmas holiday. Domestic greenery typically supports other floral holidays in the United States, in particular Valentine's Day and Mother's Day, along with continuous funeral and wedding markets.

The Olympia area is considered by interviewees as the epicenter of the NTFP industry for the Pacific Northwest. Interviewees attribute this to the historical ports and trade route connections in the Olympia area, allowing for easy access to foreign markets by sea, rail, and air. The majority of exports from the Olympia processors travel via rail through Canada to the eastern Canadian seaports where it is then shipped to Europe. Some product is shipped via air to European markets or directly through sea, traveling through the Panama Canal.

Interviewees indicate that Olympia being the epicenter also means that harvesters bring product to Olympia from southern Oregon and from British Columbia, including the encompassing area from the Cascades to the Pacific Coast. While Olympia is typically the consolidation center of the NTFP market, there have been companies that have operated out of Vancouver Island and locations in Oregon, including Portland, Salem, and Eugene.

Products are typically collected under permits or lease agreements, according to interviewees. Processors lease land from forest landowners for a period of several years, then employ harvesters to collect from those leased lands. Harvesters also will obtain leases from forest landowners to collect product on a certain segment of land for a given year. Interviewees describe bough harvests as typically being yearly sales, where a timber stand is auctioned or leased out for the bough season.

Interviewees did not discuss exact prices for products or leases, nor were they asked directly. There are some documented valuations for brush, with recent bids ranging between \$1 and \$13 per acre per year (Table I-V) (Department of Natural Resources, 2026). Historically, reported values were estimated to around \$1 to \$2 per acre per year (Lynch & McLain, 2003; Thomas & Schumann, 1993). For noble fir boughs, processors have reported a price between \$0.20 and \$0.40 per pound from 1989 to 2018 (Table I-VI) (Blatner & Alexander, 1998; Oregon State University Extension Service, 2018; W. E. Schlosser et al., 1991). Prices for other products are sporadic and from the 1990s.

Table I-V: Reported Prices of Leases for Brush, including Salal, Huckleberry, Beargrass or Other Permitted Brush

Year	Price (\$/year/acre)	Source
1993	1.90	(Thomas & Schumann, 1993)
1994	1.00	(Lynch & McLain, 2003)
2012	~5.00	(Kane et al., 2012)
2023	5.00 to 11.00	(Kitsap County Parks Department, 2023)
2026	1.01 to 13.24	(Department of Natural Resources, 2026)

Table I-VI: Reported Prices Paid by Wholesalers and Processors to Harvesters for Noble Fir Boughs

Year	Price (\$/lb)	Source
1989	0.36	(Blatner & Alexander, 1998; W. E. Schlosser et al., 1991)
1994	0.27	(Blatner & Alexander, 1998)
1995	0.20	(Blatner & Alexander, 1998)
1996	0.30	(Blatner & Alexander, 1998)
2018	0.35 to 0.40	(Oregon State University Extension Service, 2018)

Workforce

Generally, interviewees describe the harvesting workforce as immigrant labor. The ethnic composition of the workforce is generally in flux. Interviewees attribute this to immigrant labor typically coming from countries where there is social unrest, conflict, or economic hardship. To

this end, interviewees noted that the workforce had an influx of Cambodian and Vietnamese immigrants during the series of wars during the late 1900s, and more recently, Central Americans and Indonesians.

The workforce, according to interviewees, typically are the first generation of immigrants, making a living while supporting their families. The children of these immigrants typically do not enter the NTFP workforce but rather enter other industries after their education. Entry into the industry happens through immigrants who know one another.

Just as the workforce changes, interviewees suggest that what products are harvested is influenced by the workforce. Interviewees suggested that different waves of immigrants picked up different products, such as Cambodians with beargrass. Similarly, some interviewees attribute the export greenery business to Cambodian immigrants who began harvesting in the Pacific Northwest.

Thematic Results

Trust and Relationships as Informal Governance

Interviewees emphasize that the NTFP greenery industry is built on trust between landowners, harvesters, and processors. Some participants indicate long-term relationships are important for the industry, indicating that working with the same individuals helps ensure landowners know that the product will be sustainably harvested and that harvesters will have continued access to the landowner's land for years to come. The relationship between landowners and NTFP producers can be reciprocal. One interviewee indicated that harvesters and processors provide an extra layer of security for landowners by being in their forested lands, reporting damage, illegal harvesting, and dumping. One interviewee noted that it may be difficult for some landowners to consider opening up their land for access, fearing that their

land may be damaged by harvesters. A couple of interviewees highlight that law enforcement, for patrolling and investigating illegal harvesting, is relatively weak on the landscape.

From the scientific literature, there is supporting evidence that the NTFP floral industry is largely built on relational networks that are built around the communication nodes of processors and landowners with little enforcement of regulations (Lynch & McLain, 2003; Watson et al., 2018). Researchers have speculated that the causal effect of this loosely regulated and secretive industry comes from it being built on undocumented immigrants and informal economies (Love & Jones, 2001; McLain & Lynch, 2010). The industry appears to operate largely on trust, with landowners contracting with familiar harvesters and processors. The relationship goes both ways where the harvesters and processors also provide security and surveillance to the landowner while sustainably managing their product, receiving continued access to the land. These comments describe a relational industry that relies on connection and experience rather than open channels of recruitment.

Dependence on the European Floral Market

Several participants pointed out that the European market is an important market for exporting NTFP greenery, especially salal. Some interviewees attributed the demand from Europe as a product of their floral tradition of daily flowers in the household, compared to American culture that is more focused on holidays and Christmas. To this, several participants noted the declining exports to Europe, attributing this to tariffs, nearby conflicts, and the economic pressure on European consumers. These participants warned that the NTFP greenery industry would suffer with further decline in trade to Europe through further or retaliatory tariffs, European consumers moving away from their floral tradition as purchasing power

decreases, or other floral products from locations with cheaper input costs become more prominent in the market. Nevertheless, a couple of interviewees indicated that their European customers perceive the NTFP greenery, particularly salal, as an environmentally friendly greenery with few inputs compared to agriculturally grown floral greens, supporting demand. Attitudinally, participants spoke regarding European markets with uncertainty, indicating that the markets could improve.

Washington State trade data from USA Trade Online using HS code 0604.91, when adjusted and decomposed, demonstrates a decline in trade activity to Europe (Figure III). Europe generally maintained greater than 90% of the global export market from Washington State, supporting claims of the significant space that Europe plays in the Washington greenery market (Figure IV). This holds for previous findings for the industry that Europe was the largest trading partner (W. Schlosser et al., 1991). This data supports interviewee claims that the export market to Europe is declining (Figure IV).

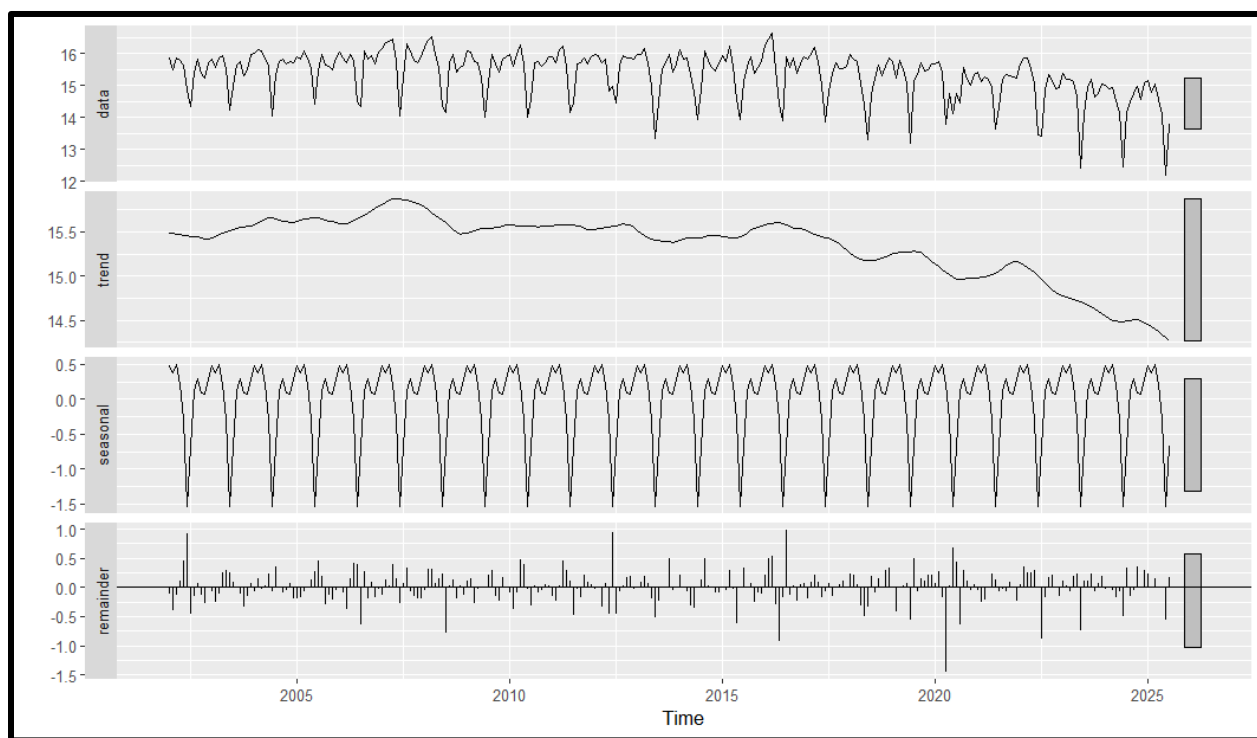


Figure III: Inflation adjusted export value reported in 2025 dollars for HS 0604.91 from Washington State to Europe. (a) The adjusted raw data, representing the monthly adjusted value. (b) The smoothed trend line, demonstrating an overall decline in exports over time, especially after 2016. (c) The seasonal variation as a by-product of smoothing that illustrates strong seasonal change in exports. (d) The remainder value that could not be explained by the seasonal changes, representing potential anomalies or shocks.

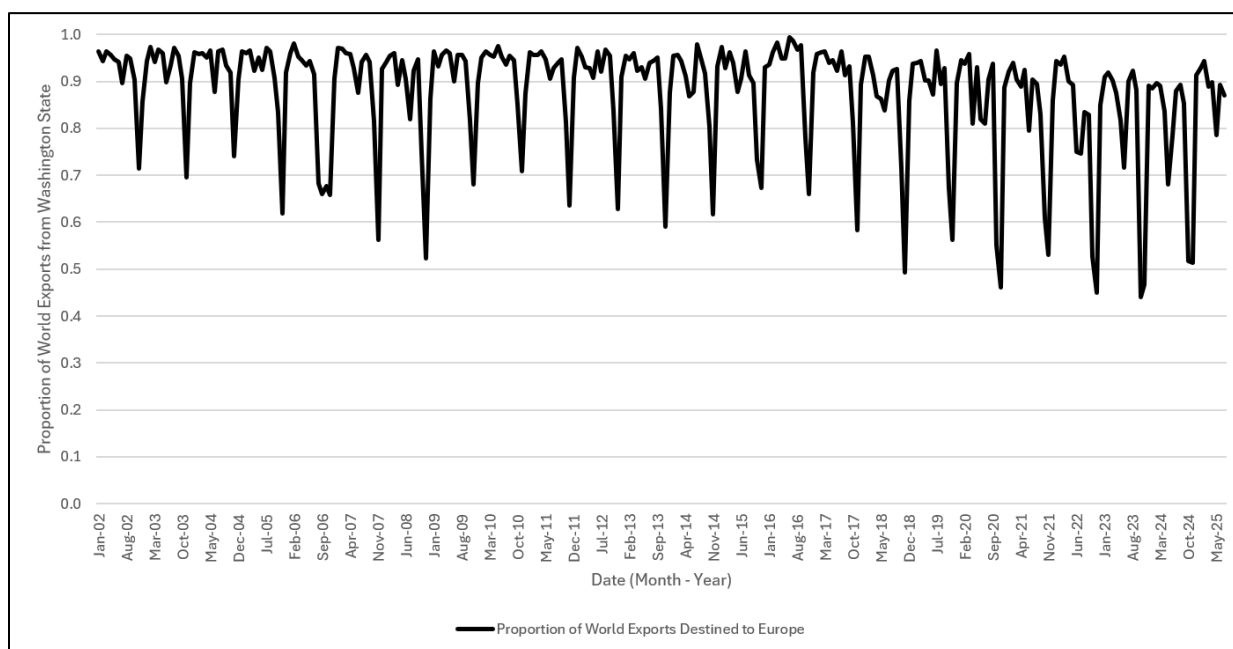


Figure IV: Proportion of inflation adjusted world export value reported in 2025 dollars for HS 0604.91(fresh foliage, branches, and other parts of plants, without flowers, or flower buds, and grass bouquets) from Washington State headed to Europe from January 2002 to July 2025.

An Immigrant Shaped Industry Facing Vulnerabilities

Most of the participants noted that the workforce is made up of mostly immigrant labor.

A couple of the interviewees noted that laborers shaped how the industry has developed and what products are currently sold. One interviewee attributed the growth of the European market to Cambodian immigrants who started picking and selling salal. Another interviewee noted what products are picked depend on ethnicity of the immigrant. Two interviewees tell of how immigrants typically only stay in the industry for one generation, supporting their family as their children go to school and enter different industries.

A couple of participants noted that that the workforce includes undocumented immigrants. These interviewees expressed concern over the current federal administration's handling of immigration policy and public arrests and raids of immigrants. One interviewee suggested that these raids have not yet occurred with their workforce, but it has increased the wariness of the laborers going to the field. A few interviewees expressed concern about what would happen to the workforce should immigrant laborers become difficult to recruit.

The scientific literature has pointed to the fact that the majority of the NTFP greenery industry workforce is immigrant labor (Lynch & McLain, 2003; McLain & Lynch, 2010). In part, the undocumented nature of the workforce led to tensions during the early 2000s as policymakers worked to address illegal harvesting and definitions of employees of the NTFP industry (McLain & Lynch, 2010). Compared to other sectors of the NTFP industry, such as the mushroom industry, the NTFP greenery industry is recorded to be notably immigrant labor with a large portion of undocumented laborers (McLain & Lynch, 2010; W. Schlosser & Blatner, 1995a). The undocumented nature of the workforce is attributed to industry secrecy and hesitancy to engage in policymaking and research (McLain & Lynch, 2010).

What was heard in the interviews and found in the literature indicate that immigrant labor is one of the primary reasons for the growth of the international market and the NTFP greenery industry in general. Interviews support the idea that not much has changed with the labor force over the past few decades, suggesting findings from the 1990s roughly remain true today. The undocumented nature of the workforce creates an institutional vulnerability for the industry as it navigates immigration policy and a workforce that typically only engages in the work for one or two generations.

Prioritizing the Non-Timber Objectives

Almost all the interviewees discussed how NTFPs, especially greenery, are rarely the focus of landowners, especially timber landowners. The exception is with boughs, where some participants noted that some landowners will grow noble fir only for boughs, scraping the timber once the unit is too old to produce boughs, and some processors are starting to lease land for the sole purpose of growing trees through bough age. To this end, some participants note landowners prioritize timber production over NTFP greenery, as greenery is seen as an incidental harvest.

Of these participants, there was a mixture of lamenting over landowners not incorporating NTFP greenery into their management plans but also seeing opportunity in amending timber management plans to increase NTFP greenery production. A few of the interviewees highlighted the adding NTFP greenery to a landowner's portfolio helps cover costs of silviculture activities and that including greenery harvest is a low-barrier opportunity. These interviewees suggested that landowners could further space out their trees, extend rotations,

and provide more warning for when the landowner intends to do a thinning or harvest to allow harvesters time to extract the resource before it is damaged by operations.

Some participants turned their attention to the National Forests. These participants suggested that bough and greenery production on the National Forests are declining as the National Forests have grown older trees and more canopy cover. Here, interviewees suggested that forest management on the federally managed lands should include more heterogeneity in stand ages and forest gaps to allow for greenery to grow in the understory and for trees to be of bough production age.

Cut-and-Sold data from the USFS is consistent with interviewee descriptions. Since 2008, the value of boughs coming from the Gifford Pinchot National Forest, the most productive NTFP National Forest unit in Washington State, has been decreasing from \$957,820 (3,913 tons) to \$52,282 (323.2 tons) in 2023 with values adjusted to 2025 USD. Similarly, permitted foliage value has decreased from peaks in 2013 of \$115,689 to \$21,022 in 2023. Overall, the revenue from NTFPs on National Forest lands in Washington has decreased from a peak in 2008 of \$2,207,601 to \$355,662 in 2023 (Figure V). While other factors may influence this, such as availability of Forest Service employees to coordinate NTFP harvests, these trends do support the claim by interviewees.

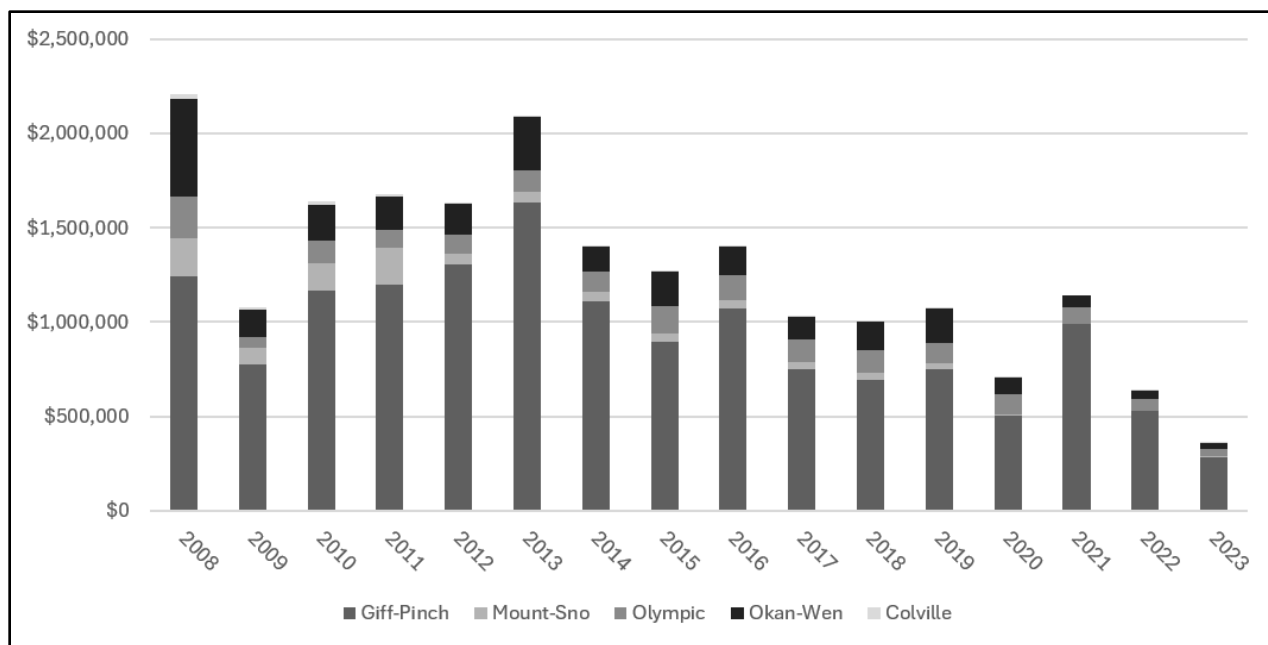


Figure V: Cut-and-Sold data for Washington State USFS National Forest units for special forest products for 2008 to 2023 in inflation adjusted total value to 2025 dollars, including firewood.

From the interviews, the scientific literature, and the USFS data, it is apparent that NTFPs can provide income to landowners through leases, permits, or contracts. The passive income that it provides may help offset operational or personal costs, such as the passive income from salal leases currently ranging between \$1 and \$13 per acre per year (Department of Natural Resources, 2026). However, the current management regime of most forest landowners only allows for incidental harvesting of greenery, other than boughs, as timber is prioritized. Here, the case can be built that forest management encourages different stages of succession and allows for forest gaps could help the NTFP greenery industry, supporting species that need forest gaps for reproduction, such as beargrass, and providing more habitat for understory species to develop into quality floral products. No matter the case, timber production and NTFP greenery coexist in a manner that supports the operations of each other.

Other Challenges and Opportunities

Illegal and Unpermitted Harvesting

Interviewees were asked about the current regulatory framework around NTFPs. Nearly universally, interviewees indicated that the current regulatory framework is working for them and that any further regulations would hinder the industry. Interviewees attribute this to decreased illegal harvesting and the sustainable nature of the industry.

Similarly, interviewees report minimal unpermitted or illegal harvesting. Some indicate that some unpermitted harvesting occurs when new harvesters try to enter the industry without any prior knowledge. Other interviewees note that there is still bough theft, especially high value bough products, like western red cedar, or in the national forests where access is easy and enforcement is stretched thin.

Forest Farming

One interviewee indicated that there may be opportunities with family forest owners who own forest land but are not in the NTFP market through forest farming (i.e., organized management of NTFPs intentionally rather than incidentally). These lands are challenged as the acreage is relatively small and may not warrant a single property for greenery harvest, unless it is a high value product such as red cedar. Forest farming may be a more appropriate approach for family forest owners, according to the interviewee, or the approach of cooperatives that allow for harvest across several nearby family forest owners.

Education and Connection

Interviewees indicated that there is a lack of connection amongst the players in the NTFP industry, from landowners to processors to harvesters. Interviewees suggest that adding connections between these players for knowledge sharing may be useful by disseminating

experiential knowledge, what make good contracts, and knowledge about sustainable harvesting and regulations.

Education was described several times as a potential challenge for those who want to enter into the industry. For harvesters, interviewees noted that occasional unpermitted harvesting occurs when prospective harvesters attempt to enter the industry without knowing how the industry works or what kind of product processors are buying. For small family forest owners, barriers include knowing how to sustainably harvest the product, how to develop a good contract with a harvester, and how to enter the market.

Climate Change

Interviewees, while skeptical about the impacts of climate change, expressed concern over climate change introducing more pathogens, pests, and extreme weather events. These side-effects of climate change may result in decreased quality products. For general trends, some interviewees worried a drier climate would impact overall growth or shift habitats. Just as climate change was identified as a challenge, certain climate outcomes may be supportive of the industry. Interviewees indicated that warmer and wetter climates would result in greater growth of understory greenery, noting that warmer winters and wet years lead to greater production. While current species distribution modeling does not support this claim (Prevéy, Parker, & Harrington, 2020; Prévéy, Parker, Harrington, et al., 2020); nevertheless, current climate projections for the Pacific Northwest does suggest a possible wetter future (Dalton et al., 2013). Nevertheless, an interviewee suggested that climate change may lead to more forest fires that result in more forest openings to foster NTFPs.

New Products

Interviewees suggested another opportunity lies in new products or the further development of markets for existing products. Some interviewees point to further expansion of mushrooms, big leaf maple syrup, Oregon grape, or other forest species not typically harvested as NTFPs in the region, such as tea and wild ramps. The expansion into new products also includes non-native species, such as wasabi, that are planted for the purpose of later harvest alongside timber, aligning more with forest farming than true wild NTFP harvests. In the case of big leaf maple syrup and Oregon grape, the current market outlets are weak and may require some assistance in becoming more developed. In another lens, interviewees indicated that a cultural change in the domestic market may further support the floral green market if American floral cultural becomes more akin to that of the European floral tradition.

Discussion

This exploratory case study set out to examine how the NTFP greenery industry is organized, sustained, and constrained, to provide an update since the last studies were conducted a couple decades ago. The industry is organized through a series of formal and informal relationships across several different industry players, including landowners, harvesters, processors, wholesalers, brokers, and final retailers. By interviewing processors and landowners and the communication nodes of the industry (Lynch & McLain, 2003), the case study describes a system of permits and informal, trust-based relationships that govern land access for harvesters and processors. Through these relationships, a supply chain ranging from British Columbia to southern Oregon supply product to the processors in Washington, who consolidate and send the product to markets, domestic and foreign. From the descriptions from

interviewees, the structure of the industry seems relatively similar to that of the 1990s.

However, some of the processors of the 1990s are no longer present when searching for initial interviewees, suggesting that the industry has shrunk. Given there is no strong database and not all processors have public facing websites or pages, industry size is difficult to report.

The industry is then sustained by the very formal and informal aspects of governance, especially through the development of long-term relationships that provide reciprocal benefits to harvesters, processors, and landowners. The industry relies on an immigrant workforce for harvesting and processing. Economically, the foreign export market to Europe and the domestic seasonal demand support the industry. Continued compatibility with timber management, allowing for incidental harvest of greenery, supplies the industry.

The industry faces several constraints. Economically, Europe has become a dominate destination for floral greenery products, helping the industry grow in the Pacific Northwest. However, this has made the industry dependent on the European consumption of floral greenery throughout the year, while bidding time between the United States market during holidays and the Christmas season. This leaves the industry vulnerable to variations in the international market that come from domestic foreign policy affecting trade and global events that impact the purchasing power of the European consumer.

The workforce is described as similar over the years, keeping with typically immigrants coming from areas of unrest or conflict. Just as the industry was built upon this workforce, the industry now faces vulnerabilities associated with domestic immigration policy. Nevertheless, the industry has provided a steppingstone for immigrant families to have employment, without need for documentation, to support the next generation to go to school and enter higher paying

industries. This too means the industry is reliant on a flow of immigrants into the region. In the absence of immigrant labor, the industry would likely dissolve.

In part, the type of industry workforce has supported a largely unregulated and ill-monitored industry, built on secrecy, trust, and long-term relationships. The case study has demonstrated that interviewees do not see the need for further state intervention in regulation, following the addition then rescission of regulations and policies in the early 2000s (McLain & Lynch, 2010). To this end, the industry is incentivized to have limited access and oversight, increasing the difficulty for research and reporting on the industry.

Data Convergence, Divergence, Absence

This case study demonstrates convergence between interviews and available economic data on the downward trend of economic growth in the greenery NTFP industry through the trade data of overall floral greens being exported from Washington State (Figure III; Figure IV). Additionally, the complications of the National Forests are supported by the Cut-and-Sold reports demonstrating decreasing bough production from federal lands (Figure V). The literature supports claims that workforce is largely immigrant and undocumented and the existing trade networks with Europe (Hansis, 1996; Lynch & McLain, 2003; W. Schlosser et al., 1991).

Divergence between interviewee claims and the literature occurs during discussions of climate change, highlighting the uncertainty interviewees perceive and what the scientific literature discusses. While some interviewees worry about climate impacts that are described in the literature (Prevéy, Parker, & Harrington, 2020; Prévéy, Parker, Harrington, et al., 2020; Still et al., 2023), others find that this may provide an opportunity for certain products. This divergence

also highlights the lack of data for climatic impacts on specific NTFP products and the understanding of how species will ultimately react on the landscape to a changing climate.

There is no available data on workforce composition and background, regional economic contribution, sustainable product populations, education, and illegal harvesting. The absence of data does not disprove interviewee claims; rather, these present areas for further investigation to challenge or support the results presented here. Nevertheless, these highlight areas where the data may not be as strong as desired.

Additionally, some supporting documents may be viewed as outdated or relatively old to the point that it may not support interviewee claims. There are no available sources on workforce composition of the industry; however, several scientific articles and dissertations support claims that the workforce is largely immigrant workers (Hansis, 1996; Lynch & McLain, 2003) whose origins fluctuate according to where there is social unrest or conflict. These articles and dissertations are several decades old, leaving many years of uncertainty since these reports and current conditions. While these do compliment interviewee claims, they do not provide contemporary support.

Publicly available data also comes with its own biases (Prior, 2003). The Cut-and-Sold data from the USFS only tells the story of the value and quantity sold versus the value and quantity cut and does not provide the rationale of why that much was sold or cut. These missing links fail to provide a full picture of the industry. Nevertheless, the convergence, divergence, or absence of data helps provide support or opposition.

Management Implications

While the case study presents an update on the NTFP industry for the Pacific Northwest, it also highlights the limitations of publicly available data, the scientific literature, and practitioner knowledge. Interviewees indicate that climate change may have a positive or negative effect on several NTFP products. The presented literature has modeled some of these effects (Prevéy, Parker, & Harrington, 2020; Prévéy, Parker, Harrington, et al., 2020). Without comprehensive monitoring and data collection, the actual effects of a changing climate will not be well understood or reported.

These gaps in the case study and the literature highlight what others have already indicated as an existing inventory and monitoring issue that lead to issues around adaptation and innovation findings from the scientific community (Frey et al., 2023). The industry remains relatively unknown in terms of economic impact, number of employees and individuals benefiting, and the amount of product that is available, or sustainable, on the landscape. Without investment to address these gaps, there will be little that the scientific community can do to help with adaptation, mitigation, or innovation for the industry.

The lack of information, along with the refusal rate for interviews, suggest that the industry remains relatively secretive and hard to study. From this, it is clear that any researcher or agency that wishes to engage in the industry for further research or management will need to invest in trust and network-building.

Further Research Needs

Presented here is the need for further investigation into the NTFP industry in the Pacific Northwest, involving both qualitative and quantitative studies that document the social

implications, economic contributions, and ecological impacts of the industry. These research needs are not new and have long been reported by others in the field (Frey et al., 2023).

However, the Pacific Northwest would benefit from the following specific research:

- Inventory and monitoring of local NTFP species;
- Monitoring and social networks of the workforce;
- Economic contributions of specific NTFP species;
- Social receptiveness of NTFP products;
- Ecological impacts of NTFP harvesting;
- Environmental tradeoffs of local NTFP harvesting and product substitutes;
- Potential of forest-farming of local NTFP species or other non-native species;
- Industry profiling and barriers to entry; and
- Comprehensive trade networking and product tracking.

Such research would support the industry and the general understanding of how NTFPs support developed economies and social connectedness to nature. Additionally, this study did not meaningfully explore the important edible or medicinal NTFPs in the Pacific Northwest.

Limitations

The study is limited by the very information gaps that have been identified. However, other limitations persist. Overall, the case study is limited by the number of interviewees. The number of interviewees who declined or refused to respond may be indicative of the distrust and secrecy of the industry noted by others (Love & Jones, 1997; Lynch & McLain, 2003). This limitation and similar limitations others have faced frames that those who wish to conduct

research in this field will need to devote time to trust-building and relationships, perhaps on the scale of complete careers researching the field. Additionally, this may be a demonstration that research institutions may need to focus on repairing and building community relations to conduct research that benefits hard-to-reach and hard-to-observe communities.

While there were available data for triangulation between interview data, trade data, and harvest data, these data were imperfect in its how it supported the interviews, not being perfect representations NTFPs. The trade data, from USA Trade Online, encompasses more than wild grown foliage and boughs. With the presentation of the data with the interviewee results, the assumption is made that the data and interviews converge on the same finding. Similarly, the cut-and-sold data from the Washington State National Forests converges with the findings in the interviews. However, it is possible that these trends may be associated with staffing being cut for special forest products, shifts in objectives, or other agency related factors rather than the claimed forest management.

Additionally, this case study only considered an exploratory case on the NTFP greenery industry of Washington State. It was limited by its scope to one portion (i.e., the NTFP greenery industry) of the overall, interconnected NTFP industry and limited by those who were interviewed. While it was justified to focus on portions of the industry, results need to be considered in the context that the entire industry relies on other portions of the industry and there are voices and communities not represented here.

The study does not discuss dynamics from the harvester's perspective nor from the perspective of Native Nation and indigenous uses of NTFPs. Work with harvester's and Native Nations highlights the importance of these communities and their roles in the NTFP industry (H.

L. Ballard & Huntsinger, 2006; Lynch & McLain, 2003). However, this case study was not designed nor had the resources to understand the complexity of harvester conditions and Native Nation usage and contribution to the industry. Further research should dedicate work to these communities and their unique perspectives and contributions.

Methodologically, the study was limited in its design to only consider interviews. Many scoping conversations and tours of operations were conducted while doing this research. However, these conversations were not recorded or included in the results here as they were not part of the design submitted for IRB approval. Many more insights and results could be expanded upon with the inclusion of this information. Future designs should incorporate participant observation into their methodologies to capture the most data possible.

Conclusions

This exploratory case study investigated the NTFP greenery industry, described how the industry is organized, sustained, and constrained. The industry is organized as a regional supply chain that has its processing center in Washington, harvesting and consolidating product from British Columbia and south through southern Oregon. The industry is supported by domestic markets around holidays and the Christmas season and the international market of floral greens to Europe for daily floral consumption. The industry is sustained through trust and long-term relationships that provide land access, security, and informal monitoring of the product and land conditions.

Evidence indicates that the industry currently faces several vulnerabilities and constraints with current economic prospects and uncertainty around the workforce. Declining trade with Europe with unfavorable federal foreign policy which threatens the international

export market that supports the industry throughout the year. Current federal immigration policy leaves those in the workforce facing uncertainty. Current land management is limiting where products can be secured and harvested.

The industry is now in a tumultuous space where continued economic trends and immigration policy may force the industry to reorganize and adapt. Without continued trade to Europe, industry members will need to consider new products or shutter operations outside of the Christmas season. Without a steady flow of immigrant labor, the industry will likely fall apart quickly. Opportunities into forest farming or marketing to increase domestic demand may help the industry weather the storm of economic downturns and unfavorable immigration policy.

Much is left to learn about the industry and to document its practices, economics, workforce, and sustainability. That future research and monitoring will require trust and relationship building by researchers and regulators alike to understand this industry that has been known for secrecy and difficulty to observe. Nevertheless, the NTFP greenery industry provides an important rural economy for the Pacific Northwest, supporting jobs across the region and providing a local product across the nation and the world.

References

- Arnett, J., & Crawford, R. (2007). *The Status of Huckleberries in Washington State* (Report 2007-07). Washington State Department of Natural Resources.
- Baldy, C. (2013). Why we gather: Traditional gathering in native Northwest California and the future of bio-cultural sovereignty. *Ecological Processes*, 2(17).
- Ballard, H. (2004). *Impacts of Harvesting Salal (Gaultheria shallon) on the Olympic Peninsula, Washington: Harvesters Knowledge, Science, and Participation* [Dissertation, University of California, Berkeley]. <https://www.proquest.com/docview/305214112?pq-origsite=gscholar&fromopenview=true&sourcetype=Dissertations%20%20Theses>
- Ballard, H. L., & Huntsinger, L. (2006). Salal Harvester Local Ecological Knowledge, Harvest Practices and Understory Management on the Olympic Peninsula, Washington. *Human Ecology*, 34(4), 529–547. <https://doi.org/10.1007/s10745-006-9048-7>
- Blatner, K. A., & Alexander, S. (1998). Recent price trends for non-timber forest products in the Pacific Northwest. *Forest Products Journal*, 48(10), 28–34.
- Blatner, K. A., Cohn, P. J., & Fight, R. D. (2010). Returns from the Management of Noble Fir Stands for Bough Production and Sawtimber. *Western Journal of Applied Forestry*, 25(2), 68–72. <https://doi.org/10.1093/wjaf/25.2.68>
- Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. *Qualitative Research Journal*, 9(2), 27–40. <https://doi.org/10.3316/QRJ0902027>
- Buttolph, L., & Jones, E. (2012). *Evergreen Boughs: A Brief Introduction to Harvesting and Marketing from Small Private Forestlands in the Pacific Northwest* (Fact Sheet No. 4; Income Opportunities for Small Woodland Owners). Institute for Culture and Ecology. https://knowyourforest.org/sites/default/files/documents/Evergreen_boughs.pdf
- Chamberlain, J., Emery, M., & Patel-Weyand, T. (2018). *Assessment of Nontimber Forest Products in the United States Under Changing Conditions* (General Technical Report SRS-232). U.S. Forest Service: Southern Research Station. <https://doi.org/10.2737/SRS-GTR-232>
- Cleveland, R., Cleveland, W., McRae, J., & Terpenning, I. (1990). STL: A Seasonal-Trend Decomposition Procedure Based on Loess. *Journal of Official Statistics*, 6(1), 3–72.
- Cocksedge, W., & Titus, B. (2006). Short-term response of salal (*Gaultheria shallon* Pursh) to commercial harvesting for floral greenery. *Agroforestry Systems*, 68, 103–111. <https://doi.org/https://doi.org/10.1007/s10457-006-9001-1>
- Continental Floral Greens acquires The Hiawatha Corporation* | *Produce News*. (n.d.). Retrieved December 2, 2024, from <https://theproducenews.com/floral/continental-floral-greens-acquires-hiawatha-corporation>
- Dalton, M., Mote, P., & Snover, A. (Eds.). (2013). *Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities*. Island Press.

- Department of Natural Resources. (2026). *Specialized Forest Products (Brush) Lease Auction Summary for the South Puget Sound Region* [Memorandum]. Washington State Department of Natural Resources.
- Dexter, L. (2006). *Elite and Specialized Interviewing*. ECPR Press.
- Federal Reserve Bank of St. Louis. "Federal Reserve Economic Data | FRED | St. Louis Fed." Accessed August 20, 2026. <https://fred.stlouisfed.org/>.
- Fredrickson, S. (2000). *Non-timber forest products: A study of salal productivity, inventory of commercial plant and fungus species, and recommendations for management on the Nanaimo rifle range lands* [MSc Thesis]. Royal Roads University.
- Frey, G. E., Chamberlain, J. L., & Jacobson, M. G. (2023). Producers, production, marketing, and sales of non-timber forest products in the United States: A review and synthesis. *Agroforestry Systems*, 97(3), 355–368. <https://doi.org/10.1007/s10457-021-00637-3>
- Hansis, R. (1996). The harvesting of special forest products by Latinos and Southeast Asians in the Pacific Northwest: Preliminary observations. *Society & Natural Resources*, 9(6), 611–615. <https://doi.org/10.1080/08941929609380999>
- Kadushin, C. (1968). Power, Influence and Social Circles: A New Methodology for Studying Opinion Makers. *American Sociological Review*, 33(5), 685–699. <https://doi.org/10.2307/2092880>
- Kane, J., Hall, J., Hanson, K., & Bowden, B. (2012). *Nisqually Community Forest Phase I Project Summary*. Nisqually Land Trust.
- Kitsap County Parks Department. (2023). *2023-007 RFQ for Brush License for Kitsap County Properties*. Kitsap County Parks Department.
- Kuhnlein, H., & Turner, N. (1991). *Traditional Plant Food of Canadian Indigenous Peoples: Nutrition, Botany and Use* (1st ed.). Routledge.
- Landgren, C., & Freed, J. (1998). *Harvesting and Marketing Noble Fir Boughs from Christmas Tree Plantations* (EC No. 1500). Oregon State University Extension Service.
- Love, T., & Jones, E. (1997). Grounds for Argument: Local Understandings, Science, and Global Processes in Special Forest Products Harvesting. In N. Vance & J. Thomas (Eds.), *Special forest products: Biodiversity meets the marketplace* (pp. 70–87). United States Department of Agriculture.
- Love, T., & Jones, E. (2001). Why Is Non-Timber Forest Product Harvesting an "Issue"? Excluding Local Knowledge and the Paradigm Crisis of Temperate Forestry. *Journal of Sustainable Forestry*, 13(3–4), 105–121. https://doi.org/10.1300/J091v13n03_10
- Lynch, K., & McLain, R. (2003). *Access, labor, and wild floral greens management in western Washington's forests*. (General Technical Report PNW-GTR-585; p. 61). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- McLain, R. (2000). *Controlling the Forest Understory: Wild Mushroom Politics in Central Oregon* [Dissertation]. University of Washington.

- McLain, R., & Lynch, K. (2010). Managing Floral Greens in a Globalized Economy: Resource Tenure, Labour Relations and Immigration Policy in the Pacific Northwest, USA. In S. Laird, R. McLain, & R. Wynberg (Eds.), *Wild Product Governance: Finding Policies that Work for Non-Timber Forest Products*. Earthscan.
- Oregon State University Extension Service. (2018). *Tall Timber Topics* [Newsletter]. Oregon State University Extension Service.
- Peter, D. H., & Harrington, T. B. (2023). Three-Year Effects of Crown Removal by Clipping or Burning on Beargrass (*Xerophyllum tenax*) Size and Biomass. *Northwest Science*, 96(1–2). <https://doi.org/10.3955/046.096.0101>
- Peter, D. H., Harrington, T. B., & Thompson, M. (2017). Effects of the Light Environment and Stand History on Beargrass (*Xerophyllum tenax*) Morphology and Demography. *Northwest Science*, 91(4), 367–382. <https://doi.org/10.3955/046.091.0406>
- Prevéy, J. S., Parker, L. E., & Harrington, C. A. (2020). Projected impacts of climate change on the range and phenology of three culturally-important shrub species. *PLOS ONE*, 15(5), e0232537. <https://doi.org/10.1371/journal.pone.0232537>
- Prevéy, J. S., Parker, L. E., Harrington, C. A., Lamb, C. T., & Proctor, M. F. (2020). Climate change shifts in habitat suitability and phenology of huckleberry (*Vaccinium membranaceum*). *Agricultural and Forest Meteorology*, 280, 107803. <https://doi.org/10.1016/j.agrformet.2019.107803>
- Prior, L. (2003). *Using Documents in Social Research*. SAGE Publications Ltd.
- Saldana, J. (2009). *Coding Manual for Qualitative Researchers*. SAGE Publications. <https://ebookcentral-proquest-com.offcampus.lib.washington.edu/lib/washington/detail.action?docID=585421>
- Schlosser, W., & Blatner, K. (1995a). Economic and Marketing Implications of the Wild Edible Mushroom Harvest in Washington, Oregon and Idaho. *Journal of Forestry*, 93, 31–36. <https://doi.org/10.1093/jof/93.3.31>
- Schlosser, W., & Blatner, K. (1995b). The Wild Edible Mushroom Industry of Washington, Oregon and Idaho: A 1992 Survey. *Journal of Forestry*, 31–36.
- Schlosser, W., & Blatner, K. (1997). *Special Forest Products: An East-Side Perspective* (General Technical Report PNW-GTR-380). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. <https://www.govinfo.gov/content/pkg/GOVPUB-A13-PURL-gpo45297/pdf/GOVPUB-A13-PURL-gpo45297.pdf>
- Schlosser, W., & Blatner, K. (2004). *Pacific Northwest Noble Fir: The king of wreaths, charms, and other Christmas ornaments* (Extension No. MISC0532). Washington State University Extension. <http://resource-analysis.com/wp-content/uploads/2018/10/KingOfWreaths.pdf>

- Schlosser, W., Blatner, K., & Chapman, R. (1991). Economic and Marketing Implications of Special forest Products Harvest in the Coastal Pacific Northwest. *Western Journal of Applied Forestry*, 6(3), 67–72.
- Schlosser, W., Blatner, K., & Zamora, B. (1992). Pacific Northwest Forest Lands Potential for Floral Greenery Production. *Northwest Science*, 66(1).
- Schlosser, W. E., Blatner, K. A., & Chapman, R. C. (1991). Economic and marketing implications of special forest products harvest in the Coastal Pacific Northwest. *Western Journal of Applied Forestry*, 6(3), 67–72.
- Shaw, E. (1949). *Minor Forest Products of the Pacific Northwest* (Research Notes No. 59). Pacific Northwest Forest and Range Experiment Station Puget Sound Branch.
- Still, C. J., Sibley, A., DePinte, D., Busby, P. E., Harrington, C. A., Schulze, M., Shaw, D. R., Woodruff, D., Rupp, D. E., Daly, C., Hammond, W. M., & Page, G. F. M. (2023). Causes of widespread foliar damage from the June 2021 Pacific Northwest Heat Dome: More heat than drought. *Tree Physiology*, 43(2), 203–209.
<https://doi.org/10.1093/treephys/tpac143>
- Thomas, M., & Schumann, D. (1993). *Income Opportunities in Special Forest Products* (Agriculture Information Bulletin No. 666). U.S. Department of Agriculture, Forest Service.
- Turner, N., & Cocksedge, W. (2001). Aboriginal Use of Non-Timber Forest Products in Northwestern North America. *Journal of Sustainable Forestry*, 13(3–4), 31–58.
https://doi.org/10.1300/J091v13n03_04
- U.S. Census Bureau. (n.d.). *USA Trade Online* [Database].
- U.S. Department of Agriculture, Forest Service. (n.d.). *Forest products cut and sold from the national forests and grasslands* [Data set].
- Vance, N., Borsting, Pilz, D., & Freed, J. (2001). *SPECIAL FOREST PRODUCTS: Species Information Guide for the Pacific Northwest* (General Technical Report PNW-GTR-513). Department of Agriculture, Forest Service, Pacific Northwest Research Research Station.
https://www.fs.usda.gov/pnw/pubs/pnw_gtr513.pdf
- Watson, K., Christian, C., Emery, M., Hurley, P., McLain, R., & Wilmsen, C. (2018). Social Dimensions of Nontimber Forest Products. In J. Chamberlain, M. Emery, & T. Patel-Weynand (Eds.), *Assessment of nontimber forest products in the United States under changing conditions*.
- Welch, C. (2006, June 6). A war in the woods. *The Seattle Times*.
<https://archive.seattletimes.com/archive/?date=20060606&slug=salal06m>
- Winkler, D. (2023). *Fruits of the Forest: A Field Guide to Pacific Northwest Edible Mushrooms*. Skipstone.

Yin, R. (2017). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE Publications, Inc.

Supplemental I-I: Interview Questions

1. How would you describe your relationship to the non-timber forest product world?
 - a. If industry: what products do you manage?
2. How would you describe the current state of the non-timber forest product industry in the Pacific Northwest?
 - a. How would you describe the different regions of the Pacific Northwest contributing to the non-timber forest product industry?
 - b. How would you describe how the non-timber forest product industry has changed over the past 20 years?
 - c. How would you describe the economic condition of the industry?
3. What would you say are the major few issues that the non-timber forest product industry is facing in the Pacific Northwest?
4. What would you say are some major opportunities for the non-timber forest product industry in the Pacific Northwest?
5. How would you describe the workforce of the non-timber forest products industry currently?
 - a. How has that changed in the past 20 years?
6. What are your views on the regulatory framework that non-timber forest products operate under?
7. How sustainable do you think current practices are for the procurement and sale of non-timber forest products?
 - a. Unpermitted harvesting of some non-timber forest products has been a point of contention for the industry for several decades. Do you have any insight regarding unpermitted harvesting?
8. How would you say is the working relationship between the major players of the non-timber forest product industry in the Pacific Northwest? (Such as other industries, federal agencies, state agencies, landowners?)
9. How does seasonal weather variations, such as spring rains or fall frosts, affect your business?
 - a. How concerned are you about the stability of weather patterns year-to-year?
 - b. Are there certain weather events or extreme weather that you worry about?
 - c. For any of these, how concerned are you about the future and potential climate change?
 - d. How does the ecology of NTFPs affect when you harvest or sell products?
10. Is there anything we have not addressed that you think we should know?

Chapter II: Climate Change and Shifting Seasonal Harvest Windows for Evergreen Boughs in the Pacific Northwest

Abstract

Evergreen boughs are a seasonal non-timber forest product (NTFP) in the Pacific Northwest, especially in western Washington and Oregon, that support rural economies and cultural traditions around the winter holidays. The harvest season of evergreen boughs revolves around product quality, site access, labor, and market demand. Several of these factors, such as product quality, are determined through observable climatic cues. Managers may use frost events as an observable indicator of the physiological processes of cold acclimation and dormancy onset in evergreen trees that are associated with improved needle retention in harvested trees and boughs. Little research has been conducted on how shifting climatic conditions will affect evergreen boughs as an economic and cultural product of the Pacific Northwest.

This chapter explores the relationship between how observable climatic cues under future climate scenarios will affect the harvest window for evergreen boughs for the winter holiday season. Downscaled data from 17 global climate models under SSP245 were ensembled to estimate developed harvest window indicators for 2015-2100. The harvest window was developed as the time between the last hot-day event of the late summer through the first snow event of the fall with the first frost event marking a potential shift product quality during the harvest window. These indicators were summarized by ownership and ecoregion.

Results indicate a shift across all climatic indicators for the harvest window as the century progresses. Particularly, the first frost may occur later in the year with the probability of frost occurring by November 15th declining by 11.5 to 15.8 percentage points on private forestlands in Washington and Oregon in the late portion of the century, dropping probabilities on private lands to between 43% and 49%. Ecoregion results demonstrate that lowland (49.2% to 65.2% in 2015-2025) and coastal (41.2% to 55.3% in 2015-2025) ecoregions typically have lower probabilities of frost occurrence compared to montane (88.2% to 93.9% in 2015-2025) ecoregions, with montane ecoregions less affected in the late century (-4.5 to -8.4 percentage point change).

These results suggest that lowland and private forestlands may have less reliable frost events by the century compared to montane and federal forestlands. These findings set the groundwork to understand the climate vulnerability of a culturally important NTFP where the harvest season is confined by climate-induced physiological processes and a cultural holiday.

Introduction

Evergreen boughs, a seasonal non-timber forest product (NTFP), are a revenue source for the wild floral green industry, which includes other wild greenery harvested for floral design and was worth approximately \$128.5 million in 1989, during the winter holiday season, sometimes making up half of yearly revenues for the industry (W. E. Schlosser et al., 1991). Washington State boasts one of the most productive bough industries, in part because the native range of noble fir (*Abies procera* Rehder) residing in the state, being one of the most prized holiday tree bough species (W. Schlosser & Blatner, 2004). Noble fir is endemic to the

Pacific Northwest, ranging from northern California to central Washington, and dominated some forests after the eruption of Mount St. Helens (Earle, 2026; Franklin & Dyrness, 1973). Washington also hosts several other important bough production species, such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western white pine (*Pinus monticola* Douglas ex D. Don), western red cedar (*Thuja plicata* Donn ex D. Don), incense cedar (*Calocedrus decurrens* (Torrey) Florin), and silver fir (*Abies amabilis* (Douglas ex J. Forbes) Loudon) (W. E. Schlosser et al., 1991).

Boughs have a unique harvest window, between September and December for use prior to the Christmas holiday. The harvest window is constrained by higher temperatures that could lead to rapid needle loss of harvested boughs, persistent snow that limits access to sites, and timing of the first frost, which is used to qualitatively determine bough readiness for harvest (Buttolph & Jones, 2012; Cercone et al., 2017; W. Schlosser & Blatner, 2004; Thiagarajan et al., 2016). Operational factors include labor supply and negotiated access to lands where the boughs may be harvested. Market conditions include the demand for boughs during the harvest season and harvests occurring prior to the end of the culturally relevant demand period for the Christmas holiday. This study focuses on the climatic indicators and when harvest can optimally occur during the season.

Unique to the evergreen bough industry is frost as an observable climatic indicator to time bough harvest. Forestry extension guidance suggests boughs must experience a frost prior to harvest, to assure trees are “hardened-off” (a process preparing trees for prolonged cold temperatures) by the frost (Buttolph & Jones, 2012; Cercone et al., 2017; W. Schlosser & Blatner, 2004). The timing of frost is a link to the physiological dormancy process that evergreen

trees experience through cold acclimation and shortening photoperiods (Nilsson, 2022). Trees and boughs harvested during dormancy have associated longer needle retention compared to those that are not in dormancy (Thiagarajan et al., 2016). As the dormancy process is not observable to managers, frost serves as a practical, but imperfect, proxy to infer dormancy onset—and the start of the bough harvest season.

Current climate research suggests that the Pacific Northwest will experience overall warming on the scale of 1.6 to 6.1°C (Dalton et al., 2013). This warming may shift heat duration during the late summer into autumn followed by delayed frosts. These shifts may mean the pre-holiday harvest season could shorten and frost dates may become unreliable or later in the potential harvest season. Little research has been conducted to understand the relationship between climate change and bough cultivation and production in the Pacific Northwest.

Shifts in the climatic constraints of the bough harvest season will be heterogeneous across the Pacific Northwest as bough harvest occurs from the lowlands to the montane landscapes, up and down western Washington and Oregon. Different elevations and ecoregions (i.e., as developed by Omernik (1987)) may be affected differently by a shifting climate, including the ownerships that exist on those landscapes (Charnley et al., 2007; J. Omernik, 1987; Rogers et al., 2021; USEPA, 2012a, 2012b). Quantified impacts may better inform managers on where and who to partner with for bough harvests under a shifting climate.

With little research on understanding the relationship between climate change and NTFPs in the Pacific Northwest, and the clear linkage between climatic indicators informing managers in bough harvesting, this study will investigate the projected changes in climatic

harvest constraints and frost reliability across ownerships and ecoregions in Washington and Oregon.

Research Questions

This chapter aims to answer the following questions:

1. How are projected changes in frost events, hot-day events, and snow-related access projected to affect the climatic-related operational window for evergreen bough harvest in western Washington and Oregon forests?
 - a. How do climatic indicators of the evergreen bough operational window, such as frost events, hot-day events, and snow-conditions shift in future climate periods?
 - b. How does the use of proxy-climate data inform management decisions when modeling geographic distribution of field-observable frost as an indicator for the physiological hardening-off process?

First, while the evergreen bough production is linked to physiological processes in evergreen trees, climatic indicators are the observable phenomena that managers can perceive and then time their operations accordingly. Second, while evergreen boughs can be harvested prior to the tree going into full dormancy, bough quality increases through the onset dormancy process through associated needle retention. This research is then based on the notion that climatic proxies can, and are, used in lieu of difficult-to-observe physiological signs.

From this, the core study hypothesis is that as climate warms, frosts will become later in the season. Similarly, the study operates on secondary hypotheses that hot days will extend into the harvest season and the first snows will become later, thereby extending access later in the season.

Literature Review

Evergreen Bough Literature

Conifer species enter dormancy through a combination of photoperiod and temperature triggers, with numerous studies noting that short days induce dormancy with temperature serves as a moderating factor to the short day induction (Ekberg et al., 1979; Lavender et al., 1968; McCreary et al., 1978; Thiagarajan et al., 2016; Timmis & Worrall, 1975; Tremblay et al., 2023; Tung & DeYoe, 1991). This dormancy induction period is also moderated by gene expression, provenance, location of the conifer species, and other environmental acclimations (Nilsson, 2022). While it is difficult to determine when a tree has entered dormancy outside of testing for gene expression within the individual tree, it is possible to estimate when the dormancy process is beginning.

Information is limited for local species for exact dormancy temperatures, daylengths, and other triggers. Of local species, noble fir (Tung & DeYoe, 1991), Douglas-fir (Lavender et al., 1968; McCreary et al., 1978), and lodgepole pine (Ekberg et al., 1979) have studies that indicate photoperiod and/or thermoperiod interactions with growth cessation and dormancy onset. Cold acclimation has been investigated for noble fir (Thiagarajan et al., 2016) and Douglas-fir (Timmis & Worrall, 1975). An extensive study on noble fir found the species is very sensitive to temperature fluctuations from autumn to spring, resulting in negative effects in crown development and whorl symmetry (C. Nielsen & Rasmussen, 2008). With the lack of evidence for each species and much of the data relying on photoperiods and thermoperiods selected by authors, this study has the underlying assumption that all species respond in a similar manner.

Few studies have been conducted on the production for evergreen boughs. From the United States, Blatner et al. (2010) constructed models to assess the economics of bough harvesting in noble fir plantations in the State of Washington, and Hinesley and Snelling (1992) described the characteristics that affect Fraser fir greenery quality on plantations the State of North Carolina (Blatner et al., 2010; Hinesley & Snelling, 1992). Nordic studies suggest that certain genetic variations support higher quality greenery (i.e., boughs, sways, and other harvested parts for decorative purposes Neilsen (2007), that management of whorls and stubs can increase the quality of boughs harvested as in Rasmussen et al. 2005), and that, generally, bough greenery from the Pacific Northwest and Nordic plantations are of similar quality postharvest (Chastagner et al., 2004; U. B. Nielsen, 2007; Rasmussen et al., 2005).

The management of bough production in the United States is well documented. Bough production is reliant on the first hard frost to induce dormancy in evergreen species to increase the lifetime of the needle foliage post-harvest (W. Schlosser & Blatner, 2004). Stands used for bough production may be harvested at least every 5 years, with resources suggesting a range of 3-5 years, on trees that range from 10-30 years in age (Buttolph & Jones, 2012; W. Schlosser & Blatner, 2004). After harvest, boughs are stored at 37 degrees Fahrenheit or in a cool forested area, with storage conditions generally moist (Buttolph & Jones, 2012). Harvest often occurs closer to population centers and areas with road access to decrease transportation costs and time in the field (Hansen & Jacobson, 2005).

The production of boughs is rarely the primary management objective of a stand. Generally, boughs are of secondary production to timber plantations and Christmas tree farms (Cerccone et al., 2017; Landgren & Freed, 1998; W. Schlosser & Blatner, 2004). In timber

plantations, boughs are a product of trimming branches from a growing stand. In Christmas tree farms, boughs must come from trees that are untrimmed or grown solely for the purpose of bough production as Christmas trees are typically grown to be full and trimmed (Landgren & Freed, 1998). For quality bough growth, branches must not interlock with branches from other trees or be shaded for more than three hours a day (Landgren & Freed, 1998). Without proper management and spacing, trees may not meet quality bough grading specifications.

Harvest generally occurs between the first frost and the point in which production and shipping make processing impossible prior to Christmas (Cercione et al., 2017), or until the site becomes inaccessible due to snow. Some sources suggest that harvests can begin in September without explicit need of frost (Vance et al., 2001), in contrast to extension guidance. Boughs are categorized into three grades for use: Grade 1, Grade 2, and Unacceptable (i.e., Grade 1 has deep green or blue color with short annual growth nodes, retention of 4 years of needles, uniform needle coverage, and symmetrical where Grade 2 has lighter coloring, longer internode growth, imperfect uniformity, and some nonsymmetrical shaping; see Supplemental II-I for grading via Schlosser & Blatner (2004)). For boughs to not be Unacceptable, the boughs must have experienced a hard frost to be hardened off (W. Schlosser & Blatner, 2004). The hardening off process, putting the boughs into dormancy, increases the bough lifespan to nine weeks post-harvest (Cercione et al., 2017).

Bough production is then affected by dormancy onset and cold acclimation of the tree. The literature suggests that a hard frost is needed to induce the increased time of needle retention (W. Schlosser & Blatner, 2004). Other literature further supports that cold acclimation increases post-harvest needle retention through experimental artificial cooling (Thiagarajan &

Lada, 2010) or harvest later in season (MacDonald et al., 2014; Mitcham-Butler et al., 1988; Pettersson et al., 2020). This has led to suggested decreased quality of product as pressure increases for earlier harvest dates (Thiagarajan et al., 2016). Dormancy is associated with increased quality in needle retention. Technical documentation for bough production suggests the need for a hard frost to harden-off boughs to ensure needle retention (W. Schlosser & Blatner, 2004). The scientific literature has found that cool temperatures and short days provide support for needle retention (MacDonald et al., 2014; Thiagarajan et al., 2016) and that having both the short photoperiod and cool thermoperiod followed by a severe hard frost deepen cold hardiness (Timmis & Worrall, 1975).

Incorporating Climate Literature

Modeling climate projections for regions is well documented and globally agreed upon (Calvin et al., 2023). For bough production, the interest is in how changes in climatic conditions affect frost dates. Average frost dates are expected to change under modeled climate scenarios through various methods, including SDMS and Artificial Neural Networks (Rahimi et al., 2017); coupled regional climate projections including shared socioeconomic pathways scenarios (Mesgari et al., 2023), S-mode PCA (Malinovic-Milicevic et al., 2018), regression kriging (García-Martín et al., 2021), coupled global climate models (Charalampopoulos & Droulia, 2022), linear regressions (Erlat & Türkeş, 2016), and differences in means (Park et al., 2021). In part, these studies indicate that the first frost likely will change more than the last frost, indicative that bough harvest seasonality will be affected.

Given the temperature gradient along elevation, attributed to adiabatic lapse rate as air expands as it rises, in the Pacific Northwest, especially west of the Cascade Crest, first frost

dates typically are earlier in higher elevations than in lower elevations (Frankson et al., 2022; Garcia et al. 2013). While it is unclear how the first frost will change for the Pacific Northwest, most regions' first frosts are predicted to occur later (Christiansen et al., 2011) with some areas already experiencing later first frost dates (Kukal & Irmak, 2018). A delay in first frost would be indicative that the lowlands of the Pacific Northwest may see decreases in potential supply, or harvest window, for boughs, with a shift in the harvest windows shifting to higher elevations.

The higher elevations are typically owned by the USFS (Charnley et al., 2007). National Forests in Washington State tend to have a higher tree age distribution compared to other landowner types (Azuma et al., 2014). If frosts will occur later across elevations and will limit the supply window, the lowland private forests, which have a larger percentage of holdings associated with bough production, will have a limited or no harvest window compared to federal forests. This combination will likely lead to supply constraints for industry players following the frost signal.

Methods

To understand the potential impacts of climate change on bough production, environmental restrictions on operations are defined beginning in late August until the site becomes inaccessible due to snow or when time to harvest, prepare, and ship the finished product before the Christmas holiday is infeasible. The standard operation window for bough harvest is then a function of being within the typical potential harvest season between the days above a certain heat threshold, marking limited harvest due to daytime high temperatures, and days where there is snow conditions deducted from the season.

Frost serves as a field-observable cue used by managers to understand when trees have had their physiological cold acclimation response. While cold acclimation is more of a function of site conditions, photoperiod, and thermoperiod, frost is a simpler environmental condition to measure. Bough harvest for slower needle loss rates occur after the first frost.

These aspects form the basis of the operational window as a product of hot day limitations, pre-frost window that may result in lower quality boughs, post-frost window for the traditional marker of quality, then when access is limited by snow (Figure VI).



Figure VI: Conceptual framing of the operational season as the time between August 15th and December 25th that is limited by hot period in the beginning of the season and a snow period at the end of the season. Frost serves a quality indicator for boughs in the middle of the season

Data Availability and Sources

This study used several sources of data to build climate indicators and analysis units (Table II-I).

Climate data came from 17 CMIP6 models from the World Data Center for Climate (WDCC) that are downscaled to 4-kilometers and bias corrected for the Northwest region of the United States (Khoshnood Motlagh & de Lima Moraes, 2025). Analysis level data, for comparisons and

data presentation, included topography data from the USGS, landownership from the Natural Resource Spatial Information Group, U.S. Environmental Protection Agency ecological zones, and the U.S. Department of Agriculture LANDFIRE land cover model (LANDFIRE, 2024; Rogers et al., 2021; U.S. Geological Survey, 2026; USEPA, 2012a, 2012b). Full data descriptions can be found in Supplement II-II.

Table II-I: Data Availability and Sources Used for the Creation and Analysis of Climatic Indicators and the Harvest Season

Data Type	Data Products	Data Description	Source
Modeled Climate Data	WDCC CMIP6 4KM Dailies: - Maximum temperature - Minimum temperature - Precipitation	Seventeen CMIP6 global circulation models that have been downscaled to 4-kilometer regional daily air surface temperature and daily precipitation, verified and corrected for bias. Data is presented as separate data sets for daily maximum temperature, daily minimum temperature, and daily precipitation.	(Khoshnood Motlagh & de Lima Moraes, 2025)
Topography	USGS DEM 2 Arc Sec	Digital elevation models from the USGS for the region.	(U.S. Geological Survey, 2026)
Landownership	Forest landownership by type. - Washington - Oregon	Forest landownership in GIS format in broad categories of small private, tribal, industrial, county, state, and federal.	(Rogers et al., 2021)
EPA Ecological Zones	Region 10 Level III Ecoregions - Coast Range - Straite of Georgia/Puget Lowland - Willamette Valley - Cascades - North Cascades - Klamath Mountains	Level III ecoregions for Washington and Oregon through the Omernick (1987) methodology in GIS format. Data is sorted by North America coding. For this study, codes 7.1.8, 7.1.7, 7.1.9, 6.2.7, 6.2.5, and 6.2.11 are used for analysis and the study area mask.	(USEPA, 2012a, 2012b)
LANDFIRE Land Cover	Existing Vegetation	Existing vegetation landcover as modeled in the 2024 iteration. A forest mask is created using the landcover types: evergreen open tree canopy, evergreen closed tree canopy, mixed evergreen-deciduous open tree canopy, and mixed evergreen-deciduous closed tree canopy.	(LANDFIRE, 2024)

Climate Indicator Creation

To describe the relationship between climatic indicators and the evergreen bough operational window, binary index protocols were developed to define the climatic conditions from the climate data from Khoshnood Motlagh and de Lima Moraes (2025). Three binary indices were developed from the data:

- Hot-day Index
- Frost Event Index
- Snow Event Index
- Pre-Frost Operational Window
- Post-Frost Operational Window

The hot-day event index is equal to 1 when the maximum surface air temperature exceeds the hot-day temperature threshold for each climate cell, year, and day. Otherwise, the index is 0. The last hot-day event, used to signal the start of the operational window, is defined as 1 for the latest hot-day event for given season with all other days as 0.

The frost event index is equal to 1 when the minimum surface air temperature does not exceed the frost event temperature threshold for each climate cell, year, and day. Otherwise, the index is 0. The first frost event indicator is defined as 1 for the earliest frost event in the index with all other days as 0.

The snow event index is equal to 1 when the maximum surface air temperature does not exceed the snow event threshold and precipitation exceeds the snow event threshold on the same day for each climate cell, year, and day. Otherwise, the index is 0. The first snow event, used to signal the end of the operational window, is defined as 1 for the earliest snow-day event

for a given season with all other days as 0. If snow does not occur during the season, the first snow event was recorded as missing for that model, year, and cell.

The pre-frost operational window start indicator is developed to be the day after the last hot-day event for each climate cell, year, and day. The operational window end indicator is developed to be the day before the first snow day event for each climate cell, year, and day. Should the first snow day event result in a missing model (i.e., no snow events), Dec. 25 was assumed to be the operational window end indicator. The operational window is then the difference between the operational start and end indicators. The post-frost operational window index is then the difference between the first frost-event and the operational end indicators.

Climatic Thresholds

Three climatic metrics contribute to the length of bough season: hot-day events, frost events, and snow events. Hot-day events are days on which the temperature may be high enough to result in rapid desiccation of the boughs upon harvesting. While desiccation is a function of air vapor pressure and air surface temperature, this research will solely use air surface temperature as a proxy. For the baseline threshold, a maximum air surface temperature of 22°C will be used as a hot-day event threshold, inspired by extension literature (Buttolph & Jones, 2012).

The frost event metric was derived from the NOAA definitions of a freeze (US Department of Commerce, n.d.). Three common definitions for the first fall freeze are (1) a frost where the air temperatures are between 0.56 and 2.22°C with a mild breeze and humid air leading to solidification of dew point moisture, (2) a freeze where temperatures reach at least 0°C, and (3) a hard freeze where temperatures reach at least -2.22°C for at least an hour. For the

baseline threshold definition, frost for this research is defined when daily minimum surface air temperature reaches 0°C or below.

The snow event metric defines snow as an occurrence when daily maximum surface air temperature does not exceed 0°C and daily precipitation is greater than 0mm. This metric is conservative to suggest that surface air temperature not exceeding 0°C will lead to lasting snowfall on the landscape. Generally, snow only forms when air temperature is at or below freezing and ground temperatures are at or below 5°C (*Science of Snow | National Snow and Ice Data Center*, n.d.).

Sensitivity Analysis

These metrics, while grounded in literature and climatological definitions, were selected to be reflective of the work that happens in the field. For example, the grey literature sometimes calls for a “hard frost” for boughs to be harvested (W. Schlosser & Blatner, 2004). For this, two additional thresholds were created for the hot-day event and frost event metrics to reference and understand how variable the climatic ensemble means were under different defined conditions. Additional hot-day event thresholds were created for 26 and 30°C to represent higher temperatures closer to OSHA heat hazard recommendations (*Heat - Heat Hazard Recognition | Occupational Safety and Health Administration*, n.d.). The two additional frost-event metrics reflect the alternative NOAA freeze definitions at 2 and -2°C.

Snow was excluded from this analysis after initial threshold testing indicated instability in the snow metric across climatic models leading to the end of season being near Dec. 25th.

Climate Ensemble Indicator Creation

All analyses were conducted in R and in QGIS (QGIS Development Team, 2026; R Core Team, 2025). The climate model outputs were processed over every year and cell to generate binary arrays that cover each day and year where 1 qualifies meeting or exceeding the threshold and where 0 is failing to meet the threshold for each metric. The analysis was confined to the operational season between August 15th and December 25th. The binary arrays were further distilled to create start and end points, as day of year (DOY), for each metric to retain the meaningful event occurrence, becoming an indicator array:

- *Frost*: The first frost event is preserved to mark an observable weather event proxy for dormancy onset.
- *Snow*: The first snow event is preserved to mark possible barrier to access.
- *Heat*: The last hot-day event is preserved to mark the end of the hot season as a potential barrier to access.
- *Operational Window*: The first and last operational days are preserved to mark the beginning and the end of the operational window for calculation of the operational window length.

Once indicator arrays were generated, the ensembled mean was calculated as a simple mean across each climate model output where each climate model is weighed the same. The standard deviation was derived for each ensembled year to represent average the average model disagreement. Climatic models that did not produce a metric within the operational season were dropped from the ensemble for that given cell. Some cells may not always have an ensembled result that included all 17 climatic model outputs.

Yearly ensembles were further distilled in periods for analysis to create period means: 2015-2025, 2026-2050, 2051-2075, and 2076-2100. The period 2015-2025 serves as the baseline, or current, period. Period means were calculated as a simple mean for every climate model in a given year across all years with the average deviation of models retained for that period.

The final products produced are:

- Daily binary indicators of each climate threshold
- Yearly DOY start and end of each climate threshold
- Yearly mean and standard deviation of each yearly DOY start and end of each climate threshold
- Period mean and standard deviation of each climate threshold as DOY

Analysis Unit Creation

After the climate indicators were created, the analysis mask and units were prepared. The analysis units were the ownership, ecoregions, and an intersection between ownership and ecoregions. The ownership units were geographically dissolved to represent the major ownership grouping (i.e., small forest landowner, industrial, state, federal, tribal, or county) across the landscape, rather than individual ownerships, for each state: Washington and Oregon. Each ownership for each state were then one polygon and unit of analysis, though the area represented may be geographically diverse. This process was also done for the ecoregions so that each ecoregion was one polygon for each state. For the intersection, the ownership and ecoregion polygons unionized to leave polygons representing each ownership for each ecoregion.

The forest mask was derived by LANDFIRE existing vegetation coniferous forest types to represent the actual forested landscape that boughs could be harvested. This mask is to weight the climate cell contribution to the forest ownership and ecoregion polygons, so that the area of the cell that is forested is the only area that contributes to the polygon climate indicator mean. The forest mask was then cross-referenced with the ownership polygons within each climatic cell. For each ownership polygon, the climate cell value is multiplied with the forested area of the ownership polygon in that climate cell, repeated for all climate cells contributing to that ownership polygon and summed, then the summed forest-weighted climate value was divided by the sum of the forested area. The product is a climate indicator value that is weighted by the contributing forested area for the ownership polygon. This process was repeated for the ecoregion polygons and the ownership-ecoregion intersection polygons. For reporting, means were developed for the reporting periods. This assumed that forest cover remains the same over the study period.

Individual, representative sites, were identified as 4km cells that were at the median climatic metric conditions (frost-event, hot-day, snow-condition) and at one of the tertile elevation groups of their respective ecoregion and ownership. These sites were then to represent the overall median climate of each elevation zone of the ecoregion and ownership. The best fitting climatic cell was selected for the representative point. The yearly climatic values are retained to demonstrate the trend of climatic change for each ecoregion for each cell.

Understanding the probability of frost occurring prior to a certain threshold data to demonstrate risk and uncertainty in frost occurrence was calculated as the number of individual climate models across a given period reporting as a frost occurring on or before a threshold

date as a proportion of the total model-year observations in the given period. For this, yearly individual model results were converted to binary arrays of whether a frost occurred on or before the calendar date of October 15, November 1, November 15, December 1, and December 15. These binary arrays were then used for each of the climate periods to determine the proportion of models that report a frost event on or prior to the threshold date in that period, evenly weighted across model and year.

Data Issues

Modeled output resulted in data gaps due to either no snow or frost events, or land unsuitable for bough production. This contributes to potential variability and increased error as the study relies on climate cells contributing to a regional mean without the full ensemble. This is apparent in the results section (see Supplemental II-III and II-IV for data) discussing trends in first snow across ownership and ecoregions where some years had no reporting data for the representative climate cell.

While adjusted for, the study makes a broad assumption that only forested land that is currently classified as coniferous forest should be considered in weighing the climate cell contributions to a regional mean. Only including coniferous forested land to contribute to the results was to remove high elevations that may not be forested due to climatic limitations and to remove areas of forest landownership that may not be permanently forested, such as industrial forest landowners who engage in other activities like mineral leasing. However, this assumption and utilizing the LANDFIRE model means that forested land that was recently harvested may have been classified as barren. With this classification not considered in the

analysis, there may be a greater area of land that could have contributed to the regional climatic means. This assumption also assumes that forest area will remain static throughout the century.

Results

The results of this study are presented in four parts. The first portion covers the projected climatic indicators across the entire study area during the harvest-season. The second portion covers ownership and ecoregion summaries illustrating the change of climatic indicators over time. The third section describes the ownership-ecoregion intersections to present finer spatial resolution results and describe spatial heterogeneity within the region. The fourth section evaluates the practical application of this work as reliability of frost during the harvest-season across ownerships and ecoregions.

Overall Climatic Indicators

The ensembled models for the near-reference period 2015-2025 period (Figure VII) produce an operational window length mean between 41 and 131 days, with operational windows starting between mean day of year (DOY) 227 and 271 and ending between mean DOY 267 and 358. The mean last hot-day event occurs between DOY 239 and 307. The mean first frost event occurs between DOY 228 and 344. The mean first snow event occurs between 269 and 357 with some areas never meeting the snow thresholds in southwest Oregon.

For the end of century (2076-2100) period (Figure VIII), the ensembled models produce an operational window length mean between 48 and 131 days, with operational windows starting between mean day of year 227 and 281 and ending between mean DOY 267 and 358. The mean last hot-day event occurs between DOY 246 and 315. The mean first frost event occurs between DOY 230 and 347. The mean first snow event occurs between 277 and 356.

The direct differences between the baseline period and end-of-century period are generally universal later operational window starts (0 to 24 days) and later operational window ends (0 to 12 days) with variations in operational window lengths (-24 to 10 days). Hot-day events typically occur later in the year but not always (-6 to 16 days) similarly to first snow events (-22 to 10 days). Frosts were generally later in the year (0 to 17 days).

Ensembled models demonstrated variable spreads across the study area. Descriptively, the last hot-day event tends to be later in the lowlands than the montane regions, especially in the lower latitudes. The first frost events have a similar relationship. Washington tends to have a longer operational period than Oregon.

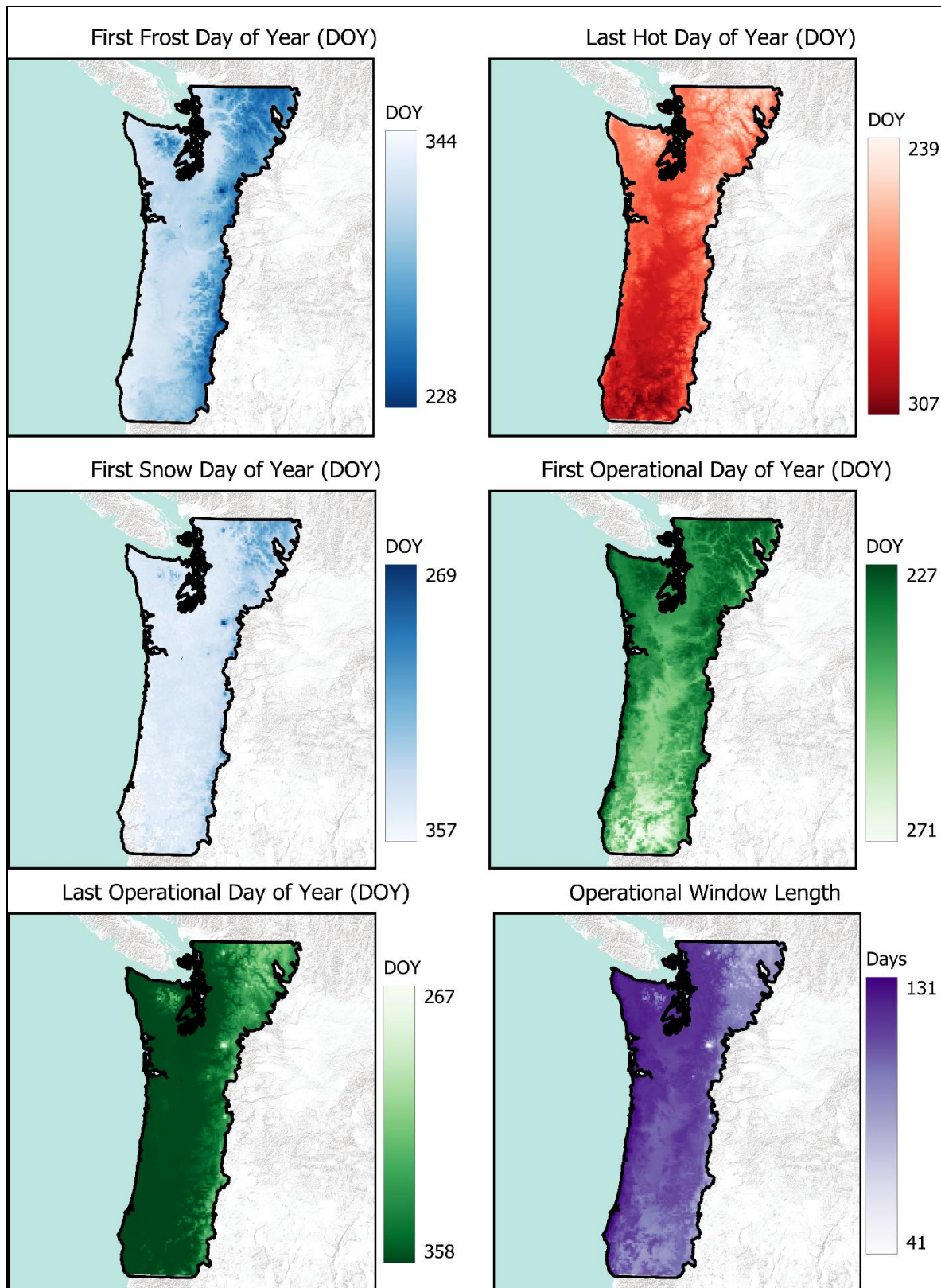


Figure VII: Climatic indicators for the entire study region during the near-reference period (2015-2025). DOY rounded to nearest day for interpretability.

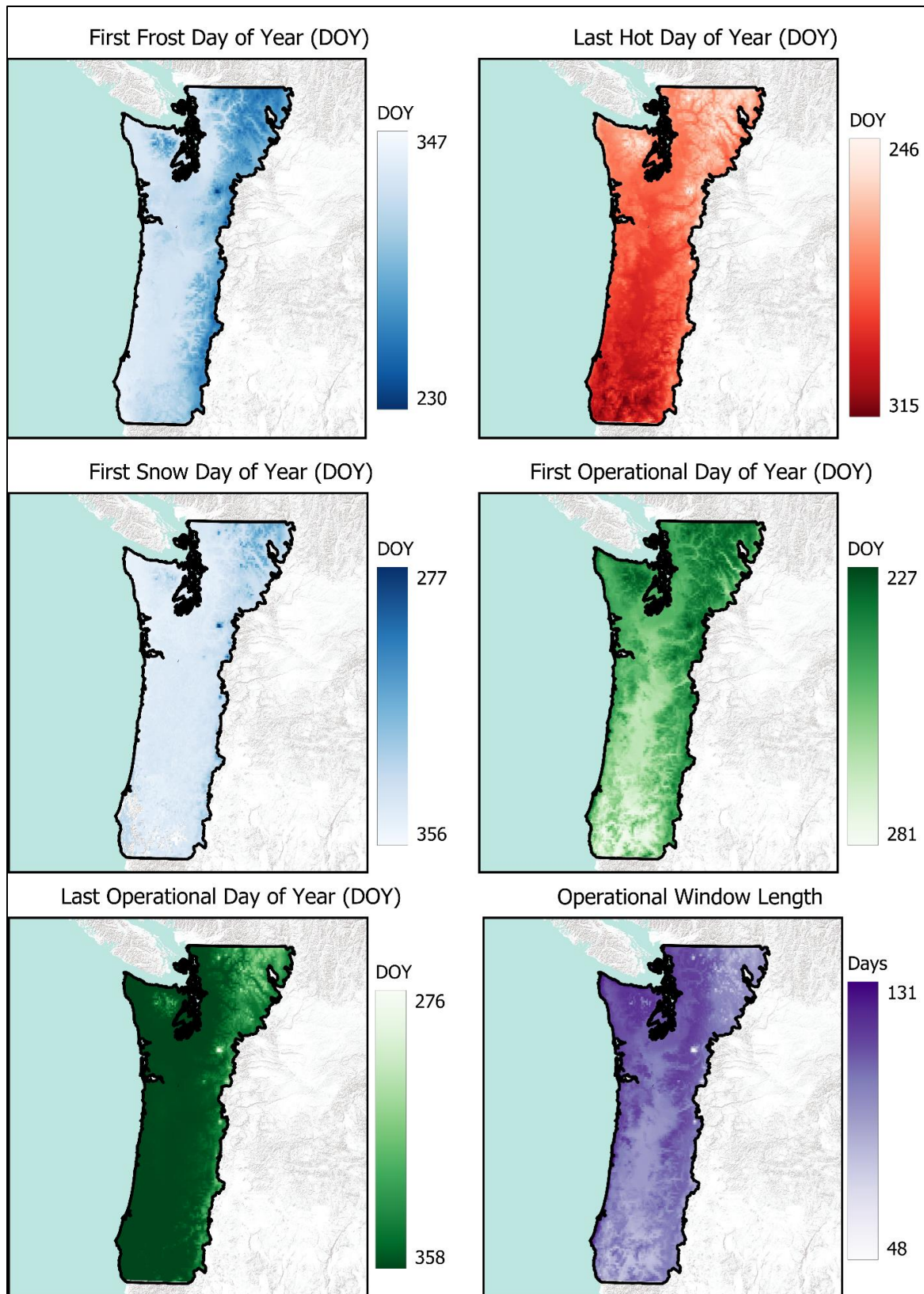


Figure VIII: Climatic indicators for the entire study region during the late century period (2076-2100). DOY rounded to nearest day for interpretability.

Climatic Metrics by Ecoregions

Most climatic metrics tend to become later in the year between 2015-2025 and 2076-2100 for most ecoregions. The first ensemble mean frost event occurs 6-11 days later, and the last ensemble mean hot-day event occurs 3-6 days later. The ensemble mean first snow event occurs four days earlier or later, indicating that the metric is more unstable compared to other metrics. The snow metric is likely more susceptible to occurring close to the end of the study season or not at all in the year, resulting in the modelled ensemble mean relying on fewer models to generate a mean, typically the more conservative models, or a regional mean relies on few climate cells that may be different from the median elevation, longitude, or latitude of the region.

Operational periods, the time between the ensemble mean operational start date and ensemble mean operational end date, vary between 101-122 days for ecoregions in the near-reference period (2015-2025) and 91-113 days in the late century period (2076-2100) with differences between periods between 3-14 days. Strictly numerically, the Coast Range of Washington has the longest operational period of 122 days, and the Klamath Mountains of Oregon have the shortest operational period of 101 days in 2015-2025 with the trend holding for 2076-2100 with 113 and 91 days respectively. The post-frost operation windows, the time between the ensemble mean first frost event and the ensemble mean operational end date, vary between 34-64 days in 2015-2025 and 29-58 in 2076-2100 with differences between periods between 4-9 days. The Cascades of Oregon have the longest post-frost operational window of 64 days and the Coast Range of Washington having the shortest post-frost operational window (34 days) in 2015-2025 with the trend holding for 2076-2100. with 58 and

29 days respectively.

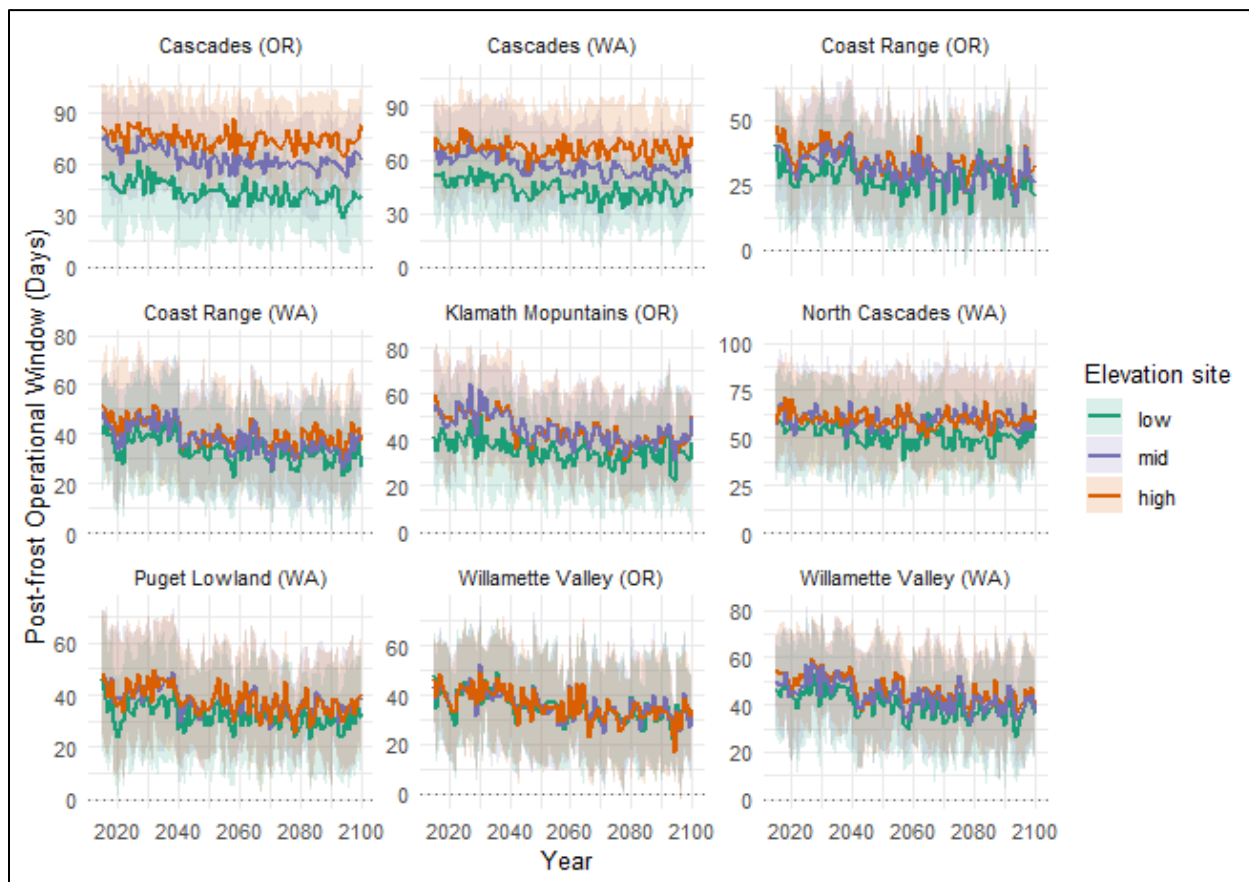


Figure IX: Post-frost operational window for elevation representative sites by ecoregion. Shaded banding represents the standard deviation.

When considering the reference sites for each ecoregion, the post-frost operation window demonstrates a decreasing trend over time (Figure IX). The tertile elevation sites show that low elevation sites tend to have less post-frost operation days compared to high elevation sites for the inland montane ecoregions in particular.

The average inter-model differences compared to the ensemble mean for the climatic metrics highlight the difference between climate model assumptions and outputs compared to each other along with the variation in the ecoregions. For instance, the standard deviation for the frost metric in the near period for ecoregions varies between 15.19 – 18.59 in 2015-2025

and 10.65 – 14.81 in 2076-2100. This variation and the ensemble means are demonstrated for the Cascades ecoregion of Washington (Figure X; Table II-II). Generally, for the moderate climate scenario, climatic triggers for the bough operational period by ecoregion are moving later in the year with a general loss of potential operational time for the season and post-frost events. While these results provide a high-level view of the shifting climate, they indicate the variability of climate related events and the uncertainty of when these events occur in the future. Notably, the first frost varies the most as a computed metric and between models, suggesting that the period in which boughs can be harvested post-frost event will get shorter and will be the least reliable in determining occurrence. Complete metric reporting and metric graphs are located in Supplement II-IV through II-VII.

Table II-II: Ensemble Climatic Indicator Means and Operational Window Lengths for Cascade Ecoregion in Washington

Ensemble Climatic Metric (DOY)	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Last Hot-Day Event	271 (8.72)	271 (8.55)	273 (9.17)	274 (9.25)
First Frost Event	287 (18.59)	289 (17.31)	295 (16.10)	297 (14.65)
First Snow Event	334 (5.46)	335 (4.04)	336 (3.46)	336 (3.29)
Operational Window Start	235 (5.46)	237 (6.58)	240 (8.94)	241 (9.71)
Operational Window End	346 (5.05)	347 (5.23)	350 (3.82)	351 (3.96)
Operation Windows (days)				
Operational Window Total	111	110	110	109
Post-Frost Window	60	58	55	54

*Period means are rounded to the nearest DOY for interpretability.

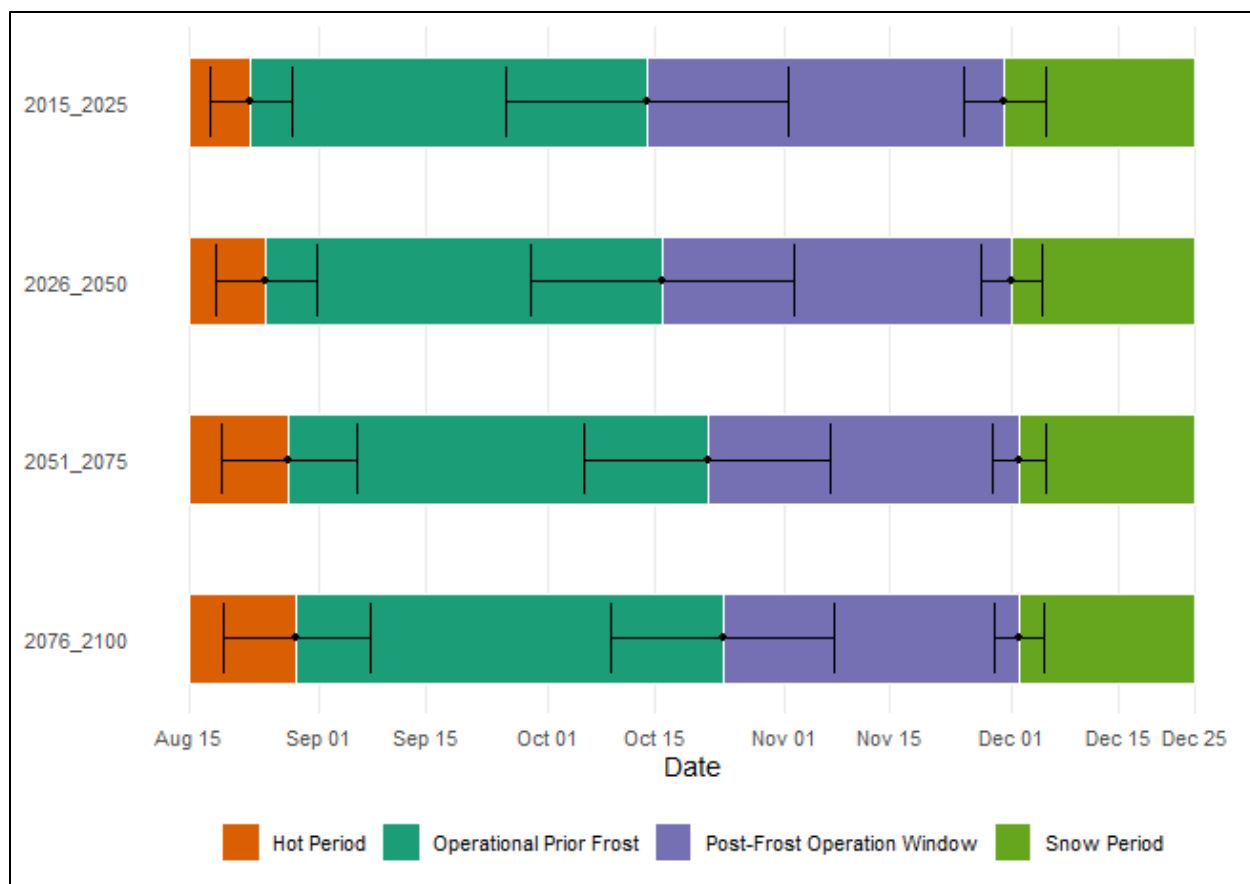


Figure X: The harvest season is separated by climatic indicators for the Cascades Ecoregion in Washington.

Climatic Metrics by Ownerships

Ownerships across Washington and Oregon showed climatic metrics occurring later in the year when comparing the near-reference period and the late century period. The ensembled mean last hot-day event occurred between 265-288 DOY (std. 7.12-9.68 days) during 2015-2025 and 268-293 DOY (std. 8.40 – 12.77 days) during the late century period 2076-2100, with differences between means ranging from three to six days. The first ensembled mean frost event occurs between 277-315 DOY (std. 12.79-16.61 days) during 2015-2025 and 287-323 DOY (std. 9.92-14.78 days) during 2076-2100, with differences between means ranging from five and ten days. The ensembled mean first snow event occurs between 331-347 DOY (std. 4.31-6.18 days) during 2015-2025 and 333-343 DOY (std. 2.60-5.14 days) during the 2076-2100, with

differences between means ranging from one to three days. The snow metric experienced errors through few models reporting for some regions during the studied season, resulting in few reporting climate cells with few reporting climate models resulting in the mean (see Supplement II-VI to see how the first snow is reported by a single climate cell).

Operational periods typically shorten over the climate periods for the ownerships. Overall, in 2015-2025, the operational period ranges between 104-125 days. For 2076-2100, the range falls to 100-114 days. The county government forestlands in Washington have the longest operational period at 125 days and 114 days in the 2015-2025 and 2076-2100 respectively. While federal government forestlands in Washington have the shortest operational period in 2015-2025 at 104 days, the private industry lands of Oregon have the shortest operational period in 2076-2100 at 100 days. Federal government forestlands in Washington experience the least amount of change of zero days between 2015-2025 and 2076-2100 while the private industry forestlands of Oregon have the greatest change of 12 days.

The post-frost operation window, defined as the difference between the ensemble mean first frost event and the ensemble mean last operational day, demonstrates some ownerships have short post-frost harvest potential, especially in 2076-2100 (Figure XI). In 2015-2025, ownerships range from 35-61 post-frost operation days with county government forestlands in Washington at 35 days and federal government forestlands in Washington at 61 days. 2076-2100, the range adjusts to 27-56 days with the same ownerships at the low and high end. The post-frost window mean differences from 2015-2025 and 2076-2100 from three to eight days of difference with state government forestlands in Oregon having the greatest change and tribal forestlands in Washington having the least.

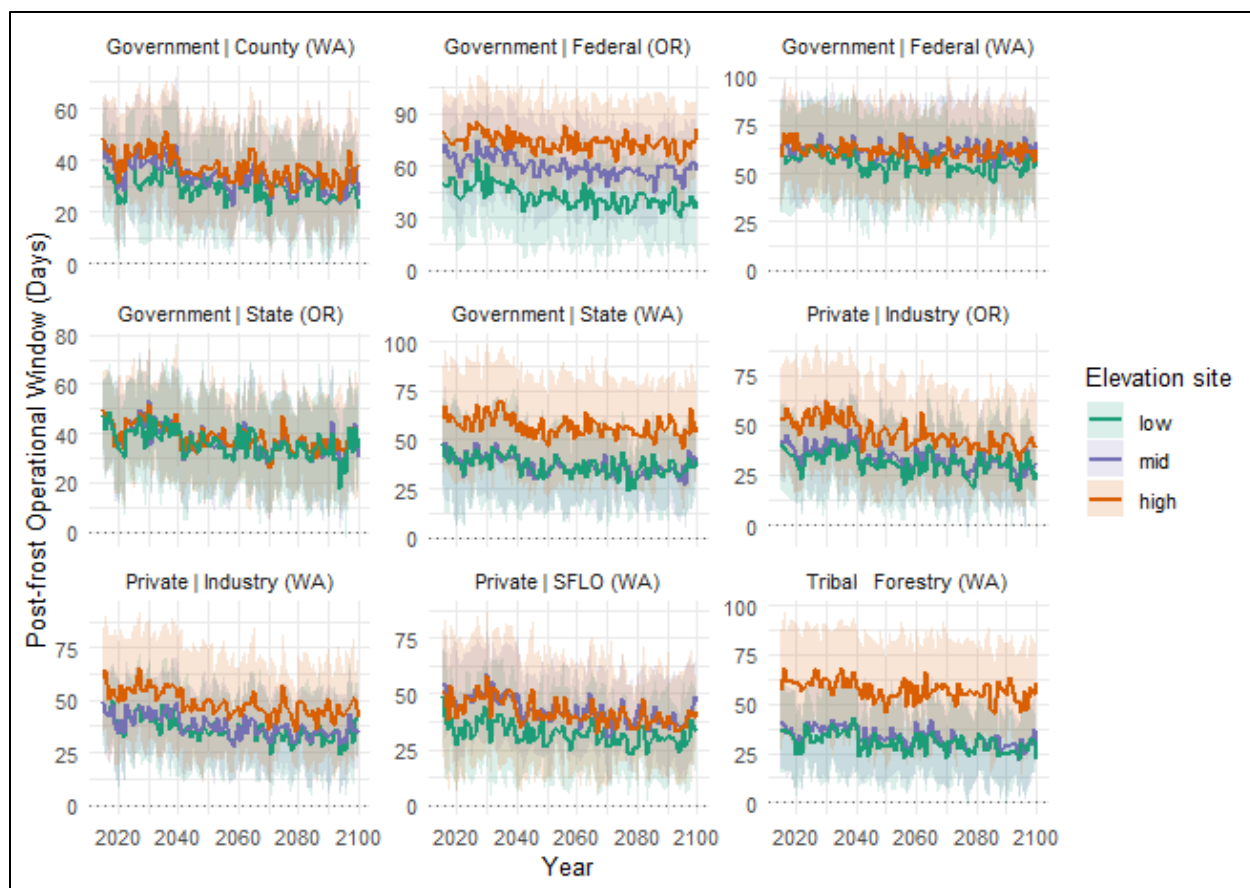


Figure XI: Post-frost operational window for elevation representative sites by ownerships. Shaded banding represents the standard deviation.

The average inter-model difference compared to the ensemble mean for the climatic metrics highlight the difference between climate model assumptions and outputs compared to each other along with the variation in the ownerships as previously reported. First frost and last hot-day event standard deviations are reported between seven and 17 days overall at some climatic period. This variation may indicate that ownerships hold land under different climatic regimes, affecting the variation between models and climate cell means to the overall ensemble mean. This variation and the ensemble means are demonstrated for private industry ownership of Washington (Figure XII; Table II-III).

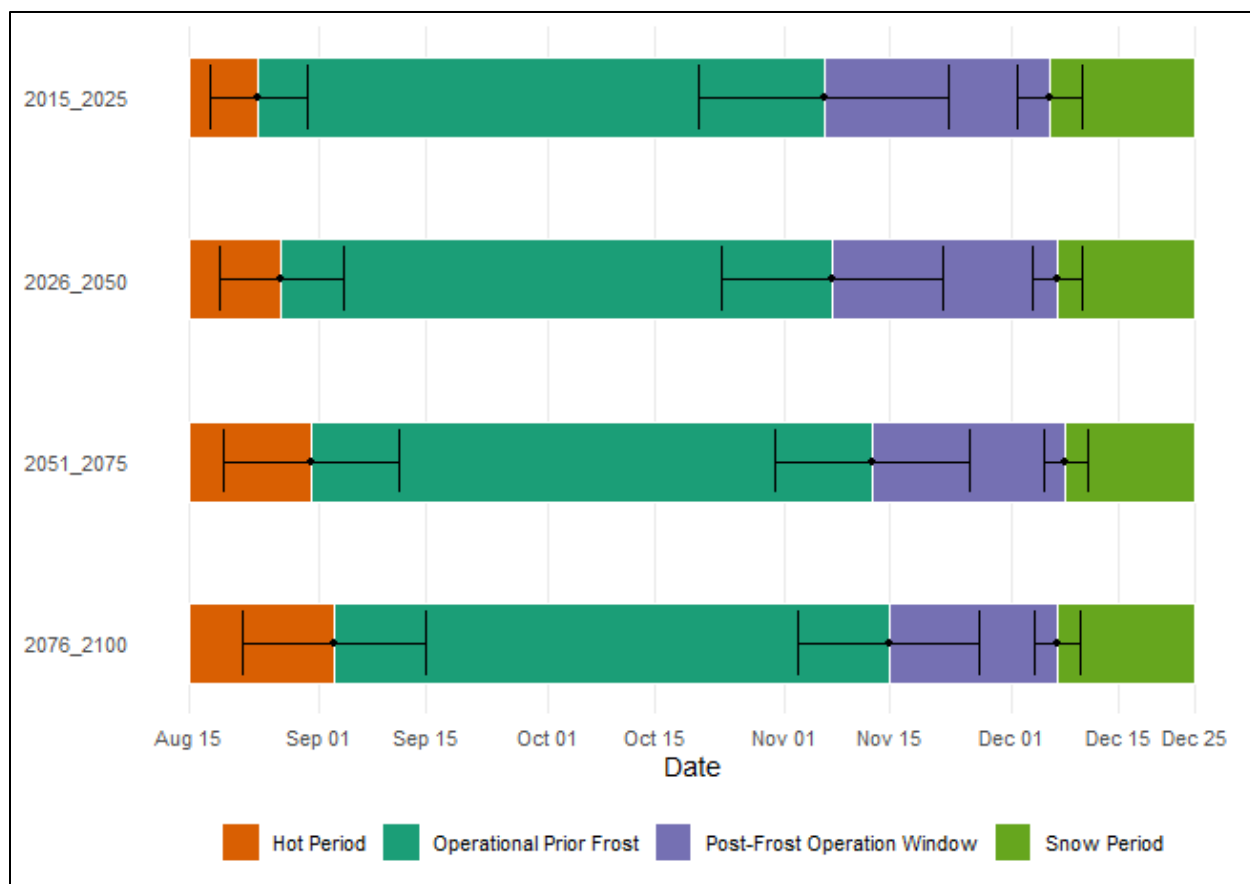


Figure XII: The harvest season is separated by climatic indicators for the private industry ownership in Washington.

Table II-III: Ensemble Climatic Indicator Means and Operational Window Lengths for Private Industry Ownership in Washington

Ensemble Climatic Metric (DOY)	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Last Hot-Day Event	273 (8.01)	274 (7.96)	276 (9.25)	278 (9.71)
First Frost Event	310 (16.51)	311 (14.51)	317 (12.77)	319 (11.92)
First Snow Event	340 (4.31)	341 (3.26)	342 (2.92)	341 (2.98)
Operational Window Start	236 (6.35)	239 (8.10)	243 (11.52)	246 (11.98)
Operational Window End	355 (1.83)	355 (1.63)	356 (0.99)	357 (1.06)
Operation Windows (days)				
Operational Window Total	119	117	113	111
Post-Frost Window	45	44	40	38

*Period means are rounded to the nearest DOY for interpretability.

Generally, for the moderate climate scenario, climatic triggers for the bough operational period by ownership are suggested to move later in the year with a general loss of potential operational time for the season and post-frost. While these results provide a high-level view of the shifting climate, they indicate relatively high variability and uncertainty about future. Complete metric reporting and metric graphs are located in Supplement II-III.

While the operational window is shortened, the change is not great, such as the for the private industry ownership in Washington losing 8 days of the operational window and 7 days of the post-frost window. The results indicate there is an effect but is more of a short curtailing of the operational window. Rather, the spread of uncertainty is far greater for frost and may be more interesting of a result.

Climatic Metrics by Ownerships within Ecoregions

Categorizing ownerships by ecoregions further demonstrates the climatic metric descriptive differences between overall reported metrics. Presented here, to exemplify these results, are the overall ending hot-day event and first frost event climatic metrics of Washington private industrial forestlands and the same climatic metrics for Washington private industrial forestlands in different ecoregions across climatic periods (Table II-IV). Industrial forest lands in the North Cascades and Cascades have earlier frost dates across all time periods while the Puget Lowlands and Coast Range had later frost dates across all time periods. Overall, first frost event means differ between ten days earlier and eight days later for the near-reference period. The North Cascades had an earlier last hot-day day event compared to the industry-wide mean while the Puget Lowlands and Willamette Valley had later last hot-day events. Overall, the last frost event means differ between five days earlier and 12 days later for the near-reference

period. These different reported metrics highlight the spatial variation of climatic exposure across an ownership class and how ownerships in different regions may experience different localized climates.

Table II-IV: First Frost Event and Last Hot-Day Event for the Washington Private Industry Forestland by Ecoregion

Metric Name/Ecoregion	2015-2025 (std.)	2026-2050 (std.)	2051-2075 (std.)	2076-2100 (std.)
All Washington State Private Industry Forestland				
Overall First Frost Event	310 (16.51)	311 (14.51)	317 (12.77)	319 (11.92)
Overall Last Hot-Day Event	273 (8.01)	274 (7.96)	276 (9.25)	278 (9.71)
Washington State Private Industry Forestland Ensembled First Frost Event by Ecoregion				
Puget Lowlands	314 (17.99)	315 (15.08)	320 (13.32)	323 (12.43)
North Cascades	300 (19.23)	302 (17.32)	307 (14.88)	310 (13.77)
Cascades	302 (21.15)	304 (18.82)	310 (16.24)	312 (14.61)
Coast Range	318 (15.31)	319 (14.61)	324 (12.63)	327 (12.58)
Willamette Valley	310 (16.41)	311 (15.66)	316 (14.47)	319 (13.49)
Washington State Private Industry Forestland Ensembled Last Hot-Day Event by Ecoregion				
Puget Lowlands	278 (8.86)	278 (8.81)	280 (9.92)	281 (10.76)
North Cascades	268 (9.10)	268 (8.21)	271 (9.21)	272 (8.70)
Cascades	275 (8.95)	275 (8.81)	278 (9.55)	278 (10.02)
Coast Range	273 (7.22)	274 (7.47)	277 (9.17)	278 (9.85)
Willamette Valley	285 (9.18)	285 (8.02)	288 (10.88)	288 (12.07)

* DOY rounded to nearest day for ease of interpretation.

To demonstrate the differences within an ecoregion, the overall ending hot-day event and first frost event climatic metrics for the Washington Cascades are presented with the same individual metrics for different ownerships in the Cascades across climatic periods (Table II-V). In

a descriptive view, the first frost event varied across ownerships, typically later for private ownership classes and earlier for the federal government ownership compared to the overall ensembled mean for the Cascades. The first frost event varied between eight days earlier and 17 days later across ownerships in comparison to the overall ecoregion mean. The last hot-day event has similar descriptive differences where private ownership has later reported last hot-day events and federal ownerships have earlier last hot-day events in comparison to the overall ecoregion mean. The ownership means varied between five days earlier and nine days later compared to the ecoregion mean. The variation for the first frost event demonstrates how ownerships may cluster in similar environmental or site conditions within the ecoregion, such as elevation, leading to heterogeneity in the reported localized climate means.

Table II-V: First Frost Event and Last Hot-Day Event for the Washington Cascades Ecoregion by Ownership

Metric Name/Ecoregion	2015-2025 (std.)	2026-2050 (std.)	2051-2075 (std.)	2076-2100 (std.)
All Washington State Cascades Forestland				
Overall First Frost Event	287 (18.59)	289 (17.31)	295 (16.10)	297 (14.65)
Overall Last Hot-Day Event	271 (8.72)	271 (8.55)	273 (9.17)	274 (9.25)
Washington State Cascade Forestland Ensembled First Frost Event by Ownership				
Private SFLO	304 (18.73)	305 (16.77)	311 (14.75)	313 (13.18)
Private Industry	302 (21.15)	304 (18.82)	310 (16.24)	312 (14.61)
Government State	300 (20.26)	301 (18.45)	308 (16.19)	310 (14.62)
Government Federal	279 (18.02)	281 (17.36)	288 (16.82)	290 (15.51)
Tribal Forestry	280 (18.56)	282 (17.56)	288 (16.59)	291 (15.65)
Washington State Cascade Forestland Ensembled Last Hot-Day Event by Ownership				
Private SFLO	280 (8.84)	280 (8.52)	282 (9.85)	283 (10.59)

Private Industry	275 (8.95)	275 (8.81)	278 (9.55)	278 (10.02)
Government State	275 (8.96)	275 (8.74)	277 (9.57)	278 (9.88)
Government Federal	268 (8.71)	269 (8.51)	271 (8.97)	272 (8.91)
Tribal Forestry	266 (9.09)	266 (8.85)	269 (9.32)	270 (8.98)

* DOY rounded to nearest day for ease of interpretation.

These segmented results for ownership-ecoregion categories highlight the spatial climatic variation and how these locations potentially impact the harvest windows for bough production. While these are climatic trends and landscapes will experience similar climatic conditions in a given year, the potential differences within ownerships and ecoregions have management implications, especially for ownerships that span across and within ecoregions.

Probability of Frost Across Ownerships and Ecoregions

The climate event results presented help describe average timing of climatic indicators to illustrate shifts due to a changing climate. However, translating these mean shifts into probability of climatic conditions occurring presents a more applicable measure for managers. The following analysis presents the probability of frost occurrence across different date thresholds to demonstrate frost reliability.

Calculated probability of frost occurring prior to or on specific threshold days for the different ownerships investigated shows that the probability of frost decreases across ownerships towards later in the century (Figure XIII; Table II-VI). Considering a stationary point of November 15th as a threshold date, ownerships experience a change of frost probability between -0.047 and -0.173 between the near-reference period (2015-2025) and late century (2076-2100) (Table II-VI). Typically, federal ownerships in both Washington and Oregon have

greater probability of a frost occurring in the near-reference period (0.935 and 0.823 respectively) and the late century period (0.888 and 0.755 respectively) compared to all other ownerships. Similarly, federal ownerships in both Washington and Oregon have the some of the smallest change in probability from the near-reference period and late century period (-0.047 and -0.069 respectively) with only tribal forestry in Washington having similar minimal change (-0.057) over the same period. County government forests in Washington have the lowest probability across all time periods, likely attributed to the moderating climate effects of the ocean. By the late century period, all private ownerships in both states have less than 0.5 probability of a frost event prior or on November 15th.

All ownerships report at least 0.75 probability of a frost event on or prior to December 15th across the climate periods. Ownerships vary greatly at earlier threshold dates, such as October 15th, when some ownerships have less than 0.25 probability of a frost event (e.g., county government in Washington and private industry in both states) and others have greater than 0.50 probability of a frost event such as the federal government forestlands in Washington.

Table II-VI: Ensemble probability of a Frost Event Prior to November 15th within Different Climate Periods Across Ownerships

Ownership Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100	Total Period Change
Washington State					
Private SFLO	0.612	0.599	0.521	0.496	-0.115
Private Industry	0.632	0.607	0.513	0.474	-0.158
Government County	0.414	0.389	0.284	0.257	-0.156
Government State	0.683	0.669	0.591	0.559	-0.123
Government Federal	0.935	0.929	0.898	0.888	-0.047
Tribal Forestry	0.632	0.634	0.587	0.575	-0.057
Oregon State					
Private Industry	0.554	0.529	0.451	0.431	-0.123
Government State	0.576	0.553	0.444	0.403	-0.173
Government Federal	0.823	0.808	0.773	0.755	-0.069

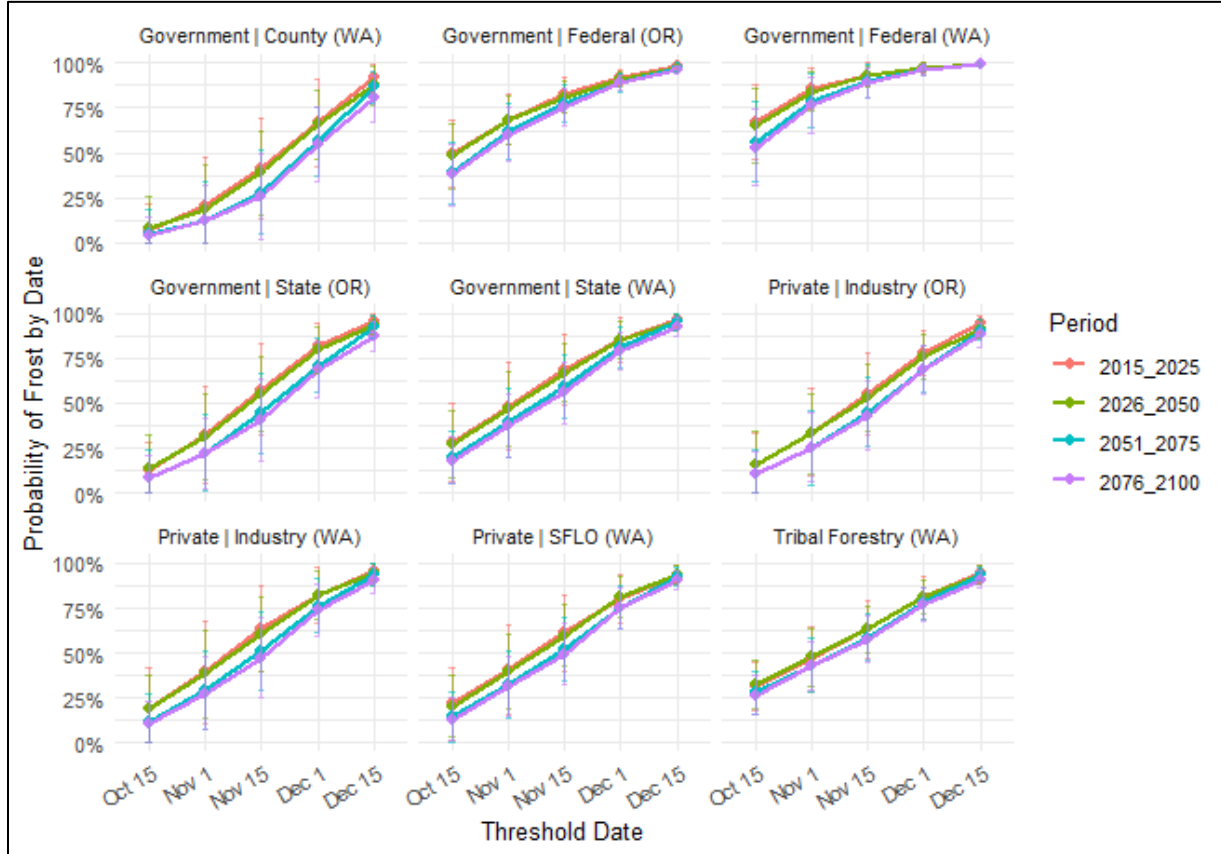


Figure XIII: Ensemble probability of a frost event prior October 15, November 1, November 15, December 1, and December 15 by ownership for investigated climate periods.

Across ownerships, the probability of frost in the early to middle portions of the bough harvest season decreases in future climate periods while late season changes are typically more stable (Figure XIII). The decreasing probability of frost in the earlier portion of the season, similar to that of the November 15th assessment, demonstrates increased risk of a shortened post-frost operational window and decreased reliability of future frosts.

Calculated probability of frost occurring prior to or on specific threshold days for the different ecoregions investigated shows that the probability of frost decreases across ecoregions towards later in the century (Table II-VII). Considering a stationary point of November 15th as a threshold date, ecoregions experience a change of frost probability between -0.045 and -0.193

between the near-reference period (2015-2025) and late century (2076-2100) (Table II-VII).

Other than the Klamath Mountains, the inland montane ecoregions tend to have greater probability of a frost event occurring in the near-reference period (0.882 – 0.939) and the late century period (0.798 – 0.844) compared to other ecoregions. The inland montane ecoregions also tend to the smallest change in probability from the near-reference period to the late century period (-0.045 to -0.084) compared to other ecoregions. The Coast Range of Oregon tends to have the lowest frost probability compared to other ownerships, likely attributed to the moderating climate effects of the ocean. By the late century period, only the North Cascades and the Cascades in both states have greater than 0.5 probability of a frost event prior or on November 15th.

All ecoregions report at least 0.75 ensemble probability of a frost event on or prior to December 15th across the climate periods with standard deviations sometimes exceeding 0.75 probability. Ownerships vary greatly at earlier threshold dates, such as October 15th, when ecoregions vary between near zero probability, as seen with the Coast Range of both states, and near 0.75 probability as seen in the North Cascades.

Table II-VII: Ensemble probabilities of a Frost Event Prior to November 15th within Different Climate Periods Across Ecoregions

Ecoregion Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100	Total Period Change
Washington State					
Puget Lowland	0.531	0.515	0.419	0.376	-0.155
North Cascades	0.939	0.932	0.903	0.894	-0.045
Coast Range	0.553	0.530	0.427	0.388	-0.165
Cascades	0.882	0.871	0.821	0.798	-0.084
Willamette Valley	0.652	0.624	0.521	0.469	-0.183
Oregon State					
Coast Range	0.412	0.387	0.314	0.299	-0.144
Willamette Valley	0.491	0.468	0.352	0.318	-0.173
Cascades	0.886	0.871	0.826	0.802	-0.084

Klamath Mountains	0.656	0.612	0.524	0.463	<i>-0.193</i>
--------------------------	-------	-------	-------	-------	---------------

All ownership-ecoregion intersection ensembled means are reported in Supplemental II-V.

Sensitivity Analysis

The use of different thresholds to test for variation in what constitutes as the last hot-day event (26° and 30°) and the first frost event (2°C and -2°C) indicate how even minor changes in the specified thresholds can alter this analysis. Using the private industrial forestland in Washington as an ownership example, as expected, the higher heat thresholds result in the last hot-day event ensembled mean occurring earlier in the year compared to the standard threshold of 22°C (Table II-VIII). For the near-reference period, the 26°C threshold ensembled mean occurred 12 days earlier and the 30°C threshold ensembled mean occurred 24 days earlier. The difference remains the same during the late century period. These results indicate that should a manager choose a higher temperature as an inoperable hot day event, the operational window will extend earlier into the year.

The first frost thresholds respond as expected with the higher threshold of 2°C, representing a softer frost criterion, occurs earlier in the year and the lower threshold of -2°C, representing a “hard frost”, occurs later in the year. For the near-reference period, the 2°C threshold ensembled mean occurs 18 days earlier. The -2°C threshold ensembled mean occurs 15 days later. Variance between models remain high, suggesting that the first frost event remains unreliable to predict even at different thresholds. Nevertheless, the lower threshold of -2°C ensembled means having a smaller reported variance compared to the warmer thresholds. The different threshold results do demonstrate that how a manager defines a “frost event” as a proxy for dormancy process will affect their post-frost operational periods.

Table II-VIII: Sensitivity Analysis for the Washington Private Industry Forestlands across all Climate Periods

Ensemble Climatic Metric (DOY)	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
22° Last Hot-Day Event	273 (8.01)	274 (7.96)	276 (9.25)	278 (9.71)
26° Last Hot-Day Event	261 (8.59)	261 (7.88)	265 (8.96)	266 (8.98)
30° Last Hot-Day Event	249 (8.87)	250 (8.01)	253 (8.72)	254 (8.85)
0° First Frost Event	310 (16.51)	311 (14.51)	317 (12.77)	319 (11.92)
-2° First Frost Event	325 (12.33)	326 (10.19)	329 (8.00)	329 (7.77)
2° First Frost Event	292 (17.40)	294 (16.23)	301 (15.12)	303 (14.21)

For ecoregions, using the Washington Cascades as an example, results are as expected for both the last hot event thresholds and first frost event thresholds (Table II-IX). The last hot-day event thresholds have ensembled means earlier in the year compared to the baseline threshold with the 26°C threshold occurring 12 days earlier and the 30°C threshold occurring 21 days earlier for the near-reference period. The first frost event thresholds have the 2°C threshold ensembled mean occurring 18 days earlier in the year and the -2°C threshold ensembled mean occurring 17 days later in the year for the near-reference period. These results support the ownership findings demonstrating how managers define a hot-day event or frost event affects the operational periods.

Table II-IX: Sensitivity Analysis for the Washington Cascades Ecoregion across all Climate Periods

Ensemble Climatic Metric (DOY)	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
22° Last Hot-Day Event	271 (8.72)	271 (8.55)	273 (9.17)	274 (9.25)
26° Last Hot-Day Event	259 (8.81)	260 (8.39)	262 (8.96)	263 (8.94)

30° Last Hot-Day Event	250 (8.65)	250 (8.01)	253 (8.39)	253 (8.54)
0° First Frost Event	287 (18.59)	289 (17.31)	295 (16.10)	297 (14.65)
-2° First Frost Event	304 (17.70)	305 (15.37)	310 (13.25)	311 (11.81)
2° First Frost Event	269 (16.55)	272 (15.96)	278 (15.87)	281 (15.10)

This sensitivity analysis demonstrates that the thresholds set are critical for determining the operational period for operators. Higher hot-day event thresholds may result in earlier operations. A warmer frost event threshold may extend the post-frost harvest window while a cooler frost event threshold may limit the post-frost harvest window. For the frost results, when using a climatic trigger as a proxy for a physiological process, local knowledge of how trees and boughs react to harvest under different temperatures will help define how long the post-frost harvest window is for that species. Baseline assumptions for climate indicators result in remarkably different results.

Discussion

Climatic Impact

The ensembled results suggest that hot-day events as a harvest constraint will shift later into the season, but the magnitude of change of hot-day events is smaller than those of frost-related metrics. This shows how the overall climate of the Pacific Northwest will remain moderated even under a changing climate where many different regions of the world will see overall heating (Dalton et al., 2013). Additionally, the overall low difference between models and the ensemble mean of the high heat threshold indicates that most climate models are in agreement of this subtle change.

However, other climatic events, such as the frost event proxy, show higher deviation between models for the period summaries. This indicates that frost (or temperatures around 0 degrees Celsius) events are not similar across models, suggesting that this weather event may be highly variable in the future and less reliable. This may also point to the general difficulty of predicting specific weather events each year or time period based on climatic trends.

Phenology Considerations

While the study did not model phenology, the climatic results suggest some impact. The results indicated that frost dates would be later in the year as the century progresses. This means that the thermoperiod influence on dormancy accumulation may be delayed, impacting the dormancy process. For noble fir in particular, this may have significant impacts to crown development and whorl symmetry as warm temperatures progress into the fall and frost become unreliable (Neilsen & Ramussen 2008). The study did not consider the other aspects to dormancy accumulation, such as photoperiod and site conditions.

Management Impacts

The core of the study demonstrates that frost, as a proxy for the onset of dormancy, is variable and trends to later in the study season. Using the literature as a rule-of-thumb for quality, the post-frost operational window decreases across ownerships and ecoregions. Generally, higher elevation sites across Washington and Oregon maintain longer and earlier post-frost operation windows compared to lowland ownerships and ecoregions. As post-frost operation windows shift later into the year, the higher elevation sites maintain the earliest windows for bough harvesting after a frost event.

The early post-frost operation window in the higher elevations is an important finding, suggesting that bough harvests may face pressure to access frost-exposed boughs from higher elevations later in the century. Higher elevations tend to be under federal ownership through the USFS. These forests, as they currently stand, tend to be older with the trend towards more forestland aging. As these forests age, trees will leave the optimal age for bough harvesting, leading to a decline in potential bough stock. Currently, the greatest bough producing national forest unit in Washington, the Gifford-Pinchot National Forest, is seeing a decline in bough harvests. Should this trend continue, federal forests may be constrained for bough harvests. Lowland forests will likely need to be substituted, potentially lower the potential bough stock that experiences a frost event.

Noble fir, the prize bough species (W. Schlosser & Blatner, 2004), is a mid- to high-elevation tree species, with a native range endemic to Washington and Oregon, though it can grow elsewhere when managed, such as the lowlands (Franklin, 1981). As the climate shifts, it may mean that the native range of noble fir will shift up in latitude and in elevation to follow the native range climatic norms (Kralicek et al., 2023). Researchers and managers may need to investigate the species distribution shift under changing climate regimes to understand where future stands of noble fir can be planted for optimal growth. With much of the mid- to high-elevation forestland under federal ownership, this may further limit the ability to harvest high-value boughs under a changing climate.

The trends in the data also show generally better conditions for the post-frost operation window and operational period in Washington State, especially in the north. An additional consideration for bough harvesters and bough processors is the shift in where the potential

supply occurs. In this moderate climate scenario, should operational periods and post-frost operation windows be more advantageous in the north, bough processing centers, typically located near Olympia, WA, may need to consider satellite operations in the northern portion of the state. Accordingly, noble firs and other high-value bough species will need to be planted in anticipation of a changing climate.

When considering boughs as a secondary forest product that financially supports timber production or serves as auxiliary revenue for other ownership objectives, these shifting climatic conditions may mean there is less opportunity for lowland ownerships of industrial forestry, small forest landowners, or state government ownership to invest in or capitalize bough production to offset forest landownership costs. Exploration in bough harvests in the lowlands across different ownerships may be more advantageous earlier rather than later in the century.

There are additional management implications that come from this work outside of bough production. Salal requires cold weather or a frost to be hardened off for cool storage, extending the longevity of the greenery (“OrcaGreen,” n.d.). Without the cold weather, salal may be damaged in coolers and have a shorter shelf life. The decrease in frost probability in the lowlands, where salal occurs, will impact the amount of salal available for cool storage.

The wild floral green industry relies on multiple sources of revenue throughout the year to remain viable. The evergreen boughs, and other products harvested for the Christmas season, are a significant portion of industry revenues, as demonstrated by Schlosser (1991). This study, along with Prevey et al. (2020), suggests that the wild green industry may experience supply constraints in the coming decades as several products react to a changing climate.

For managers the results suggest that:

- Management and elevations may look to higher elevations for more consistent frost windows;
- Planning and adaptation should consider higher elevations and how to access high elevation bough production lands;
- Operational windows remain strong in the lowlands, but frost occurrence has low reliability and predictability, possibly requiring other methods to increase needle retention, such as bough refrigeration.

Limitations

This study provides a simplified understanding of the climatic limitations of bough harvesting in the Pacific Northwest. The study has several limitations through this simplification.

Scale

The study is conducted on climatic data scaled to a four-kilometer grid. While presenting some of the finest resolution climate data available, this data grid was still coarse and does not well represent microclimates or represent the scale of forest ownerships, especially small ownerships. Averaging of other variables to match the climatic data resolution means that nuanced information is lost about the amount of forest on the landscape of the elevation of the area.

Similarly, the study area was relatively large, spanning across major ecoregions and several degrees of longitude and latitude. While this represents the bough production region of Washington and Oregon, the scale of the study presents the challenge of actionable results. Management decisions based on these climatic indicators are more relevant on the scale of individual ownership. This study attempts to remedy this limitation through the representative

site analysis and through the findings that post-frost bough windows are longer along the mid- to high-elevation band.

Additionally, only SSP245 was assessed compared to more carbon intensive scenarios. SSP245 was selected to represent the most likely climate scenario. Nevertheless, including other scenarios would highlight how projections change under different model conditions.

Extreme Weather

The study considers climatic trends over a long period of time and does not investigate extreme weather events. Extreme weather events have a prevalent role in bough production. In 2021, a heat dome in Washington State damaged trees by singeing needles and damaging new growth (Still et al., 2023). Bough production was affected by lower quality boughs and lower stock as potential boughs could not be harvested due to the shock. With boughs taking 3-4 years between harvests to regrow, extreme weather can delay a bough-potential stand an entire harvest cycle, removing that potential income for timberland owners, bough harvesters, and bough processors.

Bomb-cyclone events, hard freezes, ice storms, blizzards, wind storms, and weather-related landslides all affect bough production by damaging the product and reducing access in remote areas. Extreme weather also damages hard-to-repair infrastructure that allows for access and transportation of boughs from the forests, especially undeveloped roads that are prone to erosion and washouts. Understanding how the risk of these extreme weather events changes over time and across the landscape will help land managers plan for potential stock loss in the future.

Conclusion

This study set out to understand the relationship between a changing climate and the climatic indicators that frame the bough harvesting season in the Pacific Northwest. Generally, the findings indicate that all climatic indicators may be affected. Particularly, hot-day events may last longer into the season, and frost events occur later in the year across the study area. The probability of frost events in different ecoregions and ownerships will fall by several percentage points, particularly in private ownerships, the lowlands, and coastal ecoregions. These findings suggest that earlier frost events in the future will be associated with higher elevations and federal forestlands.

The shifts in the climatic indicators alter both the timing and the geographic area that bough harvests may occur. Lowlands and other areas that experience reliable early frosts in the past may not experience the same in the future, while the higher elevations maintain more consistent frost reliability. This puts additional pressure on bough production for federal ownership, which already has experienced declining bough production. The shift in timing and geographic scope requires managers to reconsider land access, availability of contracts and permitting, and hauling distances to processing facilities.

Bough harvesting demonstrates the constraint of biological and economic timelines. The industry benefits from the quality of a dormant bough while also needing to deliver product to markets prior to the Christmas season. This leaves the evergreen bough market fixed, unable to move with the shifting climate. Shifting climatic conditions will constrain how the industry functions in harvesting, processing, delivering, and selling evergreen boughs and products. The

ripple effect of climate change then affects not only the biological timeline but also operational decisions, flexibility, and supply chain.

These findings contribute to the current NTFP literature by providing climate change implications for a NTFPs in the United States, particularly along the West Coast. Specifically, this research demonstrates how climate change impacts a NTFP with a harvest season that is dependent on observable climatic indicators and limited by a culturally significant holiday. By relating this research to the observable climatic proxy of frost for tree dormancy, these findings are relevant to the practical operations of the industry, tying climate science to applied management.

Bough production will likely persist under the results presented in this study where frost will likely occur later in the season, and unpredictably, but still prior to the Christmas season. Nevertheless, the context in which operations occur will have to shift with ownership, access, and geography. To this end, adaptation is possible in the face of climate change.

References

- Azuma, D. L., Eskelson, B. N. I., & Thompson, J. L. (2014). Effects of rural residential development on forest communities in Oregon and Washington, USA. *Forest Ecology and Management*, 330, 183–191. <https://doi.org/10.1016/j.foreco.2014.07.018>
- Blatner, K. A., Cohn, P. J., & Fight, R. D. (2010). Returns from the Management of Noble Fir Stands for Bough Production and Sawtimber. *Western Journal of Applied Forestry*, 25(2), 68–72. <https://doi.org/10.1093/wjaf/25.2.68>
- Buttolph, L., & Jones, E. (2012). *Evergreen Boughs: A Brief Introduction to Harvesting and Marketing from Small Private Forestlands in the Pacific Northwest* (Fact Sheet No. 4; Income Opportunities for Small Woodland Owners). Institute for Culture and Ecology. https://knowyourforest.org/sites/default/files/documents/Evergreen_boughs.pdf
- Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., ... Péan, C. (with Lee, H.). (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]*. IPCC, Geneva, Switzerland. (First). Intergovernmental Panel on Climate Change (IPCC). <https://doi.org/10.59327/IPCC/AR6-9789291691647>
- Cercone, M., Lilley, W., & Fuller, D. (2017). *Balsam Fir Tip Harvesting* (Bulletin No. 7011). The University of Maine Cooperative Extension. <https://extension.umaine.edu/publications/7011e/>
- Charalampopoulos, I., & Droulia, F. (2022). Frost Conditions Due to Climate Change in South-Eastern Europe via a High-Spatiotemporal-Resolution Dataset. *Atmosphere*, 13(9), Article 9. <https://doi.org/10.3390/atmos13091407>
- Charnley, S., Fischer, A. P., & Jones, E. T. (2007). Integrating traditional and local ecological knowledge into forest biodiversity conservation in the Pacific Northwest. *Forest Ecology and Management, Biodiversity Management in Pacific Northwest Forests: Strategies and Opportunities.*, 246(1), 14–28. <https://doi.org/10.1016/j.foreco.2007.03.047>
- Chastagner, G. A., Nielsen, U. B., & Riley, K. L. (2004). Comparison of the Postharvest Quality of Noble Fir Boughs from the United States and Danish Provenances Grown in Denmark. *HortScience*, 39(3), 580–583. <https://doi.org/10.21273/HORTSCI.39.3.580>
- Christiansen, D. E., Markstrom, S. L., & Hay, L. E. (2011). Impacts of Climate Change on the Growing Season in the United States. *Earth Interactions*, 15(33). <https://doi.org/10.1175/2011EI376.1>
- Clarke, S. E., & Bryce, S. A. (1997). *Hierarchical subdivisions of the Columbia Plateau & Blue Mountains ecoregions, Oregon & Washington*. (General Technical Report PNW-GTR-395;

- p. 114). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Dalton, M., Mote, P., & Snover, A. (Eds.). (2013). *Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities*. Island Press.
- Earle, Christopher. "Abies Magnifica." The Gymnosperm Database, January 7, 2026. <https://www.google.com/maps/d/viewer?mid=14XvM5wnUhFkr8ixrn080ybfaGJ0>. Accessed August, 19, 2026.
- Ekberg, I., Eriksson, G., & Dormling, I. (1979). Photoperiodic reactions in conifer species. *Ecography*, 2(4), 255–263. <https://doi.org/10.1111/j.1600-0587.1979.tb01297.x>
- Erlat, E., & Türkeş, M. (2016). Dates of frost onset, frost end and the frost-free season in Turkey: Trends, variability and links to the North Atlantic and Arctic Oscillation indices, 1950–2013. *Climate Research*, 69(2), 155–176. <https://doi.org/10.3354/cr01397>
- Franklin, J. F. (1981). ECOLOGY OF NOBLE FIR. *Biolog and Management of True Fir in the Pacific Northwest*. <https://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub109.pdf>
- Franklin, Jerry, and C. T. Dyrness. *Natural Vegetation of Oregon and Washington*. General Technical Report PNW-GTR-008. United States Department of Agriculture Forest Service: Pacific Northwest Research Station, 1973. <https://research.fs.usda.gov/treesearch/26203>.
- Frankson, R., Kunkel, K., Champion, S., Easterling, D., Stevens, L., Bumbaco, K., Bond, N., Casola, J., & Sweet, W. (2022). *Washington State Climate Summary 2022* (NOAA Technical Report NESDIS Nos. 150-WA; p. 5). NOAA/NESDIS.
- Garcia, Elizabeth, Christina Tague, and Janet Choate. "Influence of Spatial Temperature Estimation Method in Ecohydrologic Modeling in the Western Oregon Cascades." Pt. 1611-1624. *Water Resources Research* 49 (2013). <https://doi.org/10.1002/wrer.20140>.
- García-Martín, A., Paniagua, L. L., Moral, F. J., Rebollo, F. J., & Rozas, M. A. (2021). Spatiotemporal Analysis of the Frost Regime in the Iberian Peninsula in the Context of Climate Change (1975–2018). *Sustainability*, 13(15), Article 15. <https://doi.org/10.3390/su13158491>
- Hansen, M., & Jacobson, K. (2005). *Balsam boughs: An important Minnesota resource* (p. 6) [Miscellaneous Publication]. U.S. Department of Agriculture, Forest Service, North Central Research Station. <https://research.fs.usda.gov/treesearch/14140>
- Heat—Heat Hazard Recognition | Occupational Safety and Health Administration*. (n.d.). Retrieved August 11, 2026, from <https://www.osha.gov/heat-exposure/hazards>
- Hinesley, L. E., & Snelling, L. K. (1992). Yield of Decoration Greenery Fraser Fir Christmas Trees. *HortScience*, 27(2), 107–108. <https://doi.org/10.21273/HORTSCI.27.2.107>
- Hummel, S., S. Foltz-Jordan, and S. Polasky. *Natural and Cultural History of Beargrass (Xerophyllum Tenax)*. General Technical Report PNW-GTR-864. Department of Agriculture, Forest Service, Pacific Northwest Research Research Station, 2012. https://www.fs.usda.gov/pnw/pubs/pnw_gtr864.pdf.

- Khoshnood Motlagh, S., & de Lima Moraes, A. G. (2025). *Climate data for adaptation and vulnerability assessments—Northwest* [Dataset]. World Data Center for Climate. <https://doi.org/https://doi.org/10.26050/WDCC/ClimAVA-NW>
- Knutti, R., Furrer, R., Tebaldi, C., Cermak, J., & Meehl, G. A. (2010). *Challenges in Combining Projections from Multiple Climate Models*. <https://doi.org/10.1175/2009JCLI3361.1>
- Kralicek, K., Ver Hoef, J. M., Barrett, T. M., & Temesgen, H. (2023). Spatial Bayesian models project shifts in suitable habitat for Pacific Northwest tree species under climate change. *Ecosphere*, 14(3), e4449. <https://doi.org/10.1002/ecs2.4449>
- Kukal, M. S., & Irmak, S. (2018). U.S. Agro-Climate in 20th Century: Growing Degree Days, First and Last Frost, Growing Season Length, and Impacts on Crop Yields. *Scientific Reports*, 8(1), 6977. <https://doi.org/10.1038/s41598-018-25212-2>
- LANDFIRE. (2024). *Existing Vegetation Type Layer* (Version LANDFIRE 2.50) [Dataset]. <http://www.landfire/viewer>
- Landgren, C., & Freed, J. (1998). *Harvesting and Marketing Noble Fir Boughs from Christmas Tree Plantations* (EC No. 1500). Oregon State University Extension Service.
- Lavender, D. P., Ching, K. K., & Hermann, R. K. (1968). Effect of Environment on the Development of Dormancy and Growth of Douglas-Fir Seedlings. *Botanical Gazette*, 129(1), 70–83.
- Luedeling, E. (2012). Climate change impacts on winter chill for temperate fruit and nut production: A review. *Scientia Horticulturae*, 144, 218–229. <https://doi.org/10.1016/j.scienta.2012.07.011>
- MacDonald, M. T., Lada, R. R., Veitch, R. S., Thiagarajan, A., & Adams, A. D. (2014). Postharvest needle abscission resistance of balsam fir (*Abies balsamea*) is modified by harvest date. *Canadian Journal of Forest Research*, 44(11), 1394–1401. <https://doi.org/10.1139/cjfr-2014-0199>
- Malinovic-Milicevic, S., Stanojevic, G., & Radovanovic, M. M. (2018). Recent changes in first and last frost dates and frost-free period in Serbia. *Geografiska Annaler: Series A*, 100(1).
- McCreary, D. D., Tanaka, Y., & Lavender, D. P. (1978). Regulation of Douglas-fir Seedling Growth and Hardiness by Controlling Photoperiod. *Forest Science*, 24(2), 142–152. <https://doi.org/10.1093/forestscience/24.2.142>
- McGrath, C. L., Woods, A. J., Omernik, J. M., Bryce, S. A., Edmondson, M., Nesser, J. A., Shelden, J., Crawford, R. C., Comstock, J. A., & Plocher, M. D. (2002). *Ecoregions of Idaho* [2 sided color poster with map, descriptive text, summary tables, and photographs]. U.S. Geological Survey.
- Mesgari, E., Hosseini, S. A., Houshyar, M., Kaseri, M., & Safarpour, F. (2023). Future projection of early fall and late spring frosts based on EC-earth models and shared socioeconomic pathways (SSPs) scenarios over Iran plateau. *Natural Hazards*, 119(3), 1421–1435. <https://doi.org/10.1007/s11069-023-06155-y>

- Mitcham-Butler, E. J., Hinesley, L. E., & Pharr, D. M. (1988). Effects of Harvest Date, Storage Temperature, and Moisture Status on Postharvest Needle Retention of Fraser Fir. *Journal of Environmental Horticulture*, 6(1), 1–4. <https://doi.org/10.24266/0738-2898-6.1.1>
- Nielsen, C., & Rasmussen, H. N. (2008). Frost hardening and dehardening in *Abies procera* and other conifers under differing temperature regimes and warm-spell treatments. *Forestry*, 82(1). <https://doi.org/https://doi.org/10.1093/forestry/cpn048>
- Nielsen, U. B. (2007). Genetic variation in characters important for noble fir greenery production. *Scandinavian Journal of Forest Research*, 22(2), 99–109. <https://doi.org/10.1080/02827580701231597>
- Nilsson, O. (2022). Winter dormancy in trees. *Current Biology*, 32(12), R630–R634. <https://doi.org/10.1016/j.cub.2022.04.011>
- Omernik, J. (1987). Ecoregions of the Conterminous United States. *Annals of the Association of American Geographers*, 77(1), 118–125.
- Omernik, J. M., & Griffith, G. E. (2014). Ecoregions of the Conterminous United States: Evolution of a Hierarchical Spatial Framework. *Environmental Management*, 54(6), 1249–1266. <https://doi.org/10.1007/s00267-014-0364-1>
- OrcaGreen. (n.d.). *Adomex*. Retrieved August 11, 2026, from <https://www.adomex.nl/en/orca/orcagreen/>
- Park, I. W., Ramirez-Parada, T., & Mazer, S. J. (2021). Advancing frost dates have reduced frost risk among most North American angiosperms since 1980. *Global Change Biology*, 27(1), 165–176. <https://doi.org/10.1111/gcb.15380>
- Pater, D. E., Bryce, S. A., Thorson, T. D., Kagan, J., Chappell, C., Omernik, J. M., Azevedo, S. H., & Woods, A. J. (1998). *Ecoregions of Western Washington and Oregon* [2 sided color poster with map, descriptive text, summary tables, and photographs]. U.S. Geological Survey.
- Pettersson, M., Talgø, V., Johnskås, O. R., Skage, J.-O., Torp, T., & Fløistad, I. S. (2020). Postharvest needle retention in Norway spruce Christmas trees. *Scandinavian Journal of Forest Research*, 35(8), 456–467. <https://doi.org/10.1080/02827581.2020.1795242>
- QGIS Development Team. (2026). *QGIS Geographic Information System* [Computer software]. QGIS Association. <https://doi.org/https://doi.org/10.5281/zenodo.6139224>
- R Core Team. (2025). *_R: A Language and Environment for Statistical Computing_* [Computer software]. R Foundation for Statistical Computing. www.R-project.org
- Rahimi, J., Khalili, A., & Bazrafshan, J. (2017). Analysis of late spring frost dates over Iran under current climate and future scenarios. *Modeling Earth Systems and Environment*, 3(4), 1601–1610. <https://doi.org/10.1007/s40808-017-0393-x>
- Rasmussen, H. N., Nielsen, C. N., & Jørgensen, F. V. (2005). Crown architecture and dynamics in *Abies procera* as influenced by cutting for greenery. *Trees*, 19(6), 619–627. <https://doi.org/10.1007/s00468-005-0425-4>

- Rogers, L., Cornnick, J., & Cooke, A. (2021). *The 2019 Washington State Forestland Database* [Digital Data]. [https://urldefense.com/v3/__https://nrsig.org/projects/washington-state-forestland-database__!!K-Hz7m0Vt54!i65i6_x_1S2zykVvRvzrT2aRFsY6wTgoQHt-EyuJGcUsn9cqme3WCV5oUHXunCnZ2QQOucUZgGxu8bQshK6h\\$](https://urldefense.com/v3/__https://nrsig.org/projects/washington-state-forestland-database__!!K-Hz7m0Vt54!i65i6_x_1S2zykVvRvzrT2aRFsY6wTgoQHt-EyuJGcUsn9cqme3WCV5oUHXunCnZ2QQOucUZgGxu8bQshK6h$)
- Schlosser, W., & Blatner, K. (2004). *Pacific Northwest Noble Fir: The king of wreaths, charms, and other Christmas ornaments* (Extension No. MISC0532). Washington State University Extension. <http://resource-analysis.com/wp-content/uploads/2018/10/KingOfWreaths.pdf>
- Schlosser, W. E., Blatner, K. A., & Chapman, R. C. (1991). Economic and marketing implications of special forest products harvest in the Coastal Pacific Northwest. *Western Journal of Applied Forestry*, 6(3), 67–72.
- Science of Snow* | National Snow and Ice Data Center. (n.d.). Retrieved August 11, 2026, from <https://nsidc.org/learn/parts-cryosphere/snow/science-snow>
- Still, C. J., Sibley, A., DePinte, D., Busby, P. E., Harrington, C. A., Schulze, M., Shaw, D. R., Woodruff, D., Rupp, D. E., Daly, C., Hammond, W. M., & Page, G. F. M. (2023). Causes of widespread foliar damage from the June 2021 Pacific Northwest Heat Dome: More heat than drought. *Tree Physiology*, 43(2), 203–209. <https://doi.org/10.1093/treephys/tpac143>
- Thiagarajan, A., & Lada, R. (2010). Cold acclimation influence post-harvest needle retention in root detached Balsam Fir (*Abies balsamea* (L.) Mill.). *Plant Physiology from Cell to Fruit Production Systems*, 371–378.
- Thiagarajan, A., MacDonald, M. T., & Lada, R. (2016). Environmental and Hormonal Physiology of Postharvest Needle Abscission in Christmas Trees. *Critical Reviews in Plant Sciences*, 35(1), 1–17. <https://doi.org/10.1080/07352689.2015.1133965>
- Thorson, T. D., Bryce, S. A., Lammers, D. A., Woods, A. J., Omernik, J. M., Kagan, J., Pater, D. E., & Comstock, J. A. (2003). *Ecoregions of Oregon* [2 sided color poster with map, descriptive text, summary tables, and photographs]. U.S. Geological Survey.
- Timmis, R., & Worrall, J. (1975). Environmental Control of Cold Acclimation in Douglas Fir During Germination, Active Growth, and Rest. *Canadian Journal of Forest Research*, 5(3), 464–477. <https://doi.org/10.1139/x75-064>
- Tremblay, J. D., Smith, R. F., & D’Orangeville, L. (2023). Integrating the Rate of Moisture Loss into Needle Retention Testing to Improve the Selection of Balsam Fir (*Abies balsamea*) for Use as Christmas Trees. *Forests*, 14(8), 1626. <https://doi.org/10.3390/f14081626>
- Tung, C.-H., & DeYoe, D. (1991). Dormancy induction in container-grown *Abies* seedlings: Effects of environmental cues and seedling age. *New Forests*, 5, 13–22. <https://doi.org/https://doiorg/10.1007/BF00037547>

- US Department of Commerce, N. (n.d.). *Earliest/Mean/Latest First Fall Freeze Climatology*. NOAA's National Weather Service. Retrieved August 11, 2026, from <https://www.weather.gov/dlh/FrostFreezeClimatology>
- U.S. Geological Survey. (2026). *3D Elevation Program 1 Arc Second Resolution Digital Elevation Model* [Dataset]. <https://apps.nationalmap.gov/downloader/>
- USEPA. (2012a). *Level III Ecoregions of Oregon* [Vector digital data]. ftp://ftp.epa.gov/wed/ecoregions/or/or_eco_l3.zip
- USEPA. (2012b). *Level III Ecoregions of Washington* [Vector digital data]. ftp://ftp.epa.gov/wed/ecoregions/wa/wa_eco_l3.zip
- Vance, N., Borsting, Pilz, D., & Freed, J. (2001). *SPECIAL FOREST PRODUCTS: Species Information Guide for the Pacific Northwest* (General Technical Report PNW-GTR-513). Department of Agriculture, Forest Service, Pacific Northwest Research Research Station. https://www.fs.usda.gov/pnw/pubs/pnw_gtr513.pdf

Supplemental II-I: Bough Grading System Adapted by Schlosser and Blatner (2004)

Grade 1 (Preferred) – GR1

- Deep green or blue color
- History of short annual growth nodes
- Retention of at least 4 years of needs on each branch
- Symmetrical shape to the bough
- Dense coverage and non-overlapping shoots
- Characteristic needle cupping, consistent across all boughs
- Harvested from area that has already experienced a series of hard frosts

Grade 2 (Acceptable) – GR2

- Green needle color (yellow not acceptable)
- Short annual growth nodes, can allow slightly longer internode length
- Retention of at least 4 years of needles on each branch
- Uniform coverage of shoots, bough not perfectly uniform
- Nonsymmetrical shape allowed
- Characteristic needle cupping consistent across all boughs
- Harvested from area that has already experienced a series of hard frosts

Unacceptable Traits – GRU

- Yellow needle coloration
- Long annual growth nodes
- Needle disease or needle loss within last 4 years
- Non-uniform coverage of shoots
- Needles “flat,” not cupping formation; some of this is allowed, but only a slight amount)
- Lack of fullness or usable material
- Harvested from area that has not experienced a series of hard frosts

Supplemental II-II: Data Descriptions

Climate Data

This study employs high-resolution 4-kilometer regional daily air temperature and precipitation from the “Climate data for adaptation and vulnerability assessments – northwest” study using 17 CMIP6 global circulation models (Khoshnood Motlagh & de Lima Moraes, 2025). This climate data has already been verified and corrected for bias by the study authors (Khoshnood Motlagh & de Lima Moraes, 2025). All seventeen model outputs will be ensembled to increase the rigor of results and demonstrate uncertainty (Knutti et al., 2010; Luedeling, 2012).

The seventeen different climate models from Khoshnood Motlagh and de Lima Moraes (2025) are projected over three different future scenarios of three different future time periods. The different future scenarios are based on different socio-economic pathways (SSP245, SSP370, SSP585) that describe different levels of global climate change from societal activities, with increasing pathway numbers representing more carbon intensive scenarios. For the purposes of this research, only the SSP245 socio-economic scenario was selected for assessment as a moderate emissions scenario. The time periods assessed will be 2015-2025, 2026-2050, and 2051-2075, 2076-2100. The period 2015-2025 will serve as the near-reference period to compare against the future periods for this study.

From these data, the daily surface air maximum, daily surface air minimum, and the daily precipitation will be used for temperature and precipitation thresholds in the model.

Topography

Digital Elevation Models (DEMs) from the United States Geological Survey (USGS) will provide elevation data for post-model analysis. The elevation data will allow for the data to be segmented into elevation bins to describe changes in the operational window, frost probabilities, and hot-day events. While higher resolution datasets will be used (2 arc seconds), the datasets will be aggregated to match the resolution of the climate data through averaging.

Ecoregions

To help with categorizing results, the United States Ecological Protection Agency (EPA) accepted ecoregions will be used to describe changes in the operational window, frost probabilities, and hot-day events. The ecoregions, based on Omernik's 1987 development and analysis, stem from the hypothesis regional patterns can be described by causal spatial variables (J. Omernik, 1987). The Level IV Ecoregions for Washington have since been developed and provide highly detailed description of regional ecosystem patterns based on present day conditions (Clarke & Bryce, 1997; McGrath et al., 2002; Pater et al., 1998; Thorson et al., 2003). While it is unclear how ecoregions will shift in the future due to climate change and land-use influences (J. M. Omernik & Griffith, 2014), these geographical bounds may be useful in binning shifts in environmental conditions.

Landownership

Different forest landownerships will be used to further discuss trends and possible management impacts. Forest landownership data for Washington State comes from the Natural Resources Spatial Information Group (NRSIG) at the University of Washington with forest landownership from Oregon coming from Oregon Department of Forestry (Rogers et al., 2021).

Landcover

To keep the results relevant to bough production, only land that is currently under coniferous forest cover are considered for the analysis. Using data from the LANDFIRE program provided by the United States Department of Agriculture and Department of Interior, the existing vegetative cover from the 2024 model was retrieved (LANDFIRE, 2024). For the study area, only landcover types including evergreen open tree canopy, evergreen closed tree canopy, mixed evergreen-deciduous open tree canopy, and mixed evergreen-deciduous closed tree canopy were considered as bough-potential forest coverage. The existing vegetation cover code and name for these vegetation types in the study area are provided in Supplemental II-III.

Study Area Mask

The study area is limited to the areas in Washington and Oregon that are predominantly used for bough operations: the moist forests of the Cascade Mountains to the coastline. The EPA ecoregions were used to define this study area in Washington and Oregon, using level III ecoregion categories. The study area is limited to the following North America level III ecoregion codes: 7.1.8 (Coast Range), 7.1.7 (Strait of Georgia/Puget Lowland), 7.1.9 (Willamette Valley), 6.2.7 (Cascades), 6.2.5 (North Cascades), and 6.2.11 (Klamath Mountains).

Supplemental II-III: Existing Vegetation Types included for Bough-Potential Forest Coverage from USDA LANDFIRE

Vegetation Type Code	Vegetation Type Name
7015	California Coastal Redwood Forest
7018	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland
7021	Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland
7022	Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland
7027	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
7028	Mediterranean California Mesic Mixed Conifer Forest and Woodland
7029	Mediterranean California Mixed Oak Woodland
7030	Mediterranean California Lower Montane Conifer Forest and Woodland
7031	California Montane Jeffrey Pine-(Ponderosa Pine) Woodland
7032	Mediterranean California Red Fir Forest
7033	Mediterranean California Subalpine Woodland
7035	North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland
7036	North Pacific Seasonal Sitka Spruce Forest
7037	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest
7038	North Pacific Maritime Mesic Subalpine Parkland
7039	North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest
7041	North Pacific Mountain Hemlock Forest
7042	North Pacific Mesic Western Hemlock-Silver Fir Forest
7043	Mediterranean California Mixed Evergreen Forest
7044	Northern California Mesic Subalpine Woodland
7045	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
7046	Northern Rocky Mountain Subalpine Woodland and Parkland
7050	Rocky Mountain Lodgepole Pine Forest
7053	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
7055	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
7056	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland
7058	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland
7060	East Cascades Ponderosa Pine Forest and Woodland
7156	North Pacific Lowland Riparian Forest
7158	North Pacific Montane Riparian Woodland
7172	Sierran-Intermontane Desert Western White Pine-White Fir Woodland
7173	North Pacific Wooded Volcanic Flowage
7174	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
7177	California Coastal Closed-Cone Conifer Forest and Woodland
7178	North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest
7261	Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland
7263	East Cascades Oak-Ponderosa Pine Forest and Woodland
7901	Western Cool Temperate Urban Evergreen Forest
7902	Western Cool Temperate Urban Mixed Forest
7921	Western Cool Temperate Developed Evergreen Forest
7922	Western Cool Temperate Developed Mixed Forest

9002	Columbia Basin Foothill Riparian Woodland
9022	Rocky Mountain Subalpine-Montane Riparian Woodland
9129	Mediterranean California Foothill and Lower Montane Riparian Woodland
9133	Mediterranean California Serpentine Foothill and Lower Montane Riparian Woodland and Seep
9165	North Pacific Hardwood-Conifer Swamp
9170	North Pacific Lowland Mixed Hardwood-Conifer Forest

Supplement II-IV: Tables of Climatic Indicators for Ownerships

Climatic Indicator: Frost

Ownership Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Private SFLO	311 (14.86)	311 (12.51)	316 (10.96)	317 (10.00)
Private Industry	310 (16.51)	311 (14.51)	317 (12.77)	319 (11.92)
Government State	305 (15.94)	306 (13.88)	311 (12.18)	313 (11.16)
Tribal Forestry	304 (12.79)	304 (11.37)	308 (10.53)	309 (9.92)
Government Federal	277 (16.61)	280 (15.92)	285 (15.64)	287 (14.78)
Government County	323 (14.49)	324 (14.48)	329 (12.35)	330 (12.25)
Oregon				
Government State	315 (13.51)	315 (12.82)	321 (12.16)	323 (11.68)
Private Industry	314 (13.93)	315 (13.08)	320 (11.92)	321 (11.14)
Government Federal	289 (14.72)	291 (13.98)	297 (13.24)	298 (12.37)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Last Hot-Day Event

Ownership Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Private SFLO	275 (8.36)	275 (8.14)	277 (9.50)	278 (9.95)
Private Industry	273 (8.01)	274 (7.96)	276 (9.25)	278 (9.71)
Government State	272 (8.28)	272 (7.99)	274 (9.16)	275 (9.25)
Tribal Forestry	268 (7.63)	268 (7.53)	271 (8.82)	272 (8.91)
Government Federal	265 (8.62)	265 (7.97)	268 (8.58)	268 (8.40)
Government County	271 (7.12)	272 (6.98)	276 (9.45)	277 (9.68)

Oregon				
Government State	280 (7.38)	281 (7.92)	284 (9.70)	285 (11.38)
Private Industry	288 (9.43)	289 (9.10)	292 (11.14)	293 (12.77)
Government Federal	285 (9.68)	285 (9.01)	288 (10.52)	289 (11.80)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: First Snow

Ownership Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Private SFLO	337 (5.69)	338 (3.86)	340 (3.35)	340 (3.38)
Private Industry	340 (4.31)	341 (3.26)	342 (2.92)	341 (2.98)
Government State	333 (4.90)	334 (3.33)	336 (3.99)	335 (3.47)
Tribal Forestry	331 (6.18)	332 (4.48)	334 (4.44)	334 (4.17)
Government Federal	329 (5.44)	330 (4.53)	332 (4.24)	333 (3.91)
Government County	347 (6.87)	347 (6.26)	348 (5.92)	346 (5.14)
Oregon				
Government State	341 (4.25)	342 (3.44)	343 (2.66)	343 (2.60)
Private Industry	341 (4.48)	342 (2.83)	343 (3.94)	340 (3.42)
Government Federal	335 (4.68)	335 (3.50)	337 (3.06)	337 (3.17)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational Start

Ownership Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Private SFLO	239 (7.91)	241 (9.16)	246 (11.51)	248 (11.44)
Private Industry	236 (6.35)	239 (8.10)	243 (11.52)	246 (11.98)

Government State	237 (6.57)	238 (8.03)	242 (10.83)	245 (11.15)
Tribal Forestry	233 (4.34)	235 (6.44)	239 (10.30)	241 (11.1.7)
Government Federal	234 (5.01)	235 (5.85)	238 (7.93)	239 (8.69)
Government County	232 (3.75)	235 (6.45)	241 (13.47)	244 (14.52)
Oregon				
Government State	238 (6.56)	241 (8.11)	248 (12.23)	250 (12.96)
Private Industry	245 (8.02)	248 (8.38)	254 (11.71)	257 (12.33)
Government Federal	244 (7.38)	246 (7.26)	251 (9.89)	253 (10.46)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational End

Ownership Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Private SFLO	355 (1.84)	355 (1.53)	356 (1.08)	356 (1.11)
Private Industry	355 (1.83)	355 (1.63)	356 (0.99)	357 (1.06)
Government State	352 (2.78)	352 (2.51)	354 (1.82)	354 (1.87)
Tribal Forestry	351 (2.91)	351 (2.88)	353 (2.22)	353 (2.21)
Government Federal	338 (7.62)	339 (7.13)	342 (6.24)	344 (6.00)
Government County	357 (0.97)	357 (0.85)	358 (0.53)	358 (0.37)
Oregon				
Government State	356 (1.61)	356 (1.60)	357 (0.87)	357 (0.82)
Private Industry	357 (0.96)	357 (1.00)	357 (0.57)	357 (0.65)
Government Federal	350 (3.49)	350 (3.72)	353 (2.66)	353 (2.76)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational Period

Ownership Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
-----------------------	--------------------	--------------------	--------------------	--------------------

Washington				
Private SFLO	116	113	110	108
Private Industry	119	117	113	111
Government State	116	114	111	110
Tribal Forestry	118	116	114	112
Government Federal	104	104	105	104
Government County	125	123	116	114
Oregon				
Government State	118	114	109	107
Private Industry	112	108	103	100
Government Federal	106	104	102	101

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational Period

Ownership Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
Washington				
Private SFLO	44	43	40	39
Private Industry	45	44	40	38
Government State	48	46	43	41
Tribal Forestry	47	47	45	44
Government Federal	61	59	57	56
Government County	35	33	29	27
Oregon				
Government State	42	40	36	34
Private Industry	43	41	37	37
Government Federal	60	59	56	55

*Period means are rounded to the nearest DOY for interpretability.

Supplement II-V: Tables of Climatic Indicators for Ecoregions

Climatic Indicator: Frost

Ecoregion Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Strait of Georgia/ Puget Lowlands	316 (17.22)	317 (13.92)	322 (12.05)	324 (11.01)
North Cascades	277 (16.51)	279 (15.96)	285 (15.54)	287 (14.81)
Coast Range	315 (15.19)	316 (13.13)	321 (11.88)	323 (11.17)
Cascades	287 (18.59)	289 (17.31)	295 (16.10)	297 (14.65)
Willamette Valley	310 (16.48)	312 (15.66)	317 (14.32)	320 (13.12)
Oregon				
Coast Range	323 (13.16)	324 (12.41)	328 (11.03)	329 (10.65)
Willamette Valley	319 (15.61)	320 (15.98)	325 (14.12)	327 (13.50)
Cascades	284 (17.30)	286 (16.70)	293 (15.69)	295 (14.63)
Klamath Mountains	310 (15.68)	312 (14.02)	318 (13.02)	320 (12.84)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Last Hot-Day Event

Ecoregion Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Strait of Georgia/ Puget Lowlands	275 (9.12)	275 (8.81)	277 (9.95)	278 (10.51)
North Cascades	264 (8.71)	264 (7.84)	267 (8.53)	267 (8.28)
Coast Range	271 (7.54)	271 (7.44)	274 (9.02)	275 (9.38)
Cascades	271 (8.72)	271 (8.55)	273 (9.17)	274 (9.25)
Willamette Valley	287 (9.27)	286 (8.14)	289 (10.99)	290 (12.42)
Oregon				
Coast Range	286 (8.77)	287 (8.91)	290 (11.29)	292 (13.14)

Willamette Valley	291 (9.80)	291 (9.14)	293 (11.82)	294 (13.55)
Cascades	284 (10.10)	284 (9.28)	286 (10.54)	287 (11.67)
Klamath Mountains	297 (10.27)	297 (9.65)	299 (11.93)	301 (12.93)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: First Snow Event

Ecoregion Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Strait of Georgia/ Puget Lowlands	340 (4.97)	343 (3.45)	341 (3.26)	342 (3.06)
North Cascades	329 (5.43)	330 (4.68)	332 (4.47)	333 (4.07)
Coast Range	340 (4.71)	342 (3.64)	342 (4.23)	341 (3.47)
Cascades	334 (5.46)	335 (4.04)	336 (3.46)	336 (3.29)
Willamette Valley	346 (7.75)	346 (5.48)	345 (5.14)	344 (8.10)
Oregon				
Coast Range	345 (4.78)	344 (3.12)	346 (2.58)	344 (4.87)
Willamette Valley	347 (6.13)	345 (4.19)	345 (4.21)	343 (7.36)
Cascades	335 (4.75)	335 (3.51)	337 (3.04)	337 (3.18)
Klamath Mountains	339 (4.72)	340 (3.57)	341 (3.39)	340 (3.44)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational Start

Ecoregion Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Strait of Georgia/ Puget Lowlands	239 (8.60)	241 (10.16)	245 (11.96)	247 (11.65)
North Cascades	235 (5.25)	235 (5.98)	238 (7.75)	240 (8.36)
Coast Range	234 (5.47)	237 (7.59)	241 (11.66)	244 (12.42)

Cascades	235 (5.46)	237 (6.58)	240 (8.94)	241 (9.71)
Willamette Valley	246 (10.35)	250 (10.31)	256 (12.72)	258 (12.51)
Oregon				
Coast Range	241 (7.38)	245 (8.44)	252 (12.84)	255 (13.74)
Willamette Valley	249 (10.48)	253 (10.28)	259 (12.40)	262 (12.49)
Cascades	243 (7.70)	245 (7.29)	249 (9.39)	251 (9.83)
Klamath Mountains	256 (8.84)	259 (8.32)	264 (10.40)	267 (10.29)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational End

Ecoregion Name	2015 – 2025 (std.)	2026 – 2050 (std.)	2051 – 2075 (std.)	2076 – 2100 (std.)
Washington				
Strait of Georgia/ Puget Lowlands	357 (1.18)	357 (0.90)	357 (0.51)	358 (0.50)
North Cascades	337 (8.02)	337 (7.38)	341 (6.58)	343 (6.32)
Coast Range	356 (1.50)	356 (1.32)	357 (0.82)	357 (0.78)
Cascades	346 (5.05)	347 (5.23)	350 (3.82)	351 (3.96)
Willamette Valley	357 (1.65)	357 (1.03)	357 (0.71)	357 (0.52)
Oregon				
Coast Range	357 (0.63)	357 (0.66)	358 (0.36)	358 (0.37)
Willamette Valley	357 (0.81)	357 (0.84)	358 (0.43)	358 (0.47)
Cascades	348 (4.14)	349 (4.44)	352 (3.14)	352 (3.30)
Klamath Mountains	357 (0.76)	357 (0.76)	357 (0.43)	358 (0.44)

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Operational Period

Ecoregion Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
-----------------------	--------------------	--------------------	--------------------	--------------------

Washington				
Strait of Georgia/ Puget				
Lowlands	118	116	112	111
North Cascades	102	102	103	103
Coast Range	122	120	116	113
Cascades	111	110	110	109
Willamette Valley	111	107	102	99
Oregon				
Coast Range	117	112	105	102
Willamette Valley	109	104	99	95
Cascades	105	104	102	102
Klamath Mountains	101	98	93	91

*Period means are rounded to the nearest DOY for interpretability.

Climatic Indicator: Post-Frost Period

Ecoregion Name	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
Washington				
Strait of Georgia/ Puget				
Lowlands	41	40	35	33
North Cascades	60	58	56	56
Coast Range	41	40	36	34
Cascades	60	58	55	54
Willamette Valley	46	45	40	38
Oregon				
Coast Range	34	33	30	29
Willamette Valley	39	37	32	30
Cascades	64	63	59	58
Klamath Mountains	47	45	40	38

*Period means are rounded to the nearest DOY for interpretability.

Supplement II-VI: Tables of Climatic Indicators for Ownership-Ecoregion Intersection

Climatic Indicator: Frost

	Ownership	2015 – 2025 (std)	2026 – 2050 (std)	2051 – 2075 (std)	2076 – 2100 (std)
Washington					
Strait of Georgia / Puget Lowlands	Private – SFLO	318 (17.02)	319 (14.09)	324 (12.32)	326 (11.33)
	Private – Industry	314 (17.99)	315 (15.08)	320 (13.32)	323 (12.43)
	Government – State	317 (18.31)	318 (15.04)	323 (12.82)	325 (11.62)
	Tibal Forestry	317 (17.78)	319 (15.36)	324 (13.33)	325 (11.57)
	Government – Federal	309 (18.19)	310 (14.07)	316 (12.17)	319 (11.26)
North Cascades	Private – SFLO	291 (14.67)	292 (13.19)	297 (11.88)	299 (11.15)
	Government – State	291 (16.89)	293 (15.46)	298 (13.81)	300 (12.93)
	Private – Industry	300 (19.23)	302 (17.32)	307 (14.88)	310 (13.77)
	Government – Federal	271 (16.55)	274 (16.31)	279 (16.44)	282 (15.79)
	Tribal Forestry	291 (17.08)	292 (15.55)	297 (14.42)	300 (13.37)
Coast Range	Tribal Forestry	326 (14.55)	326 (14.27)	330 (11.73)	327 (12.21)
	Private – SFLO	319 (14.78)	320 (14.09)	324 (12.31)	332 (11.53)
	Private – Industry	318 (151.31)	319 (14.61)	324 (12.63)	327 (12.58)
	Government – State	318 (15.85)	319 (14.35)	324 (12.44)	327 (12.05)
	Government – Federal	312 (17.76)	313 (13.82)	319 (12.31)	321 (11.27)
	Government – County	323 (14.49)	313 (13.82)	329 (12.35)	330 (12.25)
Cascades	Private – SFLO	304 (18.73)	305 (16.77)	311 (14.75)	313 (13.18)
	Government – State	300 (20.26)	301 (18.45)	308 (16.19)	310 (14.62)
	Private – Industry	302 (21.15)	304 (18.82)	310 (16.24)	312 (14.61)
	Government – Federal	279 (18.02)	281 (17.36)	288 (16.82)	290 (15.51)

	Tribal Forestry	280 (18.56)	282 (17.56)	288 (16.59)	291 (15.65)
Willamette Valley	Private – SFLO	309 (16.51)	310 (15.74)	316 (14.43)	319 (13.34)
	Government – State	309 (16.50)	311 (15.91)	316 (14.49)	319 (13.18)
	Private – Industry	310 (16.41)	311 (15.66)	316 (14.47)	319 (13.49)
	Tribal Forestry	312 (16.59)	313 (15.72)	319 (14.47)	321 (13.27)
	Government – Federal (OR)	321 (17.72)	323 (16.57)	328 (13.72)	329 (13.65)
	Government – Federal (WA)	314 (16.44)	315 (16.21)	321 (14.44)	323 (13.21)
	Oregon				
Coast Range	Government – State	316 (13.66)	317 (13.14)	323 (12.48)	325 (12.12)
	Private – Industry	322 (13.30)	323 (12.72)	327 (11.32)	328 (10.94)
	Government – Federal	328 (13.36)	329 (12.42)	333 (10.74)	334 (11.06)
Willamette Valley	Private – Industry	319 (15.33)	320 (15.90)	325 (13.90)	328 (13.71)
	Government – State	314 (14.85)	315 (14.59)	321 (13.77)	324 (13.25)
	Government – Federal	321 (15.84)	322 (15.60)	327 (13.52)	329 (13.47)
Cascades	Government – Federal	280 (17.21)	282 (16.80)	289 (16.18)	291 (15.22)
	Private – Industry	301 (19.53)	303 (18.32)	310 (16.20)	311 (15.03)
	Government – State	298 (21.39)	300 (20.56)	307 (19.11)	309 (17.54)
Klamath Mountains	Private – Industry	312 (15.59)	314 (13.87)	319 (12.95)	321 (12.90)
	Government – Federal	310 (15.20)	312 (13.43)	318 (12.56)	320 (11.99)
	Government - State	308 (17.43)	310 (15.62)	317 (14.09)	319 (14.29)

Climatic Indicator: Last Hot-Day Event

	Ownership	2015 – 2025 (std)	2026 – 2050 (std)	2051 – 2075 (std)	2076 – 2100 (std)
Washington					
Strait	Private – SFLO	275 (9.17)	275 (8.83)	277 (10.03)	278 (10.58)

	Private – Industry	278 (8.86)	278 (8.81)	280 (9.92)	281 (10.76)
	Government – State	274 (9.31)	274 (8.90)	276 (9.92)	277 (10.29)
	Tibal Forestry	274 (9.45)	274 (9.10)	276 (10.18)	277 (10.49)
	Government – Federal	267 (9.13)	267 (8.15)	269 (9.37)	270 (8.98)
North Cascades	Private – SFLO	273 (7.80)	273 (7.52)	275 (8.38)	276 (8.03)
	Government – State	268 (8.74)	268 (8.04)	270 (8.93)	271 (8.45)
	Private – Industry	268 (9.10)	268 (8.21)	271 (9.21)	272 (8.70)
	Government – Federal	263 (8.79)	263 (7.88)	266 (8.47)	266 (8.23)
	Tribal Forestry	269 (8.24)	269 (7.54)	271 (8.51)	272 (8.28)
Coast Range	Tribal Forestry	268 (6.81)	269 (6.76)	272 (8.63)	274 (9.06)
	Private – SFLO	273 (7.12)	274 (7.31)	277 (9.30)	279 (10.06)
	Private – Industry	273 (7.22)	274 (7.47)	277 (9.17)	278 (9.85)
	Government – State	273 (7.52)	273 (7.58)	276 (9.15)	277 (9.57)
	Government – Federal	269 (8.57)	269 (7.99)	271 (9.13)	273 (8.99)
	Government – County	271 (7.12)	272 (6.98)	276 (9.45)	277 (9.68)
Cascades	Private – SFLO	280 (8.84)	280 (8.52)	282 (9.85)	283 (10.59)
	Government – State	275 (8.96)	275 (8.74)	277 (9.57)	278 (9.88)
	Private – Industry	275 (8.95)	275 (8.81)	278 (9.55)	278 (10.02)
	Government – Federal	268 (8.71)	269 (8.51)	271 (8.97)	272 (8.91)
	Tribal Forestry	266 (9.09)	266 (8.85)	269 (9.32)	270 (8.98)
Willamette Valley	Private – SFLO	286 (9.27)	285 (8.17)	288 (10.94)	289 (12.28)
	Government – State	287 (9.39)	286 (8.18)	289 (11.00)	290 (12.50)
	Private – Industry	285 (9.18)	285 (8.02)	288 (10.88)	288 (12.07)
	Tribal Forestry	288	287	289	290

		(9.49)	(8.36)	(11.13)	(12.71)
	Government – Federal (OR)	289	288	290	291
		(9.61)	(8.31)	(11.06)	(12.36)
	Government – Federal (WA)	288	287	289	290
		(10.03)	(8.70)	(11.11)	(12.56)
Oregon					
Coast Range	Government – State	280	280	284	285
		(7.02)	(7.79)	(9.59)	(11.35)
	Private – Industry	286	287	291	292
		(8.80)	(8.96)	(11.21)	(13.07)
	Government – Federal	286	287	291	293
		(9.09)	(8.80)	(11.63)	(13.62)
Willamette Valley	Private – Industry	291	291	293	295
		(10.06)	(9.63)	(11.97)	(13.71)
	Government – State	284	284	286	287
		(9.00)	(8.42)	(10.12)	(11.73)
	Government – Federal	289	289	291	292
		(9.49)	(8.29)	(11.16)	(12.91)
Cascades	Government – Federal	283	283	285	287
		(10.07)	(9.28)	(10.46)	(11.53)
	Private – Industry	289	288	290	291
		(10.73)	(9.49)	(11.16)	(12.54)
	Government – State	282	9.37	283	284
		(11.01)	(2.81)	(10.79)	(11.78)
Klamath Mountains	Private – Industry	296	296	299	301
		(10.32)	(9.79)	(12.09)	(13.04)
	Government – Federal	294	295	298	299
		(10.29)	(9.41)	(11.56)	(12.66)
	Government - State	295	295	297	299
		(10.32)	(9.63)	(11.81)	(12.93)

Climatic Indicator: First Snow Event

	Ownership	2015 – 2025 (std)	2026 – 2050 (std)	2051 – 2075 (std)	2076 – 2100 (std)
Washington					
Strait of Georgia / Puget Lowlands	Private – SFLO	346	345	346	344
		(5.15)	(4.46)	(2.93)	(5.13)
	Private – Industry	347	345	346	344
		(5.32)	(5.29)	(2.68)	(6.28)
	Government – State	346	345	346	344
		(5.36)	(4.78)	(2.90)	(5.30)
	Tibal Forestry	347	345	346	343
		(5.93)	(5.88)	(3.88)	(6.67)
	Government – Federal	342	343	343	341
		(4.40)	(4.68)	(4.25)	(4.24)
N o	Private – SFLO	336	337	339	340

		(5.65)	(4.19)	(3.67)	(3.53)
	Government – State	332	333	334	334
		(5.02)	(3.91)	(4.46)	(3.90)
	Private – Industry	339	340	341	340
		(4.27)	(3.65)	(3.51)	(2.87)
	Government – Federal	328	329	331	332
		(5.83)	(5.09)	(4.78)	(4.41)
	Tribal Forestry	337	338	339	340
		(5.06)	(4.50)	(4.15)	(3.90)
Coast Range	Private – Industry	347	346	346	343
		(5.55)	(5.02)	(3.47)	(7.07)
	Government – Federal	340	341	342	340
		(4.73)	(3.81)	(3.42)	(3.44)
	Government – State	346	345	346	344
		(4.53)	(4.70)	(3.49)	(5.57)
	Private – SFLO	347	345	347	344
		(5.60)	(5.09)	(4.11)	(6.39)
	Tribal Forestry	345	345	349	344
		(7.72)	(9.09)	(5.18)	(6.78)
Cascades	Government – County	347	347	348	346
		(6.87)	(6.26)	(5.92)	(5.14)
	Private – Industry	339	342	342	342
		(5.75)	(3.73)	(2.86)	(2.90)
	Private - SFLO	335	337	338	337
		(5.98)	(5.30)	(4.08)	(3.35)
	Government - State	339	341	341	340
		(5.80)	(4.00)	(3.57)	(3.25)
	Tribal Forestry	330	331	333	334
		(6.21)	(4.81)	(4.59)	(4.45)
Willamette Valley	Government – Federal	334	335	337	337
		(5.72)	(4.41)	(3.55)	(3.69)
	Private – SFLO	346	346	345	344
		(7.80)	(5.49)	(5.08)	(8.11)
	Private – Industry	347	346	345	344
		(8.01)	(5.84)	(5.46)	(7.91)
	Government - State	347	347	345	343
		(6.83)	(5.47)	(5.38)	(8.58)
	Government – Federal (WA)	347	345	344	344
		(7.53)	(7.15)	(5.69)	(7.010)
Coast Range	Tribal Forestry	347	345	345	344
		(8.01)	(6.30)	(5.74)	(7.54)
	Government – Federal (OR)	346	345	346	343
		(7.88)	(6.12)	(7.91)	(7.32)
Oregon					
Coast Range	Private – Industry	345	344	346	344
		(4.73)	(3.12)	(2.54)	(4.86)
	Government - State	346	344	345	344

		(4.79)	(3.21)	(3.26)	(5.00)
	Government – Federal	346	345	346	343
Willamette Valley		(7.70)	(4.97)	(3.04)	(7.32)
	Private – Industry	348	344	346	343
		(6.19)	(4.40)	(3.67)	(7.16)
	Government – State	346	344	345	343
		(7.81)	(5.16)	(3.44)	(6.82)
	Government – Federal	347	346	345	342
Cascades		(7.53)	(5.43)	(6.37)	(9.03)
	Government – Federal	334	335	337	336
		(4.78)	(3.62)	(3.12)	(3.23)
	Private – Industry	341	342	343	340
		(4.25)	(3.61)	(2.62)	(3.37)
	Government – State	342	342	344	344
Klamath Mountains		(6.06)	(2.51)	(4.01)	(4.67)
	Private – Industry	341	341	342	343
		(5.02)	(3.44)	(3.62)	(2.21)
	Government – Federal	338	339	340	339
		(4.90)	(3.81)	(3.61)	(3.52)
	Government - State	339	341	341	341
		(4.79)	(3.74)	(4.45)	(3.04)

Climatic Indicator: Operational Start

		2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
Ownership		(std)	(std)	(std)	(std)
Washington					
Strait of Georgia / Puget Lowlands	Private – SFLO	239	241	245	247
		(8.68)	(10.24)	(11.98)	(11.64)
	Private – Industry	240	243	247	250
		(9.02)	(10.46)	(12.55)	(12.19)
	Government – State	238	240	244	246
		(8.47)	(10.16)	(12.02)	(11.71)
North Cascades	Tibal Forestry	238	240	244	245
		(8.28)	(10.20)	(11.97)	(11.65)
	Government – Federal	234	236	239	240
		(7.04)	(8.34)	(10.54)	(10.74)
	Private – SFLO	242	243	246	248
		(7.88)	(8.26)	(10.06)	(9.92)
	Government – State	236	238	240	242
		(6.44)	(7.38)	(9.39)	(9.60)
	Private – Industry	236	237	240	242
		(6.48)	(7.72)	(9.75)	(10.01)
	Government – Federal	234	235	237	239
		(4.95)	(5.55)	(7.32)	(8.03)
	Tribal Forestry	239	240	243	244
		(6.78)	(7.48)	(9.23)	(9.41)

Coast Range	Tribal Forestry	232 (3.75)	235 (6.54)	240 (12.00)	242 (12.98)
	Private – SFLO	236 (6.04)	239 (7.87)	244 (12.25)	247 (12.86)
	Private – Industry	235 (5.77)	238 (8.09)	244 (12.78)	246 (13.41)
	Government – State	236 (6.40)	238 (8.55)	244 (12.52)	246 (13.00)
	Government – Federal	234 (5.76)	235 (7.73)	240 (10.96)	242 (11.79)
	Government – County	232 (3.75)	235 (6.45)	241 (13.47)	244 (14.52)
Cascades	Private – SFLO	241 (8.05)	244 (8.85)	248 (11.21)	250 (11.33)
	Government – State	237 (6.27)	239 (7.40)	242 (9.96)	244 (10.53)
	Private – Industry	237 (6.40)	239 (7.72)	243 (10.28)	245 (10.89)
	Government – Federal	234 (4.99)	235 (6.02)	238 (8.38)	240 (9.25)
	Tribal Forestry	233 (4.70)	234 (6.01)	236 (8.33)	238 (9.14)
Willamette Valley	Private – SFLO	245 (10.13)	249 (10.19)	255 (12.70)	258 (12.59)
	Government – State	246 (10.32)	250 (10.29)	255 (12.70)	258 (12.52)
	Private – Industry	244 (9.60)	248 (9.95)	254 (12.75)	257 (12.58)
	Tribal Forestry	247 (10.67)	251 (10.29)	256 (12.57)	259 (12.21)
	Government – Federal (OR)	249 (10.54)	253 (10.10)	258 (12.26)	261 (11.91)
	Government – Federal (WA)	246 (9.41)	249 (9.52)	255 (11.96)	257 (11.89)
Oregon					
Coast Range	Government – State	238 (6.52)	241 (8.18)	247 (12.52)	250 (13.28)
	Private – Industry	241 (7.57)	245 (8.61)	253 (12.93)	256 (13.79)
	Government – Federal	240 (7.97)	245 (9.26)	253 (13.95)	256 (15.08)
Willamette Valley	Private – Industry	248 (10.49)	253 (10.24)	258 (12.41)	262 (12.66)
	Government – State	242 (8.06)	245 (8.89)	251 (11.65)	253 (11.80)
	Government – Federal	248 (10.60)	252 (10.33)	258 (12.51)	261 (12.49)

Cascades	Government – Federal	243 (7.49)	244 (7.09)	248 (9.18)	250 (9.64)
	Private – Industry	246 (8.77)	248 (8.150)	253 (10.34)	255 (10.73)
	Government – State	238 (6.83)	240 (7.36)	245 (9.89)	246 (10.75)
Klamath Mountains	Private – Industry	255 (8.95)	258 (8.46)	263 (10.53)	266 (10.54)
	Government – Federal	253 (8.94)	256 (8.82)	262 (11.36)	264 (11.06)
	Government - State	254 (9.33)	257 (8.41)	261 (10.15)	264 (10.11)

Climatic Indicator: Operational End

	Ownership	2015 – 2025 (std)	2026 – 2050 (std)	2051 – 2075 (std)	2076 – 2100 (std)
Washington					
Strait of Georgia / Puget Lowlands	Private – SFLO	357 (1.06)	357 (0.82)	358 (0.43)	358 (0.42)
	Private – Industry	357 (1.32)	357 (0.88)	357 (0.53)	358 (0.46)
	Government – State	357 (1.47)	357 (1.01)	357 (0.60)	358 (0.56)
	Tibal Forestry	357 (1.10)	357 (0.85)	358 (0.43)	358 (0.45)
	Government – Federal	355 (2.51)	355 (2.34)	356 (1.47)	357 (1.46)
North Cascades	Private – SFLO	345 (5.83)	345 (5.56)	349 (4.36)	350 (4.55)
	Government – State	344 (5.34)	345 (5.01)	348 (4.07)	349 (4.10)
	Private – Industry	351 (3.49)	351 (3.63)	353 (2.31)	354 (2.63)
	Government – Federal	333 (9.18)	334 (8.34)	338 (7.69)	340 (7.27)
	Tribal Forestry	346 (5.60)	346 (5.52)	349 (3.99)	351 (4.09)
Coast Range	Tribal Forestry	357 (1.20)	357 (0.85)	358 (0.53)	358 (0.34)
	Private – SFLO	357 (1.04)	357 (0.82)	358 (0.49)	358 (0.36)
	Private – Industry	357 (1.24)	357 (0.97)	357 (0.57)	358 (0.47)
	Government – State	357 (1.40)	357 (0.99)	357 (0.59)	358 (0.48)
	Government – Federal	356	356	356	357

		(2.03)	(1.89)	(1.13)	(1.16)
	Government – County	357	357	358	358
		(0.97)	(0.85)	(0.53)	(0.37)
Cascades	Private – SFLO	355	355	356	356
		(2.20)	(1.81)	(1.10)	(1.18)
	Government – State	353	353	355	356
		(3.15)	(3.07)	(1.81)	(2.08)
	Private – Industry	354	354	355	356
		(2.75)	(2.52)	(1.50)	(1.68)
Willamette Valley	Government – Federal	343	343	347	348
		(6.48)	(6.76)	(5.08)	(5.26)
	Tribal Forestry	341	342	345	347
		(6.29)	(6.52)	(5.13)	(5.09)
	Private – SFLO	357	357	357	357
		(1.72)	(1.11)	(0.74)	(0.54)
Coast Range	Government – State	357	357	357	357
		(1.60)	(1.05)	(0.73)	(0.53)
	Private – Industry	357	356	357	357
		(1.81)	(1.18)	(0.72)	(0.52)
	Tribal Forestry	357	357	357	358
		(1.59)	(1.07)	(0.68)	(0.52)
Willamette Valley	Government – Federal (OR)	357	357	357	358
		(1.77)	(0.93)	(0.65)	(0.51)
	Government – Federal (WA)	357	356	357	357
		(1.89)	(1.77)	(1.09)	(0.85)
Oregon					
Coast Range	Government – State	357	356	357	357
		(1.60)	(1.56)	(0.86)	(0.76)
	Private – Industry	357	357	358	358
Willamette Valley		(0.69)	(0.68)	(0.37)	(0.38)
	Government – Federal	358	357	358	358
		(0.35)	(0.53)	(0.29)	(0.32)
Cascades	Private – Industry	357	357	358	358
		(0.75)	(0.84)	(0.39)	(0.50)
	Government – State	256	356	357	357
Klamath		(1.85)	(1.31)	(0.69)	(0.65)
	Government – Federal	357	357	357	358
		(1.20)	(0.86)	(0.57)	(0.55)
Cascades	Government – Federal	347	347	351	352
		(4.71)	(5.03)	(3.62)	(3.76)
	Private – Industry	355	355	356	357
Klamath		(1.90)	(2.16)	(1.17)	(1.44)
	Government – State	355	354	356	357
		(2.63)	(2.84)	(1.53)	(1.83)
Klamath	Private – Industry	357	357	358	358
		(0.70)	(0.65)	(0.37)	(0.38)
Klamath	Government – Federal	356	356	357	357

	(1.03)	(1.10)	(0.66)	(0.65)
Government - State	357	357	358	358
	(0.89)	(0.95)	(0.51)	(0.49)

Climatic Indicator: Operational Period

	Ownership	2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
Washington					
Strait of Georgia / Puget Sound	Private – SFLO	119	116	112	111
	Private – Industry	117	114	110	108
	Government – State	119	116	113	112
	Tribal Forestry	120	117	114	112
	Government – Federal	121	119	117	116
North Cascades	Private – SFLO	103	102	102	102
	Government – State	108	107	107	107
	Private – Industry	115	114	113	112
	Government – Federal	99	99	101	101
	Tribal Forestry	107	106	107	106
Coast Range	Tribal Forestry	125	123	118	115
	Private – SFLO	122	119	113	111
	Private – Industry	122	119	114	112
	Government – State	121	119	114	112
	Government – Federal	122	120	117	115
	Government – County	125	123	116	114
Cascades	Private – SFLO	114	111	107	106
	Government – State	116	115	112	111
	Private – Industry	117	115	113	111
	Government – Federal	108	108	109	109
	Tribal Forestry	108	108	109	109
Willamette Valley	Private – SFLO	112	107	102	100
	Government – State	111	107	102	99
	Private – Industry	113	108	103	101
	Tribal Forestry	110	106	101	98
	Government – Federal (OR)	108	104	99	97
	Government – Federal (WA)	111	107	102	100
Oregon					
Coast Range	Government – State	119	115	110	107
	Private – Industry	116	112	105	102
	Government – Federal	117	112	105	102
Willamette Valley	Private – Industry	109	104	99	96
	Government – State	115	111	106	104
	Government – Federal	190	105	100	97
Cascades	Government – Federal	104	103	102	102

Klamath Mountains	Private – Industry	109	107	103	102
	Government – State	117	114	112	111
	Private – Industry	102	99	95	92
	Government – Federal	103	100	95	93
	Government - State	103	100	96	94

Climatic Indicator: Post-Forst Operational Period

Ownership		2015 – 2025	2026 – 2050	2051 – 2075	2076 – 2100
Washington					
Strait of Georgia / Puget Sound	Private – SFLO	39	38	33	32
	Private – Industry	44	42	37	35
	Government – State	40	38	34	32
	Tribal Forestry	40	38	34	32
	Government – Federal	47	44	40	38
North Cascades	Private – SFLO	54	53	52	51
	Government – State	54	52	50	49
	Private – Industry	51	49	46	44
	Government – Federal	61	60	59	58
	Tribal Forestry	55	54	52	51
Coast Range	Tribal Forestry	32	31	28	31
	Private – SFLO	39	37	33	26
	Private – Industry	39	38	33	31
	Government – State	39	38	33	31
	Government – Federal	44	42	38	36
	Government – County	35	33	29	27
Cascades	Private – SFLO	51	50	45	43
	Government – State	53	52	47	45
	Private – Industry	52	50	45	44
	Government – Federal	64	62	59	59
	Tribal Forestry	62	60	57	56
Willamette Valley	Private – SFLO	48	46	41	39
	Government – State	47	46	41	38
	Private – Industry	47	46	41	38
	Tribal Forestry	45	44	38	36
	Government – Federal (OR)	36	34	30	28
	Government – Federal (WA)	42	41	35	34
Oregon					
Coast Range	Government – State	40	39	34	32
	Private – Industry	35	34	31	30
	Government – Federal	30	28	25	23
Willamette Valley	Private – Industry	39	37	32	30
	Government – State	42	41	36	33

Cascades	Government – Federal	36	35	31	29
	Government – Federal	67	65	62	61
	Private – Industry	54	52	47	45
	Government – State	57	55	49	48
Klamath	Private – Industry	46	43	38	37
	Government – Federal	46	44	39	37
	Government - State	49	47	41	38

Supplement II-VII: Graphical Representation of Climatic Indicators for Ownerships

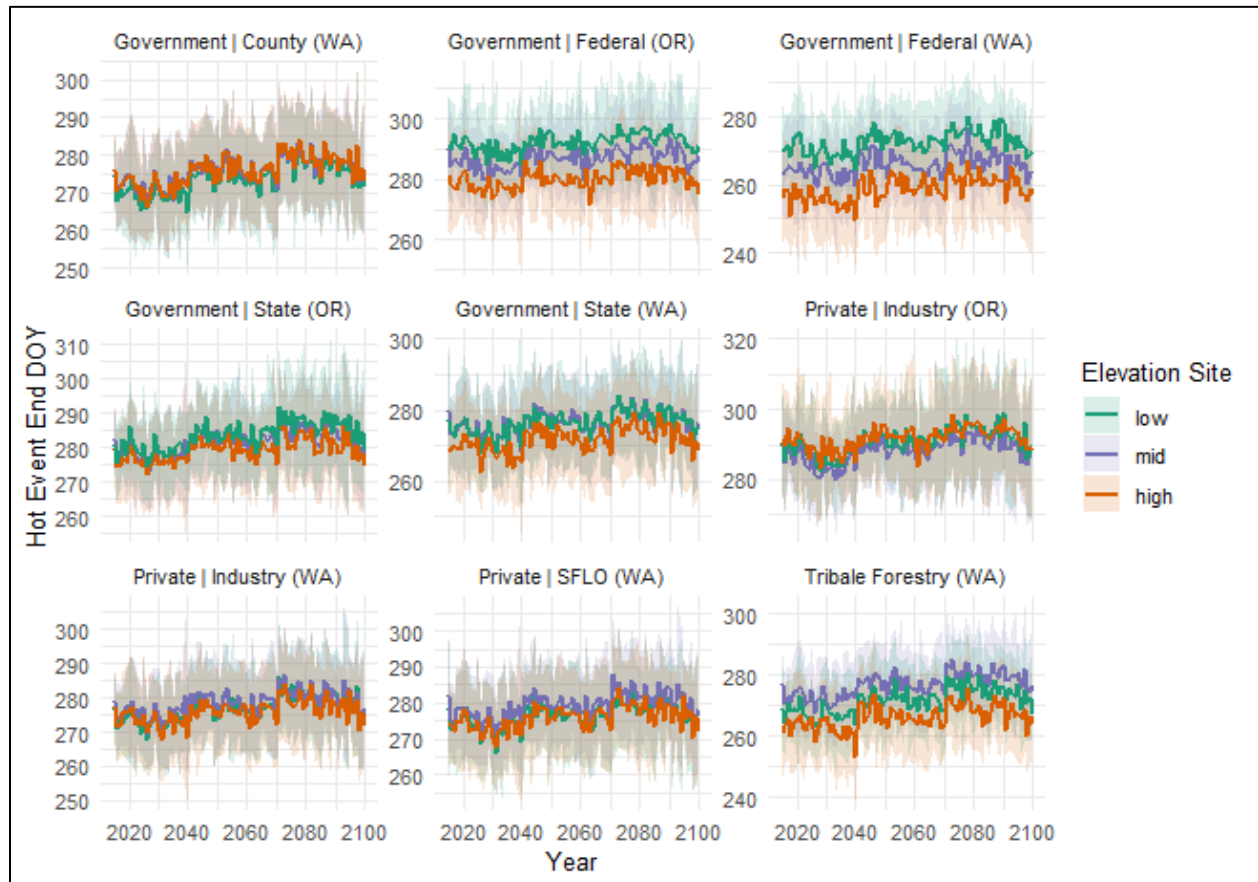


Figure: Last Hot-Day Event by Ownership for 2015-2025

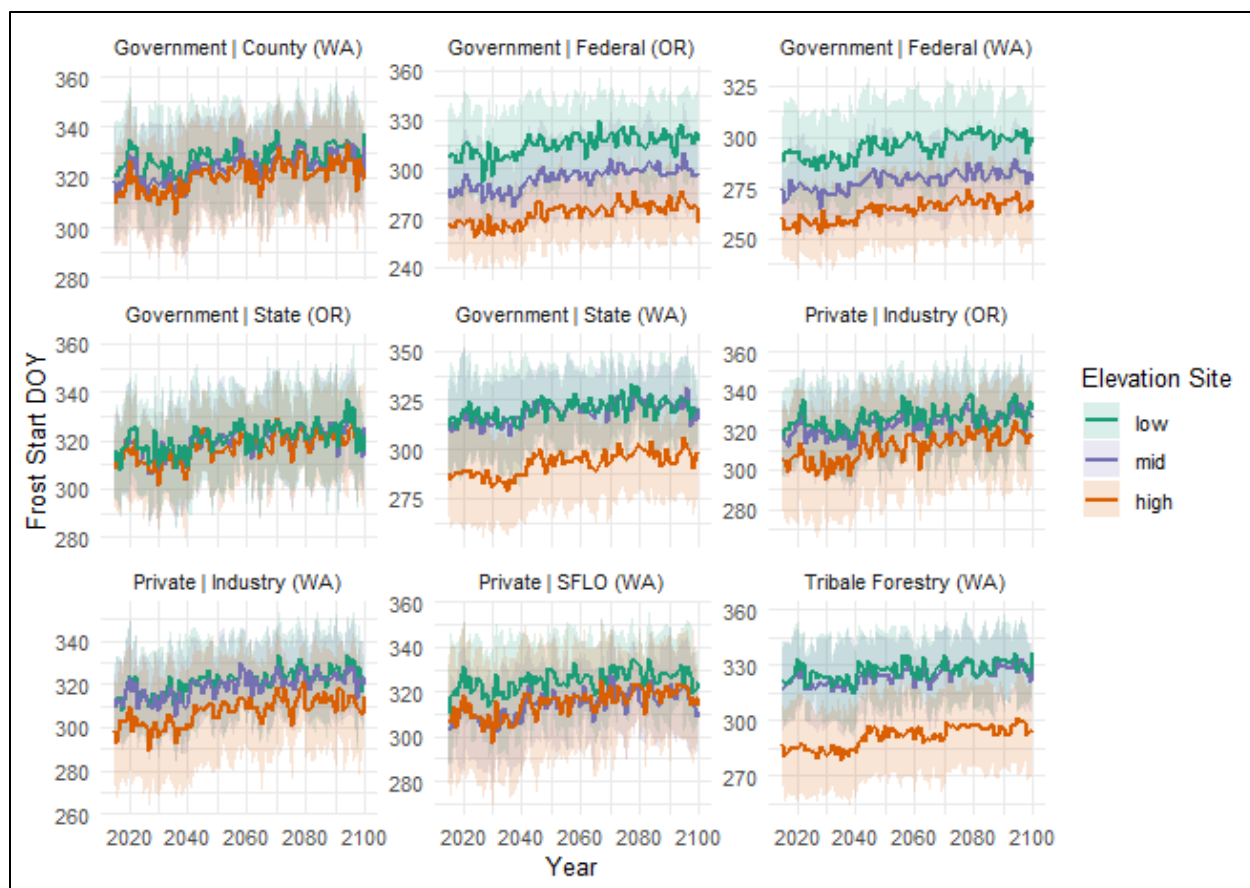


Figure: First Frost Event by Ownership for 2015-2025

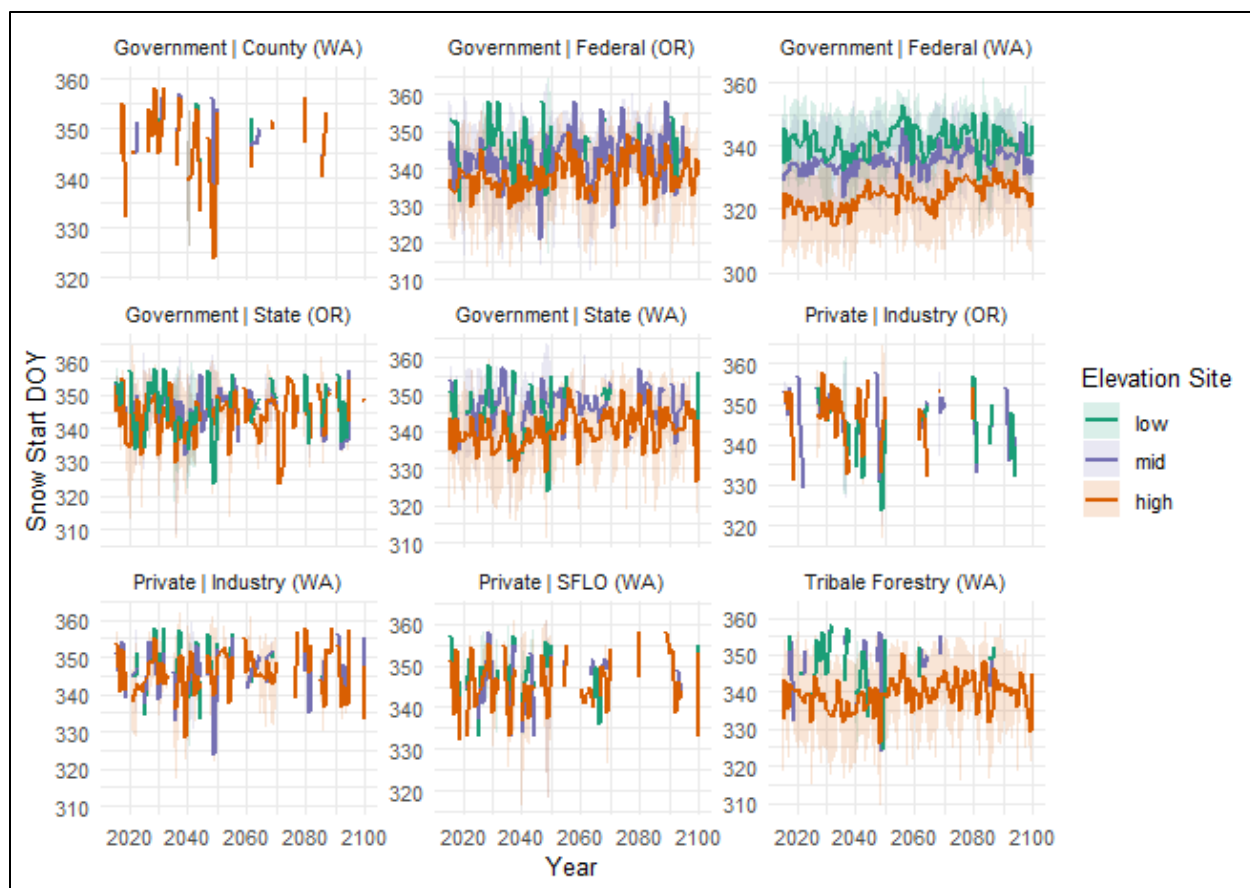


Figure: First Snow Event by Ownership for 2015-2025

Supplement II-VII: Graphical Representation of Climatic Indicators for Ecoregion

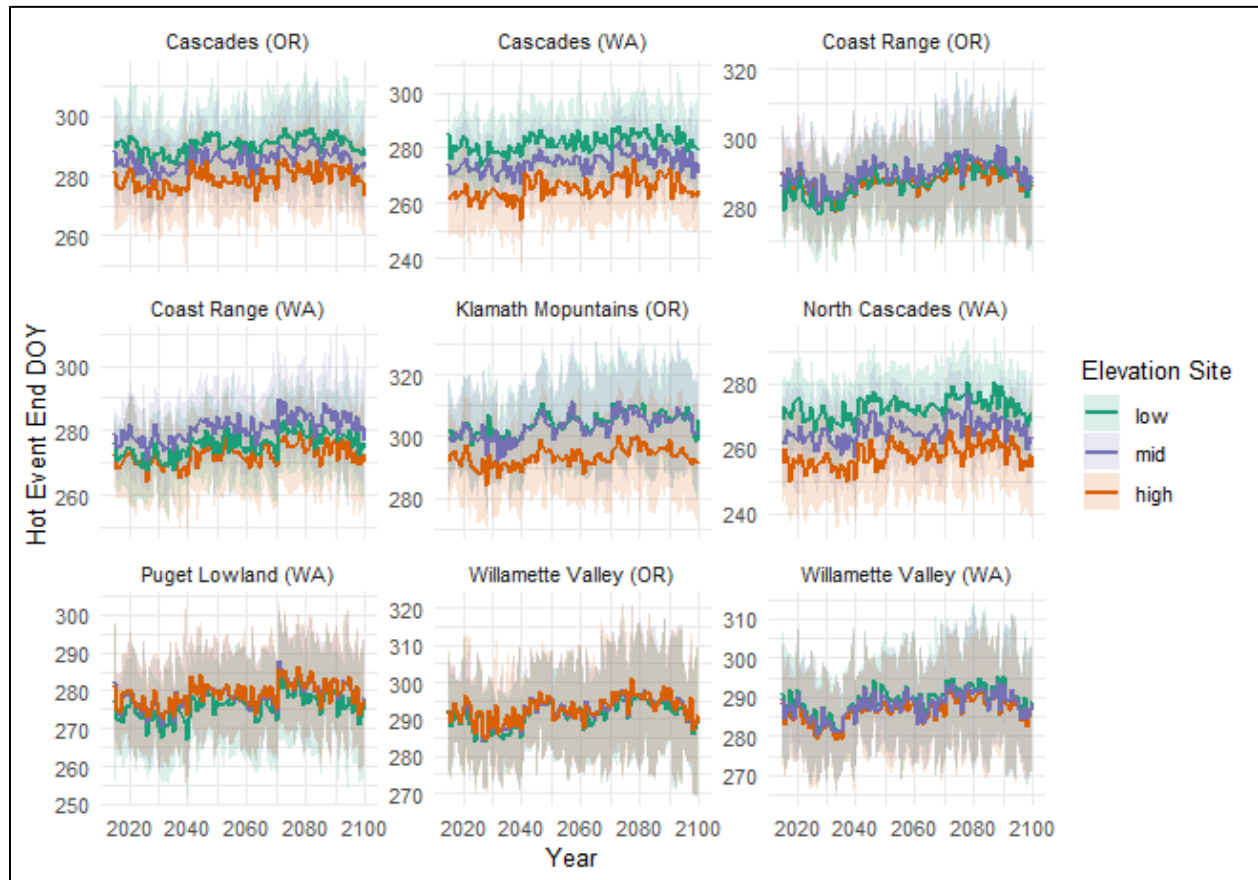


Figure: Last Hot-Day Event by Ecoregion for 2015-2025

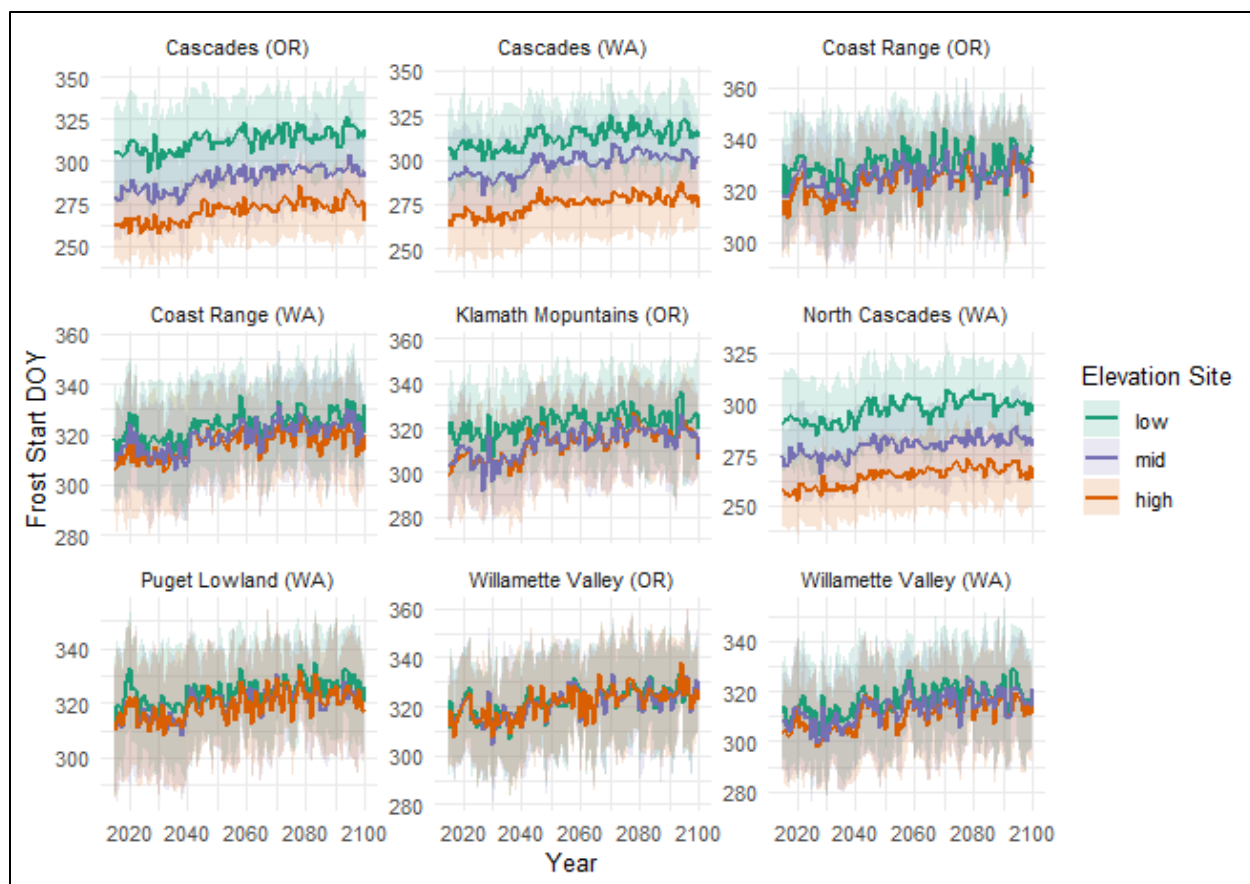


Figure: First Frost Event by Ecoregion for 2015-2025

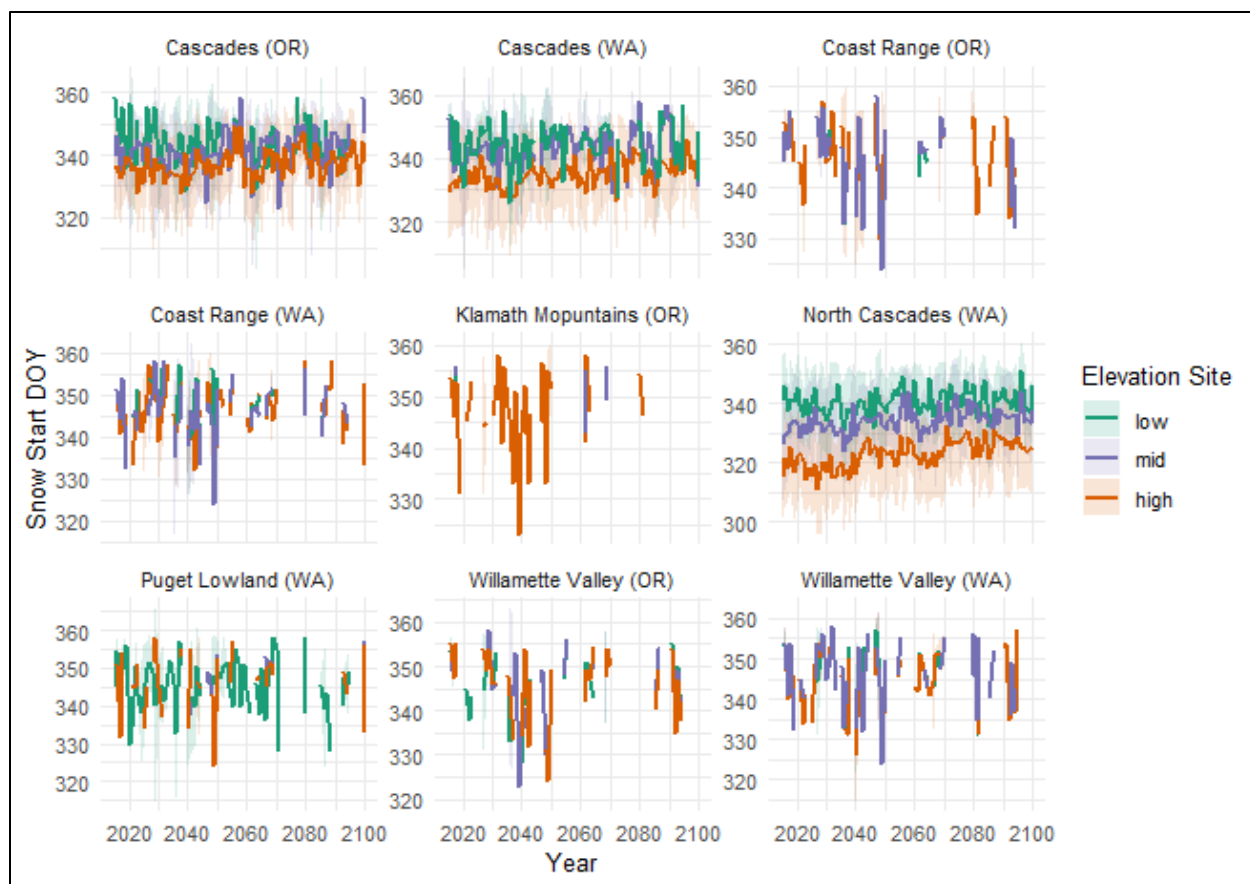


Figure: First Snow Event by Ecoregion for 2015-2025

Chapter III: Paying for Restoration: Landowner Preferences, Public Support, and the Feasibility of Watershed Restoration in the Stillaguamish

Abstract

Private landowners' participation in restoration and conservation programs is key to meeting restoration efforts. The scientific literature has largely focused on specific, large landowner types when it comes to restoration choice experiments, especially agricultural and forest landowners. Here, a split-sample discrete choice experiment, for both willingness-to-accept and willingness-to-pay, is applied to landowners in the Stillaguamish Watershed through a survey. A mixed logit model approach describes estimated program attribute preferences, preference heterogeneity, and respondent-level interactions. Results for the willingness-to-accept indicate that landowners are negatively influenced by increasing contract lengths and monitoring visits, with programmatic framing of conservation easements being less preferred than vegetative enhancement. Shorter landowner tenure on the landscape, being of younger age, and higher environmental identity scores were associated with a greater likelihood to indicate enrollment. For the willingness-to-pay model, results indicated that increasing fees were associated with declining support, and programmatic framing of salmon habitat enhancement and water quality improvements were favored over recreation improvements and sport fishing opportunities. Duration of fee program was not significant. Respondents' prior participation in restoration activities and having a higher environmental identity score were associated with higher support while larger acreage ownership was associated with lower support, likely to reflect the cost-burden of a per-acre fee system. Pseudo-policy simulations were developed from the split sample to demonstrate politically feasible funding levels and predicted number of acres that

would be enrolled into a program throughout the watershed. The simulations indicate that internally generated revenues could not cover the cost of restoring all acres that landowners would be willing to enroll in conservation programs. Overall findings suggest key program attributes and landowner characteristics that can be used in program creation to help encourage conservation engagement and be used in developing funding mechanisms that could garner the majority of landowner support. Specifically, conservation program attributes that encourage enrollment are higher payments to landowners, shorter contracts, and less monitoring visits. For funding mechanisms, lower payments from landowners and demonstrating funding goes towards salmon habitat enhancement or water quality improvement could improve willingness-to-pay.

Background

Conservation and restoration work often requires collaboration and cooperation between private landowners to achieve landscape-scale restoration goals and to create continuity in habitat. Researchers have sought to understand what the drivers and barriers are for private landowners to engage in conservation activities on their land, especially in the framework of existing or potential sponsor conservation programs, such as the work through the Natural Resources Conservation Service (NRCS).

Conservation programs for private landowners are largely voluntary, requiring incentives to encourage landowners to enroll. Decision makers and managers are left to estimate how much incentives are required to balance possible deterrents, such as loss of working land, government oversight, long-term costs and maintenance. Some research indicates that willingness to participate in these programs varies between landowner groups, such as

agricultural landowners being more willing to participate compared to residential landowners (Armstrong & Stedman, 2012; Trenholm et al., 2017). With few studies on residential landowners or all landowners indiscriminately studied, there is an opportunity to expand on what incentives, and different program structures could encourage residential landowners to participate in conservation programs.

While understanding financial incentives to participate in programs is a critical part of developing and maintaining restoration programs, determining how much individuals are willing to pay for restoration activities may also inform an estimated total community restoration valuation. When coupled, willingness-to-pay and willingness-to-accept can provide insight into a possible mismatch between how much individuals value restoration and how much they need in financial incentives to engage in restoration activities.

Research Questions

The proposed research seeks to explore the barriers and drivers for landowners' willingness-to-pay (WTP) for restoration that may not necessarily be on their land and for landowners' willingness-to-accept (WTA) in the form of incentives to participate in restoration work on their land. The study will address the following research questions:

- How do program attributes, such as incentive payment, contract duration, and monitoring frequency, affect landowners' willingness-to-accept participation in restoration programs on their land?
- How do policy attributes, such as landowner payment, duration of payment program, and program purpose, affect landowners' willingness-to-pay for restoration in the watershed?

- How do respondent preferences for program attributes and policy attributes vary across respondent demographics, acreage, location, and environmental identity?
- What is the potential supply of funding and acres for restoration within the watershed?

Using a split sample WTP and WTA design, this study seeks to answer these questions by providing main effects for response coefficients of program attributes and the number of respondent-identified acres that would be enrolled in both the WTA and WTP programs. Further, respondent-level characteristics are incorporated into the models to understand how respondent characteristics affect individual WTA and WTP, including variables of environmental identity, prior conservation participation, subwatershed location, riparian status, acreage, and age (Table III-I).

The study contributes to the stated preference and environmental economics literature in several ways. Primarily, the study addresses the combined WTA and WTP of the same population, coupling the supply for local funding with the demand for incentives to engage in restoration. In a similar manner, the study expands on other studies that built models to determine how many acres landowner's would enroll as a portion of their total land rather than a simple binary of land enrollment (Greiner, 2023). The combination of the self-identified enrolled acres in the WTA programs and the estimated WTP of the watershed presents the opportunity to develop policy scenarios showcasing how stated-preference experimental designs can be further applicable in the landscape for decision-makers.

Table III-I: Variable Hypothesis Table for Willingness-to-Accept and Willingness-to-Pay with Supporting Literature

Variable	Hypothesized Sign	Supporting Literature
Willingness-to-Accept Model		

ASC – Vegetative Enhancement	-	None available
ASC – Conservation Easement	-	None available
Payment to Landowner	+	(Knoot et al., 2010; Luther et al., 2022; Z. Ma et al., 2012; Rabotyagov & Lin, 2013)
Contract Length	-	(Rabotyagov & Lin, 2013)
Monitoring Frequency	-	(S. E. Vedel et al., 2015)
Environmental Identity Score	+	(LeVert et al., 2009; S. Rosenberg & Margerum, 2008)
Prior Conservation Participation	+/~	(Luther et al., 2022; Z. Ma et al., 2012; Rabotyagov & Lin, 2013)
Subwatershed location	~	(Trenholm et al., 2017)
Riparian Status	~	None available
Acreage	+	(Rabotyagov & Lin, 2013)
Age	+/~	(Luther et al., 2022; Z. Ma et al., 2012; Rabotyagov & Lin, 2013)

Willingness-to-Pay Model

ASC – Yes Vote	-	None Available
Payment from Landowner	-	(Mueller, 2014; Petrolia et al., 2014)
Program Length	-/~	(Kim & Haab, 2009)
Funding Purpose	~	(Oluoch et al., 2021)
Environmental Identity Score	+	(Montgomery & Helvoigt, 2006; Nielsen-Pincus et al., 2017)
Prior Conservation Participation	+	Assumed as a relation to trust and experience (Bell et al., 2003; Naughton et al., 2019)
Subwatershed Location	~	(Mueller et al., 2018)
Riparian Status	~	None Available
Acreage	-	As an association with land income and expenses (Mueller et al., 2013)
Age	+/-	(Nielsen-Pincus et al., 2017; Papenfus & Weber, 2025; Petrolia et al., 2014)

+ denotes a positive and statistically significant sign.

- denotes a negative and statistically significant sign.

~ for hypothesized sign denotes an unsure coefficient but expected significance

Study Area and Context

The Stillaguamish River originates in the Cascade Mountains, flows westward, and enters the Puget Sound near the city of Stanwood, Washington in the United States (Figure XIV). The Stillaguamish Watershed encompasses 684 square miles, predominantly with forestry and

public lands in the eastern portions and flatter floodplains to the west with significant agricultural and rural development. While mostly rural, the watershed also contains the cities of Stanwood and Arlington. Nearly 80% of the original wetlands associated with the watershed have been drained or destroyed through the development of agriculture and the implementation of flood control infrastructure.

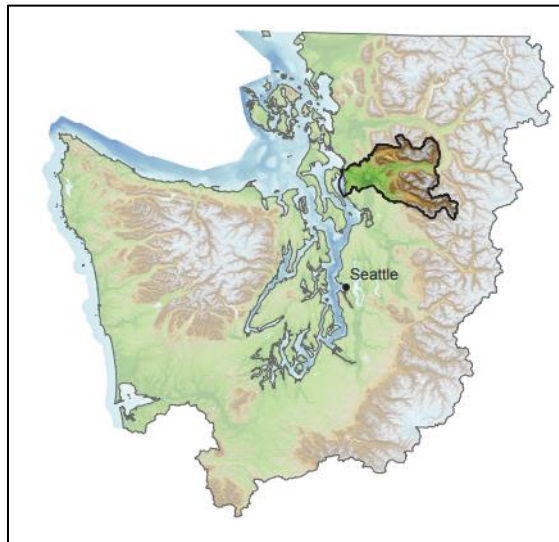


Figure XIV: Location of the Stillaguamish Watershed in Western Washington (Northwest Indian Fisheries Commission, 2016)

Since 1990, the Stillaguamish Watershed has been under a restoration plan to address water quality issues and wetland loss. The Stillaguamish River also provides critical habitat to endangered and threatened runs of Chinook Salmon (*Oncorhynchus tshawytscha* (Walbaum, 1792)) and Bull Trout (*Salvelinus confluentus* (Suckley, 1859)), making it a priority restoration area for local agencies and conservation organizations. Recent work has focused on furthering and incentivizing restoration along the riparian zone on private landowner properties. However, even with steps to restore the watershed, several subwatersheds are below the viable levels of habitat protection (Comte et al., 2026).

The Washington State Department of Fish and Wildlife (WDFW) seeks to better understand motivations, opinions, and barriers to restoration in the Stillaguamish Watershed. WDFW has contracted for the development of a landowner survey in the Stillaguamish Watershed to gain a better understanding of these matters. The survey serves as the basis of an economic analysis of landowner motivations and barriers to restoration, which may inform program and policy decisions in landowner restoration programs.

Selected Literature Review

Willingness-to-Accept and Other Conservation Adoption Literature

In the United States and Canada, the literature on stated preferences for landowners to engage in conservation or restoration work largely follows agricultural and forest landowners. In a study for implementing prairie strips on agricultural land in the United States Midwest, agricultural landowners were more likely to engage in programs if they believed that there would be benefits to their operations or to the environment, along with higher payment levels and previous engagement in federal conservation programs (Luther et al., 2022). Similarly, a review of studies found that motivations and barriers are associated with farm management and characteristics, economic factors, social norms, trust and government perception, and environmental awareness all affect agricultural landowner decisions in enrollment (Ranjan et al., 2019). For forest landowners, a study with Washington State small forest landowners found that contract length, extent of parcel enrollment, management objectives, harvesting history, and distance from development and public lands all affect their WTA for conservation contracts (Rabotyagov & Lin, 2013).

Findings across the forest landowner and the agricultural landowner literature are inconsistent. Some studies find that demographic variables, such as increasing levels of education and increasing age, positively influence willingness to accept (Z. Ma et al., 2012; Rabotyagov & Lin, 2013). Other studies do not find a statistically significant finding when it comes to these demographic variables (Luther et al., 2022). In the same manner, previous engagement by the landowner in conservation programs, such as CRP or EQIP, was found to have a positive effect on willingness to accept (Luther et al., 2022; Rabotyagov & Lin, 2013) but not always (Z. Ma et al., 2012). These differences could be particular to the sample population or attributed to the variables that were included or omitted from the modeled utility equations. There could be further differences in management objectives, personal preferences, or eligibility differences (Z. Ma et al., 2012). A survey in the Southeast United States found that payment, contract length, and management objectives are the primary factors influencing willingness to accept. The survey also found that payment offered eventually had diminishing returns in an S-shaped curve, indicating that as payments increased to a certain point, adoption rate plateaued. The authors accredited the adoption rate plateau indicates the influence of some other limiting factor that payments do not compensate for well (Schneider et al., 2025).

Non-choice experiments additionally add to the barriers of adoption for working lands. In Oregon, a study found that landowners were motivated to conduct restoration from a “moral obligation” but were hindered by the financial cost of restoration and the time investment (S. Rosenberg & Margerum, 2008). An interview study regarding private forestland in the United States Midwest found that barriers to restoration were likely linked to financial cost, management challenges, and development (Knoot et al., 2010).

Some work included residential landowners as part of the stated preference design. A study in two Ontario, Canada watersheds employed two similar choice experiment surveys for farm landowners and rural non-farm landowners, finding that some latent groups of non-farm landowners had higher marginal WTA compared to their farm counterparts (Trenholm et al., 2017). A study based in the Chesapeake Bay watershed in the United States found that residential landowners were less willing to adopt riparian buffers compared to agricultural landowners (Armstrong & Stedman, 2012). These studies suggest that residential landowners may need more incentives to enroll in conservation or restoration programs. Nevertheless, as highlighted by Trenholm et al. (2017), there is heterogeneity based on distinct latent classes, where the generalized statement that residential landowners may need more incentives may not always hold true.

Outside of choice experiments, residential landowners may have different variables that impact their decision to adopt environmentally-friendly practices. A survey of residents in Massachusetts found that landowners were more likely to adopt water-conserving landscaping if it was aesthetically pleasing and were concerned about the possibility of pests and incurring landscaping costs (Stacy et al., 2021). A study conducted in Vermont found that adoption of green stormwater infrastructure varied depending on whether the stormwater problem was perceived as a household or neighborhood problem compared to a watershed problem, along with perceived permitting barriers (Coleman et al., 2018).

A survey across rural landowners in Indiana found that while all rural landowners generally were willing to try implementing a vegetated buffer, those who identified as farmers were more likely to have already implemented a vegetative buffer, enrolled in a conservation

program, and were already restoring or creating wetland habitat. These findings suggest that rural residential and small agricultural landowners are potential target candidates for conservation and restoration programs. Perceived costs were a barrier across all rural landowners (Perry-Hill & Prokopy, 2014). A contingent valuation survey in Vermont and Massachusetts found that landowners were more likely to sell their land for easements should they be paid more, held ecocentric values, recently harvested their land, or were absentee owners (LeVert et al., 2009). The study also suggested that landowners in different, but similar, states differed in their willingness, suggesting possible differences in local cultures and state practices even in a relatively small area (LeVert et al., 2009).

Several studies point to possible best management practices that could also increase adoption of conservation and restoration across landownerships. Trust and personal connection (Coleman et al., 2018; Knoot et al., 2010), increased cost-share or payment from programs (Knoot et al., 2010; Luther et al., 2022; Z. Ma et al., 2012; Rabotyagov & Lin, 2013), and targeted outreach (Perry-Hill & Prokopy, 2014) were all identified as best practices.

The WTA and participation literature highlights that economic incentives can encourage individuals to participate in conservation and restoration, following expected economic theory on utility when benefits outweigh costs. However, the literature could still be expanded on understanding how to develop WTA and participation studies for general populations in localized contexts. This may be an artifact of current conservation and restoration programs being designed for specific landowners, such as agricultural, shoreline, or forest landowners. Nevertheless, restoration and conservation goals often are for entire regions and must face landscape ownership heterogeneity.

Willingness-To-Pay and Valuation Literature

Regarding salmon-related literature, a study spanning regions of the West Coast reported that individuals were more likely to vote yes on the WTP instrument if they had confidence in state and partner institution involvement in salmon enhancement projects (Bell et al., 2003). A longitudinal study from 1996-2002 in Oregon found that WTP declined over that time period associated with changing economic conditions and demographics. The authors suggest that the decline in WTP may also be associated with media coverage of failed restoration projects and increased state expenditures on salmon recovery. While most respondents stated salmon recovery is important, few of the respondents selected high WTP categories indicating a mismatch between attitudes and action (Montgomery & Helvoigt, 2006). A more recent study from Oregon found that individuals had a relatively high WTP for salmon recovery, linked to a bequest value of salmon existing in the future and acknowledgement of watershed health as a part of salmon recovery. The study found that those with a higher degree of education, higher income, and those who were younger had a positive association with WTP (Papenfus & Weber, 2025).

For more general restoration literature, a study on paying a monthly sum for forest restoration in Arizona found that residents were more likely to pay a higher bid amount if they were aware of the program, concerned with wildfire protection and the threat of drought, and had a higher income. The study highlighted that residents were more likely to pay more for programs that they thought would negate risk (Mueller, 2014). A year before, a published study found that irrigators who had a positive perception on restoration, were concerned about drought, had a higher income, and the less they paid in irrigation costs were more likely to vote

yes on the presented WTP bid (Mueller et al., 2013). A later study in the same region suggests there may be a negative relationship with WTP for those who have a view of a notable feature in the restoration area and for those who lived further away from the watershed where restorations projects were to occur (Mueller et al., 2018). These studies from Arizona show consistent positive WTP for restoration in a watershed and how perceived risk affects valuation for restoration.

In a nation-wide study concerning the restoration of the Louisiana coastline found that respondents who have resided or used the area, had environmentally-friendly behaviors, were older, were more politically liberal, and who held more trust in the federal and state government were more likely to support higher bid amounts (Petrolia et al., 2014). Another study on restoring prairies were more likely to have a higher WTP if they participated in outdoor activities, grew up near prairies, or had some sort of environmental education (Li & Ando, 2023). When considering WTP on private compared to public lands, a survey from Baltimore found that respondents were willing to pay more for restoration on public lands compared to private lands, suggesting respondents preferred public lands restoration compared to that of private lands (A. B. Rosenberg et al., 2023). A valuation survey based on willingness-to-tax found that respondents were more likely to have a higher WTP if they had higher income, were more politically liberal, were younger, had a higher education attainment, and had positive place attitudes (Nielsen-Pincus et al., 2017). A survey in the Southeast United States found that respondents had a higher WTP for recreation, followed by species conservation, then carbon sequestration (Oluoch et al., 2021). A nation-wide study on monarch butterfly conservation found that respondents were supportive of restoration across all butterfly breeding regions

but had a higher WTP for the region where the respondent resides (Diffendorfer et al., 2014). Another study for white bark pine conservation found that higher income, higher education, and formerly seeing a white bark pine prior to the survey positively influenced WTP (Naughton et al., 2019). These studies demonstrate the importance of experience or interaction with the good or place being valued, how political ideology affects WTP, and proximity to a place or good affect value.

The WTP literature overall demonstrates that respondents are typically willing to pay for restoration and conservation, and supports economic theory that paying impacts utility, resulting in diminishing willingness to pay as bid amounts increase and the general positive association of payment level and an individual's income. The literature highlights how environmental identity and connection affects how willing respondents are to support a payment scheme. The purpose of payments also illustrates how program framing translates to public support.

Study Design and Methods

Study Population and Survey Design

The study population includes all landowners recorded for tax parcels in the Stillaguamish Watershed other than utility landowners. The population is stratified by riparian status, where: riparian status equates to the landowner is within the regulatory 150-foot riparian buffer zone along any watercourse of the Stillaguamish River, excluding portions of the river classified as part of the bay or Puget Sound. Of all landowners, 30% have parcels in the riparian zone and 70% have parcels in the uplands. The landowners were sampled by the inverse proportion of riparian status to ensure adequate representation of the riparian

landowners (Cochran, 1977). Riparian landowners are paramount for understanding restoration, especially in a watershed context. This oversampling design ensures that there is adequate representation of riparian landowners for the survey analysis.

With 10,000 surveys and after address cleaning, all parcels with riparian status were selected for the survey. The remainder of surveys planned for the riparian zone that were not used were equally distributed among the upland parcels in the less than 5 acres, 5 to 20 acres, and greater than 20-acres categories. For both acreage sizes and riparian status, the survey relies on self-reporting of acreage size and riparian status. This means that respondents may not select their acreage or riparian status that is reflected in county parcel data, as respondents may not accurately know their acreage, riparian status, or may answer for one of many parcels they own in the watershed.

The results presented here are non-weighted as there is a lack of clear landowner population data within the geographic area that could be compared to the respondent sample. Using estimated acreage bins based on parcel data and collapsing the “less than 0.5 acres” and “0.5 to 1 acres”, weights would be between 0.7 and 1.2 for acreage bins to weight respondent responses. However, estimated acreage bins from parcel data may not reflect complete ownership of respondents in the Stillaguamish Watershed or how respondents view the size of their property. Without a secondary variable to adjust these weights, the data remained unweighted.

The survey was designed and implemented through Qualtrics software (Qualtrics, Provo, UT). Both English and Spanish version of the survey were offered. Landowners along with tribal and agency officials reviewed the survey and provided feedback. A modified version of the

Dillman method (Dillman et al., 2014) was used to solicit responses with a postcard with information about the survey followed by a letter with a QR code and a \$2 incentive two weeks later. Two weeks thereafter, another postcard was sent to remind landowners to fill out the survey. An additional \$200 gift card incentive was provided via a lottery system. This was to maximize the response rate and to minimize nonresponse bias. Descriptive statistics were compared between early and late respondents, parcel sizes, and riparian status for the purpose of initial nonresponse bias checks (Dillman et al., 2014). The study team sent out 10,000 surveys, receiving 1,373 usable responses, for a response rate of 13.7%. The survey was reviewed by the University of Washington Institutional Review Board and received an exempt status: STUDY0002323.

Conceptual and Theoretical Framework and Instrument

Choice experiments, like this one, are derived from the standard random utility model (Train, 2003). We assume that landowners have an expected utility from their land by how they manage it. Utility is then modified by the adoption of a restoration program or through electing to pay for restoration activities within the watershed. Opting for neither restoration nor paying for restoration represents the baseline utility that the landowner currently receives from the land management.

Willingness-to-Accept Model Framework

For the WTA, we test payment per acre, contract length, monitoring frequency, label alternatives, and respondent-level data. The utility function :

$$\begin{cases} V_{i,VE,t} = \alpha_{VE} + X_{it,VE}\beta_i + Z_i\gamma + \eta_{program,i} \\ V_{i,CE,t} = \alpha_{CE} + X_{it,CE}\beta_i + Z_i\gamma + \eta_{program,i} \\ V_{i,SQ,t} = 0 \end{cases}$$

was used to describe willingness-to-accept, where:

- i is the respondent;
- t is the task choice;
- X are the program attributes of payment, contract length, and monitoring, with an exponential coefficient on payment;
- Z are respondent-level variables (i.e., environmental identity, prior conservation participation, subwatershed location, acreage, age, longevity in watershed);
- VE defines the choice selection of the labeled alternative: “Vegetative Enhancement”;
- CE defines the choice selection of the labeled alternative: “Conservation Easement”;
- SQ defines the choice selection of “Status Quo”.

Model development used an iterative process to assess the respondent-level interaction effect model using these utility functions. First, a multinomial logistic model was used to understand baseline effects under the independence of irrelevant alternatives (IIA) assumption (i.e., the respondent choice is independent of the conditions of the other alternatives presented). Then, a program-attribute mixed logit model was developed to understand main effects and heterogeneity within respondent choices. Respondent-level heterogeneity was tested across the main effect variables one or two at a time. Insignificant heterogeneity effects were removed from the final structural mixed logit for ease of interpretation and model performance. For the respondent-level interaction mixed logit model, respondent-level

variables were added to the model one at a time to test for significance and model improvement. Variables were dropped if they are insignificant or decrease model performance without meaningful interpretation through AIC, BIC, and log-likelihood metrics. When another variable became insignificant after adding another interaction, that variable was dropped from the model unless the relationship has clear interpretation.

The utility function described how program attributes and respondent-level variables affected a respondent's choice in selecting one of the restoration programs or the status quo. The status quo, or business as usual, was then assumed to be baseline, representing that the respondents do not gain nor lose from their current utility by choosing to manage their land as they do so currently. The utility expressed for the respondent was then normalized to the status quo baseline. This was the primary stage of this analysis.

This primary utility model was a labeled experiment approach (i.e., vegetative enhancement and conservation easement). This model specified that the coefficients on attributes are considered generic across labels. The alternative-specific constants (ASCs) represented the preference difference between the label alternatives. This assumed that respondents perceived the attributes similarly across labels (Hensher et al., 2015).

The second stage of the utility analysis was understanding how many acres an individual would be willing to enroll under the restoration program that they have selected, removing responses that have selected the status quo. This modeled a conditional supply decision compared the attribute effects as described in the primary model. The second stage supply model came from Greiner (2023), where a discrete-continuous concept was applied to demonstrate that the decision to participate in a program and the decision to enroll a specific

amount of land are related but separate decisions. Acreage was considered as a continuous outcome conditional on restoration enrollment, as the survey did not collect WTA respondents' total acreage other than in broad categories.

Willingness-To-Accept Instrument Design

The WTA instrument was designed to understand what barriers and incentives are needed to encourage a landowner to participate in a restoration program. The three attributes were developed with two different program types, as described in Table III-II. The attributes included annual payment to the landowner per acre in U.S. dollars (USD), longevity of the contract in years, and monitoring frequency by program sponsor in months. Annual payments were developed from average NRCS payment schedules for riparian habitat establishment and restoration for Washington State, approximately \$700 per year per acre then set at approximately 50%, 100%, 150%, and 200% of that benchmark. Longevity of contract mirrors other real-world programs and monitoring frequency came from input provided by agency officials.

The program types included a conservation easement program or a vegetation enhancement program in Table III-III. The conservation easement program was developed to mirror the Washington State's Forestry Riparian Easement Program (FREPP). The vegetation enhancement program was inspired by the Natural Resources Conservation Service's Conservation Reserve Enhancement Program (CREP).

Table III-II: Attributes and Attribute Levels of the Willingness-to-Accept Instrument

Attributes	Description	Levels
Annual Payment to Landowner	The amount of money that the individual receives per	\$350 \$700

	acre per year for the restoration program.	\$1,050 \$1,400
Length of the Contract	The number of years that the restoration program is active.	5 10 20 40
Monitoring Frequency	The number of visits per year from the program sponsor for monitoring.	1 2 4
Program Type	The types of program (alternatives) the individual may choose.	Vegetation Enhancement Conservation Easement

Table III-III: Description of Choice Labels in the Willingness-to-Accept Instrument

Program Type	Definition to Respondents
Vegetation Enhancement	<i>The State would give you money each year to add and maintain native vegetation on your land. The State would assist with the initial purchasing of materials and labor. You would be responsible for long-term monitoring and maintenance of the site.</i>
Conservation Easement	<i>The State would pay you for the right to access and manage the portion of your land placed into the conservation easement. You would give up the development and management rights to that portion of your land to the State.</i>

Alternatives were not considered as parameters in this model through the explained generic coefficient assumption. Similar structuring of utility and labeled alternatives have been applied elsewhere in environmental economics (Lizin et al., 2016).

Willingness-to-Accept Experimental Design

The WTA and the WTP components were part of the larger survey instrument. Through the split-sample design, all landowners had a 50% chance of being in the WTA or the WTP sample. The split-sample was designed to reduce the cognitive burden on the landowners filling out the survey and to prevent landowners from anchoring responses between the instruments.

Respondents received six task choice sets in the survey across four blocks for a total of 24 different choice sets. Each of the choice sets included one follow-up question that asks for how many acres the respondent would be willing to put into the program. Only one task choice was presented at a time. Once the respondent finished all choice sets, they were asked how certain they were of their choices and rationale for selecting the status quo. Cheap talk, telling the respondents about hypothetical bias and asking respondents to consider the presented options as if their selection had real-world consequences, was used to encourage engagement and accurate responses (Cummings & Taylor, 1999). A full example of what respondents received can be found in Supplemental III-III.

Due to time constraints for this study, no significant pretesting was conducted other than cognitive interviews with agency officials and some landowner reviews of the survey. Changes were made to survey to reflect the feedback from agency officials and landowners by clarifying questions, defining key terms, and adjusting answer options to be more reflective of the landowner experience. The reviewed literature provides reasonable justification for signs and possible magnitudes for the parameters suggested, but these studies were not specific enough to the target population to use such magnitudes with certainty. Published best practices for efficient design generation have demonstrated that *a priori* magnitudes and signs perform better than naïve designs even under uncertain *a priori* information, as long as the *a priori* information is reasonable (Table III-IV) (Ferrini & Scarpa, 2007). Following Ferrini and Scarpa (2007), near-Bayesian designs were created as there was reasonable evidence for signs and magnitude but with uncertainty. While

Landowner payment was assumed to be the main driver with a positive effect on the utility as found in several studies (Rabotyagov & Lin, 2013; Schneider et al., 2025; Trenholm et al., 2017). The effect of contract length was assumed to be negative and less than that of landowner payment from findings previously reviewed (Rabotyagov & Lin, 2013; Schneider et al., 2025). Monitoring effects were assumed to be negative by the opinions of the researchers and program managers familiar with the study; however, there appeared to be little literature addressing monitoring in WTA analyses involving landowners and restoration programs. A Danish study found that monitoring resulted in a higher WTA for landowners than no monitoring, indicating that monitoring has a negative effect on landowners (S. Vedel et al., 2015). This study indicated the negative effect monitoring has on utility, but given the distinctly different population of the study, what will be found in the United States is uncertain. The distribution of the monitoring effects was set wide to reflect the uncertainty of impact.

Given there were no direct relationships in the literature, priors were selected as small at the discretion of the researcher, as supported by Ferrini and Scarpa (2007). Standard deviations then exceeded the threshold of a positive and negative prior mean to represent the expectation but uncertainty around the magnitude and expected sign of the mean. The MNL model was described as:

$$U_{nij} = ASC_j + \beta_{Payment} Payment_{nij} + \beta_{Contract} Contract_{nij} + \beta_{Monitoring} Monitoring_{nij} + \varepsilon_{nij}, \quad j \in \{VE, CE\}$$

Where:

- U_{nij} is the utility (U) of the respondent (i) for every task (n) for each labeled alternative (j);

- ASC_j is the alternative specific constant (ASC) for each labeled alternative (j);
- β is the coefficient for each variable;
- $Payment_{nij}$ is the payment level for the respondent (i) for every task (n) for each labeled alternative (j);
- $Contract_{nij}$ is the contract length level for the respondent (i) for every task (n) for each labeled alternative (j);
- $Monitoring_{nij}$ is the monitoring level for the respondent (i) for every task (n) for each labeled alternative (j);
- ε_{nij} is the random error for the respondent (i) for every task (n) for each labeled alternative (j).

The efficient design was calculated in the proprietary software Ngene by ChoiceMetrics (ChoiceMetrics, 2025). The design was optimized using a multinomial logit (MNL) parameter and the specified prior distributions. The design used 500 draws using the Halton method (Halton, 1960). To minimize dominant choice tasks between the different program types (Vegetation Enhancement and Conservation Easement), the efficient design was constrained to only allow for combinations where the payment to the landowner for each program was between one step below or above the other, or equal. The Bayesian MNL D-error for the near-Bayesian design is 0.026373.

Table III-IV: Assumed Mean and Standard Deviation of Priors for the Near Bayesian Design of the Willingness-to-Accept Instrument

Attribute	Mean for Prior	Std. Dev. for Prior
$\beta(\text{Program Type})$	0	0.8
$\beta(\text{Landowner Payment})$	0.2	0.6
$\beta(\text{Length of Contract})$	-0.2	0.6
$\beta(\text{Monitoring Frequency})$	-0.1	0.6

A naïve approach, where the priors were set to zero, was also calculated to understand the difference in efficiency between the two designs. This is not evidence of ex post performance of the design as the design calculations are not directly comparable and may not actually reflect ex post performance (Ferrini & Scarpa, 2007). The naïve approach assumed that all priors are set to zero and there are no constraints on the design. The MNL D-error for the naïve design is 0.025121. The ending choice blocks can be found in Supplemental III-I.

Willingness-to-Pay Model Framework

For the WTP, the model tested a per acreage fee collected from the landowner with longevity of the fee program and the stated purpose of the funding program. The WTP experiment was presented as a series of referendum questions where the respondents “votes” for or against the given referendum scenario. The utility function:

$$\begin{cases} V_{i,Yes,t} = \alpha_{Yes} + \beta_{pay,i}Pay_{it} + \beta_{length}Length_{it} + \beta_{purpose,i}Purpose_{it} + Z_i\gamma + \eta_{Yes,i} \\ V_{i,No,t} = 0 \end{cases}$$

described the willingness to pay where:

- i was the respondent;
- t was the task choice;
- α was the alternative specific constant;
- Pay was the per acre per year cost to the landowner, with a negative lognormal payment coefficient;
- $Length$ was the longevity of the fee program;
- $Purpose$ was the stated purpose of the fee program, effects coded;

- Z represented the respondent-level variables (i.e., environmental identity, prior conservation participation, subwatershed location, acreage, age, longevity in watershed).

Model development underwent an iterative process to reach a respondent-level interaction effect model using these utility functions. First, a multinomial logistic model was used to understand baseline effects under the IIA assumption. Then, a program-attribute mixed logit was developed to understand main effects and heterogeneity within respondent choices. Heterogeneity was tested across the main effect variables, beginning with payment and payment program length then each purpose statement individually. Insignificant heterogeneity effects were removed from the final program-attribute mixed logit for ease of interpretation and model performance. For the respondent-level interaction mixed logit model, respondent-level variables were added to the model one at a time to test for significance and model improvement. Variables were dropped if they were insignificant or decrease model performance without meaningful interpretation. Model performance was assessed for each variable added through the overall changes of AIC, BIC, and log-likelihood. If another variable became insignificant after adding another interaction, that variable was dropped for model performance unless the relationship had clear interpretation. The final model presented the clearest interpretation and associated model performance variables.

Willingness-to-Pay Instrument and Experimental Design

The WTP instrument was a modified referendum task. Respondents were prompted to “vote” for each of the choice sets that they were given. Three attributes were developed as

described in Table III-V. The attributes included annual payment from landowner per acre in USD, number of years that the payment program is established, and the framed purpose of the payment program. The referendum was modeled after special district assessments that are conducted in the Stillaguamish Watershed and nearby watersheds and counties. Modeling the referendum after nearby special districts formed the basis that the referendum is only for landowners rather than all residents.

The per-acre payment mechanism was developed to provide an equitable funding mechanism that weighs the acreage of the landowner as a function of their impact on the landscape. This model assumed structures similar to those of flood control districts in the region where assessments are often per-acre or by the value of improvements on the landowner's parcel. By constructing the design similar to that of other special assessments in the area, the instrument construction framed the choice to structure that is similar to that in which respondents are familiar (Carson & Groves, 2007). Additionally, the assumption lies that larger landowners may be eligible for enrolling more acres into a restoration program compared to smaller landowners, suggesting that incentives may benefit larger landowners compared to smaller landowners.

Table III-V: Attributes and Attribute Levels for the Willingness-to-Pay Instrument

Attributes	Description	Levels
Yearly Payment from Landowner	The amount of money that the individual pays out per acre per year for the fee program.	\$10 \$25 \$50 \$100
Length of Fee Program	The number of years that the fee program lasts	5 10 20

Purpose of Fee Program	The stated purpose that the fee program would support in terms of restoration.	• Improve sport fishing opportunities • Enhance salmon habitat • Enhance recreation in watershed • Improve water quality
------------------------	--	---

With this, respondents received six task choice sets across four blocks for a total of 24 possible choices. Once the respondent finished all choice sets, there were several follow-up questions, including how certain they were of their responses, how many total acres they own in the Stillaguamish Watershed, rationale for if they selected status quo, if they would be more willing to adopt a flat fee compared to an acreage assessment, and if they would be willing to donate instead of having an annual assessment. These follow-up questions tested whether the respondent is protesting the per-acre mechanism or if they are truly against funding restoration activities.

Cheap talk was also used to encourage engagement and accurate responses (Cummings & Taylor, 1999). A full example of what respondents received can be found in Supplemental III-III.

With the same constraints as the WTA instrument, a near-Bayesian D-efficient design was developed for the WTP following Ferini and Scarpa (2007) guidance. Table III-VI describes the assumed prior signs and distributions. Payment from the landowner is expected to have a negative effect, with the greatest impact (Mueller et al., 2013; A. B. Rosenberg et al., 2023). Length of the payment program is expected to have a negative effect, taking from WTA literature on contract length (Rabotyagov & Lin, 2013; Schneider et al., 2025), with a wide distribution due to uncertainty. The purpose of funding is a categorical variable and is designed to

be effects coded (i.e., the reference category is the negative sum of all the variable level coefficients). As the program does not support near-Bayesian methods with effects variables, the priors were set to zero. The MNL utility for the WTP:

$$U_{nit} = ASC_i + \beta_{Payment} Payment_{nt} + \beta_{Duration} Duration_{nt} + \sum_k^{K-1} \beta_k Z_{knt} + \varepsilon_{nit}$$

Described so that:

- i is the vote alternative (“yes” or “no”0);
- Z_k denotes the levels of the purpose statement, effects coded so that the model includes salmon habitat enhancement, water quality improvement, and recreation improvements and sports fishing improvements is the inverse of the grand purpose mean.

Table III-VI: Assumed Means and Standard Deviations of Priors for the Near-Bayesian Design of the Willingness-to-Pay Instrument

Attribute	Mean for Prior	Std. Dev. for Prior
$\beta(Landowner\ Payment)$	-0.2	0.6
$\beta(Length\ of\ Fee\ Program)$	-0.1	0.8
$\beta(Purpose)$	0	NA

The designs were made in Ngene (ChoiceMetrics, 2025). The near Bayesian efficient design resulted in a d-error of 0.352532. Similarly to the WTA, a naïve design was made with priors set to zero. The naïve design resulted in a d-error of 0.349473. The d-error for the WTP instrument is expected to be higher than the WTA with a categorical variable. The naïve design is lower than the Bayesian design. The resulting choice blocks can be found in Supplemental III-II

Willingness-to-Accept and Willingness-to-Pay Analysis

The experiments were designed to be compatible with mixed logit models, allowing for more flexibility and avoiding the IIA of multinomial logit models (Hensher et al., 2015; Train,

2003). Through an estimated error component random parameters logit, individuals' choices were modeled at each task choice while accounting for the respondent's unobserved preference that breaks the IIA assumption. The mixed logit design also supported the repeated choice decisions made by the respondent. The results of the model better reflect the heterogeneity in individual decisions by the assumption that each individual had a different coefficient associated with a variable.

For the analysis coefficient development, the payment variable was divided by \$100 for the WTA and \$10 for the WTP for scaling. Contract duration and length of the fee program were divided by 10 for scaling. Scaling of the continuous and temporal terms helped in the estimation and interpretation of results while having no impact on the utility specification and predicted probabilities (Train, 2003).

All estimation was conducted in Apollo (Hess & Palma, 2019). For model draws, models used Sobol draws of 1,000. Respondent-level variables are defined in Table III-VII.

Table III-VII: Definitions and Adjustments of Variables used in the Willingness-to-Accept and Willingness-to-Pay Models

Variable	Definition	Data Adjustment
Age	Self-reported age via bins: 18-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80 and older.	Respondents are given the median age of their respondent bin, then the data is centered. Group 18-19 dropped due to lack of respondents. Group 80 and older given 85.
Acreage	Self-reported acreage via bins: less than one-half, 0.5-1, 2-5, 6-10, 11-20, 21 and more.	Acreage treated as categorical given the wide range that is feasible above 20 acres. Bins may be merged for analysis.
Tenure	Self-reported ownership and tenure bins: less than a year, 1-5 years, 6-10 years, 11-20 years, 21+ years, I	Bins were treated as categories. Bins may be merged for analysis.

	do not live in the Stillaguamish Watershed.	
Subwatershed	Self-reported property location via HUC 10 subwatersheds for the Stillaguamish Watershed.	Subwatersheds are aggregated into larger regions for analysis.
Riparian Status	Self-reported property location of whether or not the property is 150 feet from a stream, river, or natural water body.	Treated as a binary category.
Prior Restoration Participation	Self-report previous activity, interest, or disinterest in 12 different specified restoration activities.	If the respondent ever selected “Yes, I have” for any item, coded as 1 otherwise 0. Treated as a binary category
Environmental Identity Score	A Likert scaling belief question of 7 paired statements.	Respondents were given a summative score based on the 7 questions for totals between 7 and 35. Summed responses scaled to Z-scores.

The environmental identity score came from a series of bipolar questions in our survey inspired by Stets and Biga’s (2003) work on environmental identity as reported by the respondent (Stets & Biga, 2003). The measure was an additive scale of bipolar statements about how the respondent views their relationship with the watershed and asks the respondent to score along a scale where they fall along the statements. The scale was then scored 1 through 5 with a score of 1 on the item being more anthropocentric and a 5 on the item being more ecocentric. The scores were totaled for each respondent, resulting in a “environmental identity” score, with a lower score associated with anthropocentrism and a high score associated with ecocentrism. This tool has been implemented elsewhere, showing promising results of high scores associated with conservation willingness compared to lower scores (Scholl & Humphery, 2017).

When testing respondent-level variables, variables were scaled and centered as appropriate. For this analysis, environmental identity score was centered and scaled. Age was

converted to a continuous variable, using the midpoint of the age bins, and centered.

Conversion of age to a continuous variable was to lessen the parameter burden of the model.

Supply of Restoration Land and Funding Scenarios

Inspired by Greiner (2023), asking how many acres respondents were willing to enroll into a restoration program and the total number of acres a respondent has in the watershed allowed for the calculation of a projected number of acres that are in “willing” to be restored and a hypothetical budget amount set by a watershed fee (Greiner, 2023). Under certain payment to landowner and payment from landowner schemes, policy scenarios were developed to understand the supply of restoration funds, the demand for restoration, and the amount of money the local population would be willing to put forward for that restoration.

For the policy scenarios, WTA results considered the choice probability and self-elected acreage responses across the watershed to develop expected enrollment projections under the WTA alternatives. The WTP scenarios calculated the predicted support for fee systems that will be used to compute the projected funding collected under the fee scenario. These policy scenarios were compared to demonstrate functionality.

As self-elected enrollment and reported total acres were voluntary, missing data became a persistent issue. To address missing data, total estimated acres were derived by assigning the median reported total acreage by selected acreage bin from respondents who reported to those who did not. The conditional acres that a respondent would enroll was calculated for missing data points as the midpoint of reported shares by acreage bin, which would then be used against the estimated or reported total acres to get conditional enrolled acres. Enrolled acres were constrained to be no more than the estimated or reported acres.

Results

Survey Sample Demographics

Through the random selection process conducted in Qualtrics and after removing surveys that were incomplete or duplicates, the WTA sample resulted in 672 respondents and the WTP sample resulted in 701 respondents. From selected demographics, the group demographics are relatively simpler, with the sex category having the largest difference at 4%. These demographics suggest that the two sample populations are comparable for this analysis (Table III-VIII).

Table III-VIII: Comparison of Selected Demographics for WTA and WTP Respondent Samples

Variable	WTA Respondent Sample (n = 672)	WTP Respondent Sample (n = 701)
Age 20-29 years	14 (2%)	13 (2%)
Age 30-39 years	65 (10%)	84 (12%)
Age 40-49 years	112 (17%)	101 (14%)
Age 50-59 years	103 (15%)	104 (15%)
Age 60-69 years	169 (25%)	159 (23%)
Age 70 -79 years	154 (23%)	176 (25%)
Age 80+ years	36 (5%)	48 (7%)
Age No Answer	19 (3%)	16 (2%)
Subwatershed Stanwood	138 (21%)	150 (21%)
Subwatershed Arlington	209 (31%)	204 (29%)
Subwatershed Pilchuck	76 (11%)	90 (13%)
Subwatershed North Fork	114 (17%)	122 (17%)
Subwatershed South Fork	135 (20%)	135 (19%)
Riparian Status	435 (64%)	439 (63%)
Sex Female	274 (41%)	260 (37%)

Willingness-to-Accept Model Results

The WTA model creation underwent an iterative process, beginning with a MNL baseline model that is then compared to the developed mixed logit randomized parameter structural model and interaction model. The MNL baseline model only considers the program attributes and alternative specific constants for each labeled alternative. The mixed logit structural model

incorporates the program attributes and alternative specific constants with estimated error on specific attributes. The final interaction model incorporates respondent level information to the structural mixed logit. The final model developed balances model diagnostics (BIC, AIC, log-likelihood, pseudo-r²) and variable significance. A final model was determined after 16 model specifications.

Across the hypothesized interactions and resulting significance, the final mixed logit model retains the structural components of the WTA design and respondent-level data of environmental identity, length of ownership, and age. Other tested variables, including acreage, residency, and geographic location were excluded for either loss of respondents through missing data or preference not to answer, insignificance, or worsening model diagnostics measure outputs. The three core models demonstrate improvement in model performance in variance explained and lower AIC and BIC measures (Table III-IX). All model outputs can be found in Supplemental III-V through III-XIV. Due to missing data, the model included 653 respondents, 19 respondents less than the complete sample.

Table III-IX: Comparison of Key Model Developments for WTA

Measure	MNL	Program Mixed Logit	Interaction Mixed Logit
ASC Vegetative Enhancement	-0.370 (<0.001)***	-1.092 (0.001)**	-1.967 (<0.001)***
ASC Conservation Easement	-1.401 (<0.001)***	-2.560 (<0.001)***	-3.435 (<0.001)***
<i>ASC Estimated Standard Deviation[‡]</i>	-	6.929 (<0.001)***	6.402 (<0.001)***
Payment to Landowner	0.056 (<0.001)***	2.338 [†] (<0.001)***	2.425 [†] (<0.001)***
<i>Estimated Standard Deviation</i>	-	1.002 (<0.001)***	1.099 (<0.001)***
Contract Length	-0.192 (<0.001)***	-0.426 (<0.001)***	-0.422 (<0.001)***

<i>Estimated Standard Deviation</i>	-	0.625 (<0.001)***	0.621 (<0.001)***
Monitoring Visit Frequency	-0.054 (<0.001)***	-0.100 (<0.001)***	-0.100 (<0.001)***
Environmental Identity Score	-	-	2.074 (<0.001)***
0 – 20 Years of Ownership in Watershed	-	-	2.010 (<0.001)***
Age	-	-	-0.059 (0.025)*
Pseudo-r ²	0.017	0.381	0.389
Log Likelihood	-3767.12	-2364.87	-2332.69
AIC	7544.24	4745.73	4687.38
BIC	7575.61	4795.92	4756.38

· $p < 0.1$

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

† The modeled coefficient for Payment to Landowner is negative. However, since payment is treated with an exponent, the coefficient becomes positive in the utility model. The coefficient is represented here as positive for ease of interpretation.

‡ Constrained to be the same for both the ASC for Vegetative Enhancement and Conservation Easement

The final model indicated there was significant heterogeneity in the core program attributes of payment to landowner and contract length. Monitoring visit frequency had a significant coefficient but an insignificant estimated standard deviation that was dropped from the final model construction to improve interpretability. These results suggest there were characteristics to program participation, payment received, and contract length that were not observed in the model but have significant bearing on how individuals perceived those program attributes. The individual level heterogeneity indicates that some individuals hold coefficients to program attributes that are of greater impact in the expected sign or at times in the opposite direction. In the case of contract length, for example, the finding indicates that some respondents hold a positive coefficient with contract length, differing from the modeled negative coefficient.

The alternative specific constants were negative and significant, indicating that individuals hold a negative utility value to enrollment of their land into a program. The payment

coefficient was significant and positive, after considering the exponent transformation, as found elsewhere in the literature (Knoot et al., 2010; Luther et al., 2022; S. Ma et al., 2012; Rabotyagov & Lin, 2013) as monetary compensation alleviates the loss utility of enrollment. Contract length was significant and negative, supported by the literature (Rabotyagov & Lin, 2013), indicating that for every unit increase in contract length, individuals perceive their utility negatively affected. Monitoring visit frequency demonstrates a negative coefficient, suggesting that individuals prefer less visitations from program monitors. The estimated median marginal WTA along with confidence intervals and heterogeneity calculations are in Table III-X.

Tenure of ownership in the Stillaguamish Watershed and environmental identity score were both significant, suggesting those who are more ecocentric from the scaled environmental identity score and those who have been in the Stillaguamish Watershed for 0-20 years are more likely to indicate interest in enrolling. Age had a negative coefficient, suggesting that those who are older are less likely to indicate enrollment.

Table III-X: Median Marginal WTA for Programmatic Attributes

Variable	mWTA Median (\$USD/acre)	95% CI (\$USD/acre)	5th-95th Heterogeneity (\$USD/acre)¹
Contract Length (1-year increase)	33.34	21.28 to 49.39	-98.20 to 441.51
Monitoring Visits (1 additional visit)	113.15	57.62 to 191.41	18.61 to 692.02

¹ The distribution of mWTA within the 5th and 95th percentile of the distribution of the standard deviation, representing the spread across all individuals of the population rather than the uncertainty.

From the final interaction model, choice shares were predicted from the estimated coefficients. To demonstrate the relationships between incentives and the differences between labeled alternatives, three scenarios were developed. The first scenario described low financial incentive (\$350 per acre) and high programmatic burdens (contract length of 40 years and 4

monitoring visits). The second scenario described a moderate incentive and burden situation (\$700 per acre, contract length of 10 years, and 2 monitoring visits per year). The final scenario was a high incentive, low burden program offering of \$1,400 per acre, contract length of 5 years, and 1 monitoring visit per year. Under these scenarios, the predicted choice share indicated the model’s predicted respondent choice percentage from the collected sample (Table III-XI).

Table III-XI: WTA Scenario Comparison of Predicted Choice Shares from Respondent Sample

Scenario	Payment (\$USD per acre)	Contract Term (Years)	Monitoring (Visits per year)	Vegetative Enhancement Predicted Share ¹	Conservation Easement Predicted Share ¹	Status Quo Predicted Share ¹
Low Incentive	\$350	40	4	30.7%	7.1%	62.3%
Moderate Incentive	\$700	10	2	39%	9%	52%
High Incentive	\$1,400	5	1	44.5%	10.3%	45.2%

¹Predicted share is the percentage of choice sets the model predicts will be selected under the scenario inputs.

The predicted choice shares illustrate that high incentives, low burdens result in higher program choice predicted shares compared to low incentives, high burdens. The status quo predicted share remains relatively high, indicating the overall perceived burden of program enrollment. The “Conservation Easement” labeled alternative results in a lower predicted choice share compared to the “Vegetative Enhancement” labeled alternative. This indicates that respondents hold an unobserved higher utility loss associated with programmatic framing of conservation easements.

Willingness-to-Pay Model Results

The WTP model creation began as an iterative process, beginning with a MNL baseline model that was then compared to developed mixed logit randomized parameter models. The

baseline program attribute model creation began only considering the attributes presented to the respondents (landowner fee, length of program, funding purpose). After a final structural model was created, interactions with respondent-level data were then tested for significance and model contribution. The final model balances model diagnostics (BIC, AIC, log-likelihood, pseudo-r²) and variable significance. A final model settled after 23 model iterations.

Across the hypothesized interactions and significance, the final mixed logit model retained the structural components of the WTP program design and respondent-level data of environmental identity, large-acreage category, and prior-participation. Other tested variables, including age, multi-acreage categories, residency, geographic location, and tenure of residency were excluded for either loss of respondent data through missing data or preference not to answer, insignificance, or worsening model diagnostics measure outputs. The three core models (MNL, structural mixed logit, interaction mixed logit) demonstrated improvement in model performance in variance explained and lower AIC and BIC measures (Table III-XIII). Key model outputs can be found in Supplemental III-XX through III-XXXVII.

Table III-XIII: Comparison of Key Model Developments for Willingness-to-Pay

Measure	MNL	Program Mixed Logit	Interaction Mixed Logit
ASC (Yes)	-0.203 (0.076)	0.436 (0.191)	0.181 (0.655)
<i>Estimated Standard Deviation</i>	-	4.029 (<0.001)***	3.466 (<0.001)***
Landowner Payment (per acre per year)	-0.169 (<0.001)***	-0.452 (<0.001)***	-0.975 (<0.001)***
<i>Estimated Standard Deviation</i>	-	0.995 (<0.001)***	0.875 (<0.001)***
Duration of Funding Program	0.006 (0.256)	-0.004 (0.800)	-0.004 (0.780)
Purpose – Salmon Habitat Enhancement	0.425 (<0.001)***	1.301 (<0.001) ***	1.260 (<0.001)***
<i>Estimated Standard Deviation</i>	-	1.042 (<0.001)***	0.976 (0.001)**

Purpose – Recreation Improvement	-0.334 (<0.001)***	-0.794 (<0.001)***	-0.778 (<0.001)***
Purpose – Water Quality Improvements	0.409 (<0.001)***	1.016 (<0.001)***	0.988 (<0.001)***
<i>Estimated Standard Deviation</i>	-	2.116 (<0.001)***	2.067 (<0.001)***
Prior Restoration Participation	-	-	0.810 (0.024)**
Environmental Identity Score	-	-	1.419 (<0.001)***
Own 21+ Acres	-	-	-2.306 (0.009)**
1-5 Acres x Payment	-	-	0.695 (<0.001)***
6-10 Acres x Payment	-	-	1.274 (0.001)***
11-20 Acres x Payment	-	-	1.231 (<0.001)***
21+ Acres x Payment	-	-	0.498 (0.277)
Pseudo-r ²	0.073	0.332	0.352
Log Likelihood	-2384.86	-1714.97	-1654.35
AIC	4781.72	3449.95	3342.71
BIC	4819.78	3513.39	3450.56

· $p < 0.1$

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Results of the finalized interaction model suggest that there were significant standard deviations for structural program attributes. Length of program term before another referendum vote had a statistically insignificant coefficient and standard deviation. Overall, these results indicate high preference heterogeneity. This may indicate that additional taxation or restoration activities may be viewed as polarizing in the sample.

As expected, the payment term was negative, suggesting that respondents were less likely to vote “yes” as the amount paid increased. The modeled program purpose variable suggested that individuals typically rank enhancing salmon habitat, improving water quality, and recreation respectively above improving sport fishing with enhancing salmon habitat and improving water quality as positive influences on voting “yes.” Sport fishing, representing recreational fishing, was the implied effects-coded baseline for this model, as such the coefficients are in relation to the grand mean for interpretation. In a difference comparison, the

median marginal WTP for the program purpose being “salmon habitat enhancement” was \$33.92 (CI 95: \$24.10 – \$44.93). Table III-XIV describes purposes median m marginal WTP differences.

Respondent level data indicated that attitudinal factors and acreage size have a statistically significant impact on respondent willingness-to-pay. Based on a scaled environmental identity score, those with higher scores, or score that reflect a more ecocentric attitude, were more likely to consider voting in favor of the referendum when all else is held constant, indicating an association between personal belief and respondent’s willingness to engage in restoration funding. Prior participation in restoration programs also had a positive influence. Large acreage owners, those owning more than 21 acres, resulted in a negative coefficient. This may be related to the additional financial burden large landowners have when charged on a per-acre basis.

Testing acreage categories from 1 to 20 acres against the payment variable highlights a sensitivity to the payment amount compared to those with less than one acre. This result suggested that some small to medium landowners (i.e., 1-20 acres) were more influenced by a change in the payment variable rather than the referendum itself.

Table III-XIV: Median Marginal WTP Across Programmatic Purposes

Programmatic Comparison	Median mWTP (\$USD)	95% CI (\$USD)	5th-95th Heterogeneity (\$USD)¹	Share Positive²
Salmon Habitat Enhancement vs. Sport Fishing Opportunities	33.93	24.10 to 44.93	-36.08 to 297.02	0.83
Water Quality Improvements vs. Sport Fishing Opportunities	27.96	17.72 to 41.10	-105.02 to 343.71	0.71
Recreation Improvements vs. Sport Fishing Opportunities	7.27	1.96 to 14.53	-81.48 to 149.03	0.62

Salmon Habitat Enhancement vs. Recreation Improvement	29.43	21.07 to 39.46	3.00 to 178.95	0.98
Water Quality Improvements vs. Recreation Improvement	21.47	13.36 to 31.95	-32.41 to 202.26	0.80
Salmon Habitat Enhancement vs. Water Quality Improvements	2.72	-3.26 to 9.12	-100.33 to 127.20	0.55

¹ The distribution of mWTP within the 5th and 95th percentile of the distribution.

² The proportion of individual medians above zero.

Total WTP scenarios were developed for each purpose statement and set to ten-year program duration, understanding that program duration has a negligible effect on the model. The median total WTP for a program aimed at funding salmon habitat enhancement lasting 10 years is \$21.65 (95% CI: \$12.75 to \$28.94), whereas the median total WTP for a program aimed at funding sport fishing opportunities lasting 10 years is -\$10.58 (95% CI: -\$24.52 to -\$1.13) (Table III-XV). Using the salmon enhancement 10-year scenario as an example, if the median total WTP is applied to all properties in the Stillaguamish that fit under the survey instrument criteria (187,997.54 acres), the annual payment would be \$4,070,146.74 (95% CI: \$2,396,968.64 to \$5,440,648.81).

Table III-XV: Median Total WTP for 10-Year Policy Purpose Scenarios

10-Year Policy Purpose	Median Total WTP (\$USD)	95% CI (\$USD)	5 th -95 th Heterogeneity (\$USD) ¹	Share Positive ²
Salmon Habitat Enhancement	21.65	12.87 to 28.94	-28.89 to 188.04	0.82
Water Quality Improvement	16.55	7.63 to 25.53	-69.51 to 205.15	0.71
Recreation Improvement	-2.39	-12.57 to 4.51	-98.64 to 60.56	0.46
Sport Fishing Enhancement	-10.58	-24.52 to -1.13	-193.44 to 89.67	0.36

¹ The distribution of mWTP within the 5th and 95th percentile of the distribution.

² The proportion of individual medians above zero.

Pseudo-Policy Scenario Development: Funding Projections and Estimated Restoration-Willing Acres

Willingness-to-Pay Referendum Frontier Curves

Using the results of the WTA and WTP models, hypothetical policy scenarios can be developed to illustrate the possible funding scenarios and the supply of land that would be available for enrollment. These scenarios can indicate how supportive the respondent sample would be of the funding program and how many acres the respondent population would likely be willing to put into the conservation programs.

First, from the WTP scenarios, frontier curves are created to illustrate predicted majority support for referendums across the payment continuum. The calculated frontier curve for the respondent population by purpose indicates that there is no calculated majority support for the purposes of sport fishing opportunities and recreational enhancements. Salmon habitat enhancement purpose frontier intersects with the 50% support line at \$18.62 and water quality improvement purpose frontier intersects with the 50% support line at \$15.23 (Figure XV). These frontier curves indicate that it is unlikely that a referendum framed to support sport fishing opportunities and recreational enhancements would be supported by the respondent sample at any given monetary value.

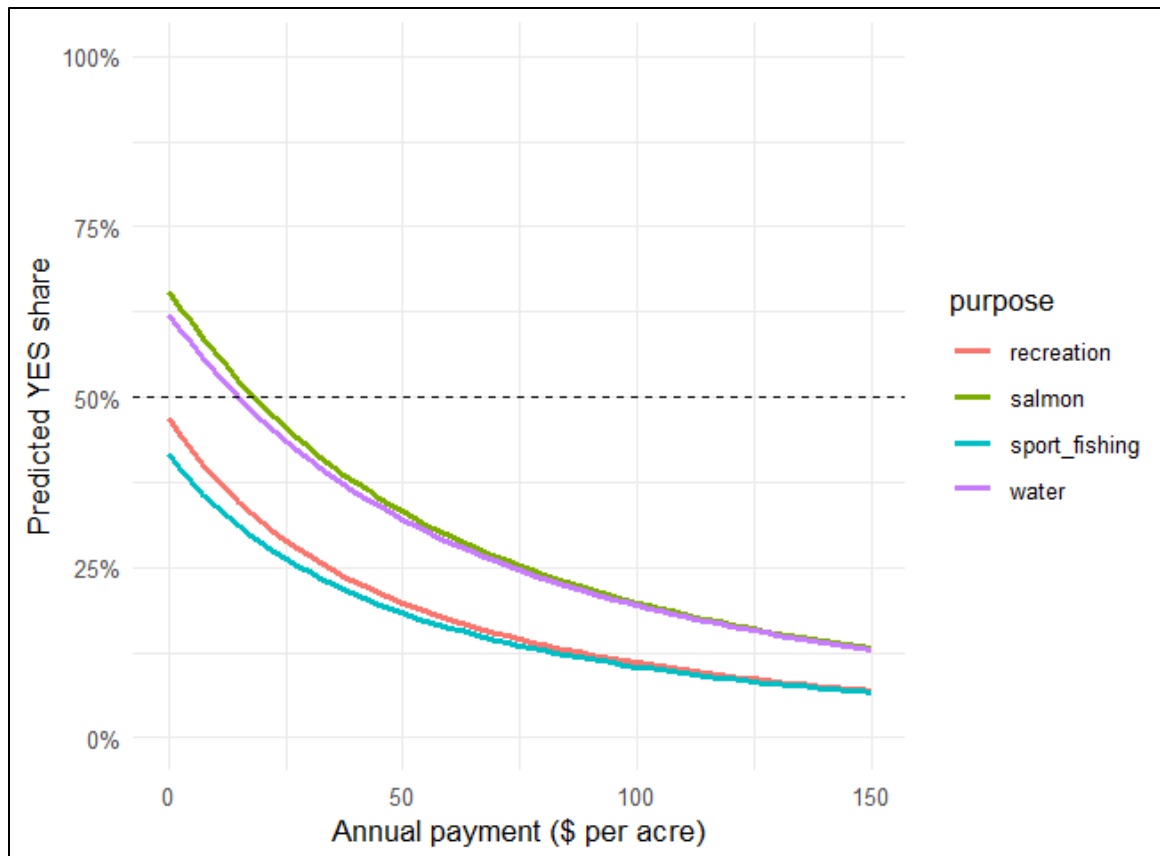


Figure XV: Willingness-to-Pay Frontier Curves by Program Purpose with Expected Majority Support. Dashed line represents 50% of predicted "yes" share of the respondents. Intersection between the purpose frontier curves and the majority support line would indicate a success "pass" of the referendum.

The WTP model indicates that those with larger acreages may not be as willing to support a referendum. To illustrate this change, frontier curves were developed for landowners owning more than 20 acres of land and those who own less than 20 acres of land. The frontier curves indicate that the median WTP is lower, as expected, at the intersects of the 50% support line. In these simulated cases, those owning 20 acres or more of land do not have a frontier curve that intersects the 50% support curve under and referendum purpose (Figure XVI). Those with less than 20 acres have frontier curves that intersect the support line at \$19.92 for salmon habitat enhancement and at \$16.50 for water quality improvements. Recreation and sport fishing opportunities have no frontier curve intersects with the support line. These results

suggest that a different fee system or different incentive system may be needed to encourage those with larger acreage to be willing to support a referendum.

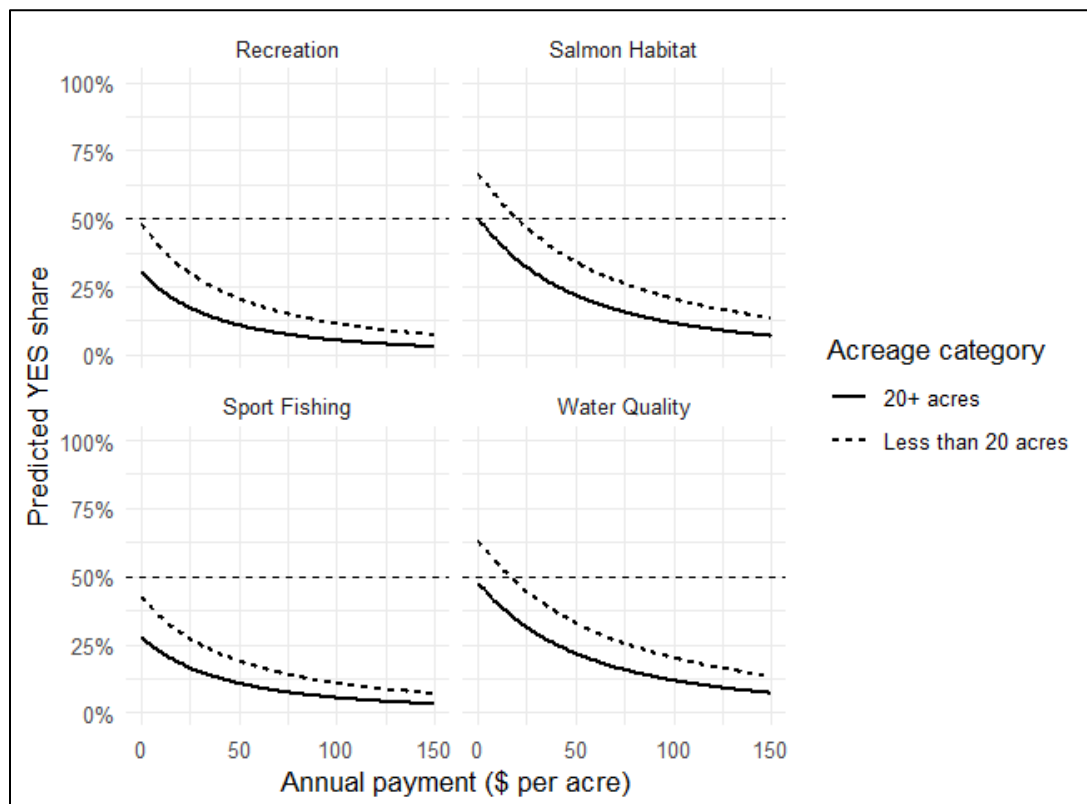


Figure XVI: Willingness-To-Pay Frontier Curves by Program Purpose and Acreage Category with Majority Support Line. Dashed line at 50% represents when a predicted 50% of respondents support the WTP referendum.

Restoration Contract Scenarios, Expected Enrollment, and Expected Costs

To combine the results of the WTP and WTA models, the WTP salmon habitat enhancement scenario is compared against several different WTA modelled contract bundles. To determine the WTP outcome, the taxable area is assumed to be 187,997.54 acres. The eligible taxable area is then multiplied by the continuous range of possible payments per acre of land, using the estimated median frontier curve intersect of \$18.624 to represent estimated politically feasible taxes. For the WTA, four different contract bundles are developed (Table III-XVII). The number of estimated funded acres are then calculated through the estimated revenue from the WTP payment range for each scenario. The estimated “interested” acres, or

acres that the WTA model estimates from respondent level data as respondent willing-to-enroll acres, are then compared against the funded constrained acre curve.

Table III-XVII: Pseudo-Policy WTA Program Scenario Attribute Levels

Scenario	Payment to Landowner (\$USD per acre per year)	Contract Duration (years)	Monitoring Frequency (visits per year)
Low Payment 40-year Contract	350	40	4
Moderate Payment 10- year Contract	700	10	2
High Payment 20-year Contract	1,050	20	2
Maximum Payment 5-year Contract	1,400	5	1

The resulting scenario outputs suggest that the largest number of acres can be restored under a low payment – 40-year contract WTA contract bundle, with 10,002 acres at the \$18.62 frontier price. The moderate payment – 10-year contract would restore 5,001 acres, the high payment – 20-year contract would restore 3,334 acres, and the maximum payment – 5-year contract would restore 2,501 acres, all at the \$18.62 frontier price (Figure XVII). These show the contrast between contract specifications and actionable restoration on the landscape.

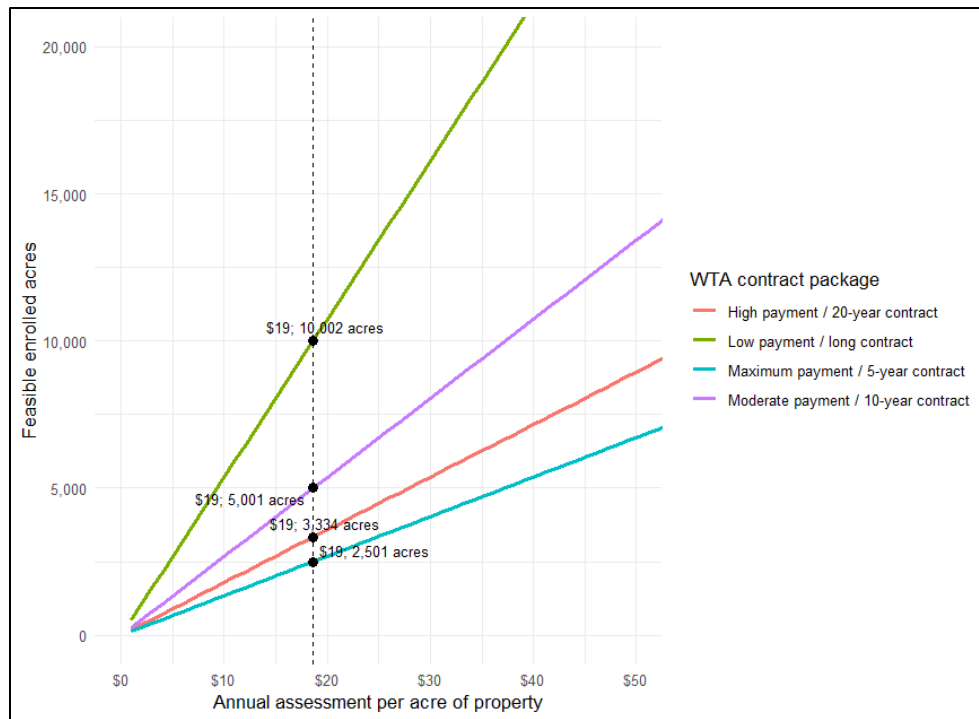


Figure XVII: Number of Financially Viable Acres by WTA Program Package with Majority Support Line for WTP Scenario. Dashed line represents the majority support value from the WTP frontier curve analysis of \$18.62 for funding salmon habitat enhancement with a program length of 5 years.

From the different WTA contract scenarios, the number of expected enrolled acres is developed through calculating the conditional share of acres each respondent would enroll into a program, representing a share of their total acreage. The expected enrolled acres represents the supply of acres that are available in the watershed. Coupled with the WTP funding curve, the funding constrained acres are the total number of acres enrolled in a given year out of the expected enrollment (Figure XVIII).

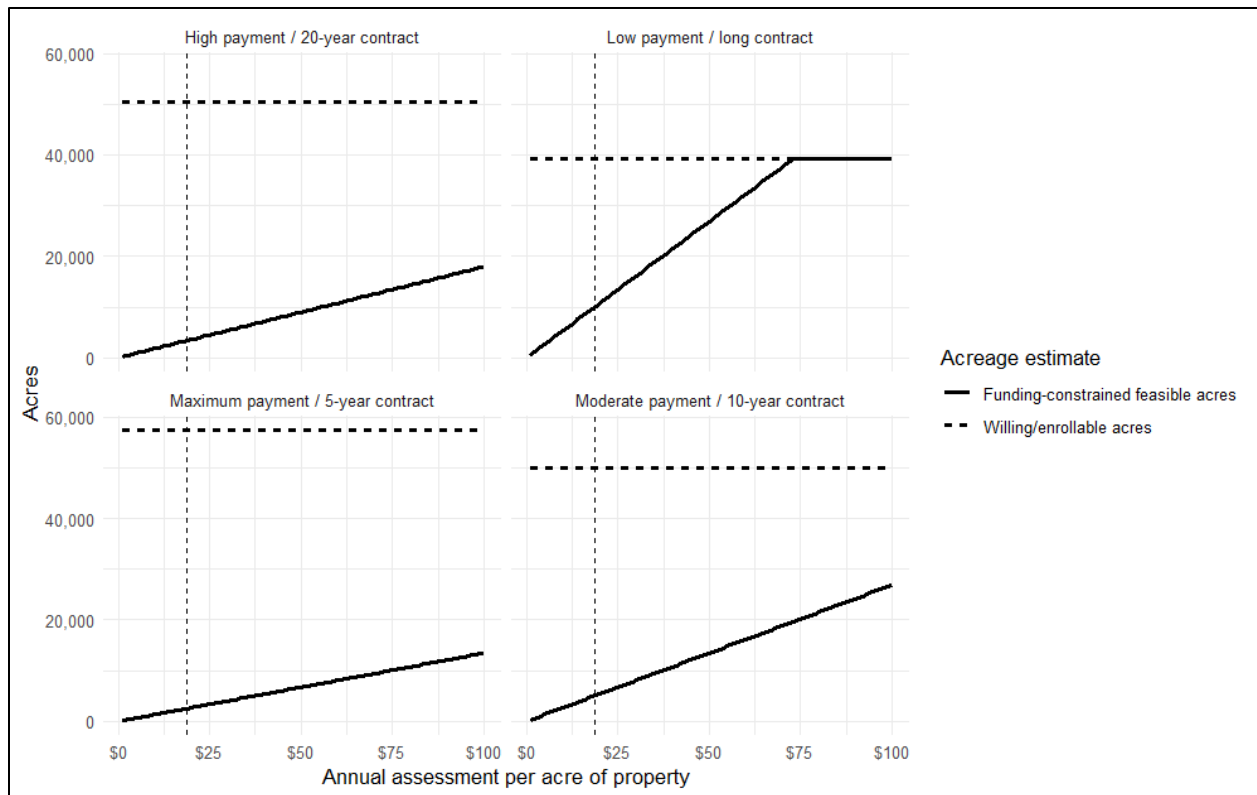


Figure XVIII: Financially Constrained and Enrollment Interested Acres across WTA Program Scenarios Compared under WTP Scenario. Vertical dashed line represents the majority support value from the WTP frontier curve analysis of \$18.62 for funding salmon habitat enhancement with a program length of 5 years.

Under the project WTP and WTA scenarios, at the WTP frontier amount, all scenarios result in less enrolled acres than enrollable acres each year, indicating that there is more willing-acre supply that politically feasible funding in this modeled scenario (Figure XVIII). In the example of the low payment–long contract scenario, there would be an expected 39,294 acres that would be willing-to-accept the given contract, resulting in an annual total cost of \$13,752,729. However, at the annual WTP frontier of \$18.62 per acre, total annual revenues are \$3,500,822, leaving an annual \$10,251,958 shortfall in programmatic funding should all acreages be enrolled in one contract cycle per year (Table III-XVIII).

Table III-XVIII: Pseudo-Policy Scenarios with Expected Acreage Enrollment, Expected Annual Costs, and Financial Limitation Differences

Scenario	Expected Willing Acres	Financially Constrained Enrollment (Acres)	Expected Annual Total Cost	Annual Funding Gap at Frontier WTP
Low Payment 40- year Contract	39,294	10,002	\$13,752,779	-\$10,251,958
Moderate Payment 10-year Contract	50,070	5,001	\$35,048,786	-\$31,547,964
High Payment 20- year Contract	50,563	3,334	\$53,091,553	-\$49,590,731
Maximum Payment 5-year Contract	57,322	2,501	\$80,250,702	-\$76,749,881

More favorable programs also result in more acres that would be willing-to-accept restoration program. The low payment–long contract scenario as the expected 39,294 acres that would be willing-to-accept a restoration program contract compared to the maximum payment–short contract scenario with 57,322 acres. The difference of roughly 18,028 acres illustrates how contracts that are perceived as more beneficial to the landowner results in more total acreages that could be encouraged to undergo restoration.

However, restoration goals in the Stillaguamish Watershed are for 8,000 acres of riparian habitat by 2055 (Stillaguamish Implementation Review Committee, 2005). While it is unclear how many of these acres would be riparian, these scenarios do significantly advance the 8,000-acre goal. The low payment-long contract scenario would enroll more than the restoration target, while high payment scenarios would still enroll thousands of acres for restoration.

Discussion

Considerations from the Willingness-to-Accept

The WTA model indicates that there are significant unobserved differences in how individuals view the labeled “Vegetative Enhancement” and “Conservation Easement” programs. The conservation easement alternative is less favored than the vegetative

enhancement. There could be elements that were not tested in this model of trust, autonomy, and relationship to the land that could explain this variation. Further, for simplicity, respondent level data was only tested against the overall alternative specific constant rather than the individual alternative specific constants of the labeled options. This research could be expanded by testing against each labeled option. Additionally, the choice sets did not randomize which option was presented first, allowing for potential bias.

Nevertheless, the differences in labeled alternative choice selection suggests a deeper impact on how programs are framed to respondents and how respondents engage with instruments with these programs. One clear finding is that vegetative enhancement framings for conservation programs are preferred over conservation easements. Managers and decision-makers should be advised to incorporate this finding into program development.

Allowing for estimated standard deviation on core program attributes significantly improved the model performance, suggesting there is significant heterogeneity in the responses received. Added respondent-level data did decrease the amount of variance explained by the estimated error; however, it appears there are other unobserved variables that could be added to the model that may explain some of this error.

Qualitative answers, where landowners were allowed to write-in during portions of the survey, provide some insight into the heterogeneity in responses. One respondent included a response that they would prefer a longer contract length, as it would ensure that their land would be preserved for their family. This is contrary to the modeled negative coefficient on contract length, supporting the statistically significant estimated standard deviation. To this end, decision makers should be advised to allow for flexibility in program design with landowners,

potentially crafting individual programs that fit each landowner's needs. To a methodological point, researchers may want to include areas for respondents to explain their answers and then report on those findings, allowing for future studies to incorporate aspects of qualitative findings into models for testing.

Significant variables in age and tenure may be the most applicable for program managers regarding where to target energy into advertising such conservation programs. From the model, younger landowners and those who have been on the landscape between 0 and 20 years are more likely to indicate that they would enroll into a group. Additionally, managers will need to manage the tradeoffs that contract lengths and monitoring frequency incur to landowners, requiring more compensation for the perceived lost utility.

Barriers to Engage in Willingness-to-Accept

If a respondent ever selected "status quo", the respondent would be prompted to state their rationale after all choice sets. Out of the 672 responses, the top reasons were respondents not wanting monitoring activity on their land, not believing that their land would be eligible for the programs, and not believing that their land needed restoration with 181, 188, and 195 responses respectively. The least selected options were concerns about restoration programs decreasing the respondent's income from their land or concerns about restoration activities resulting in an increased risk of erosion or flooding on their land.

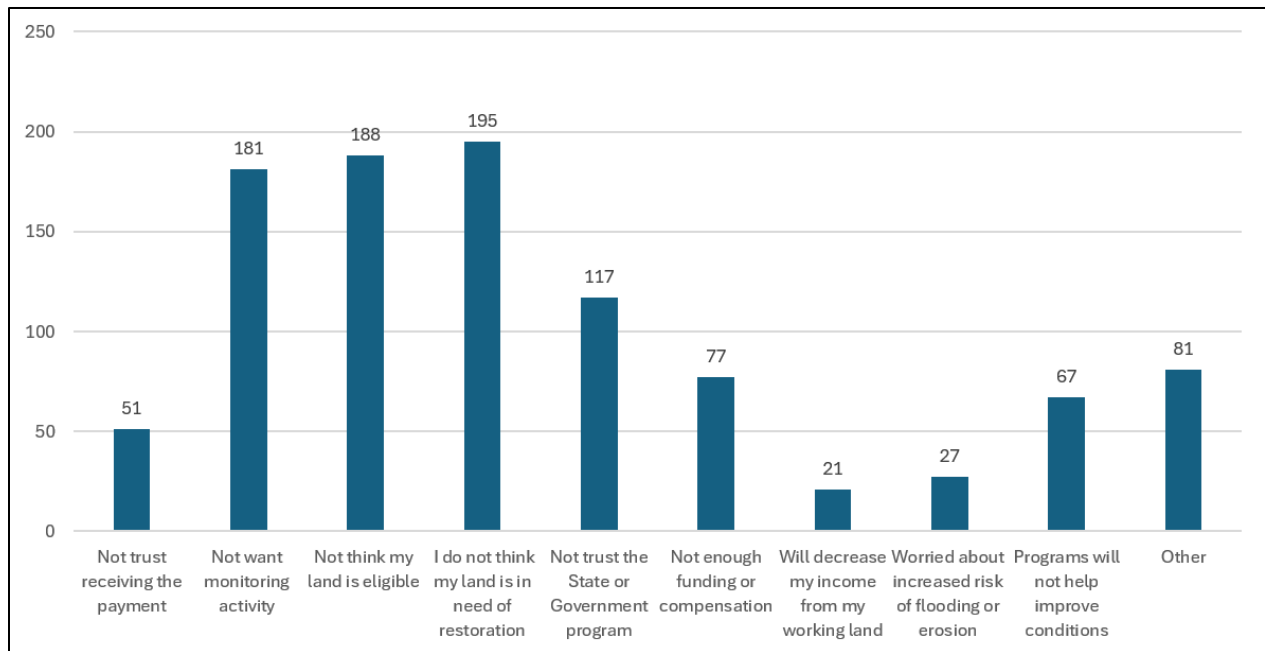


Figure XIX: Willingness-to-Accept Respondent Rationale for Selecting "Status Quo" during Choice Tasks (n=672)

Exclude Variables in Willingness-to-Accept Model

Excluded variables in the final interaction mixed logit provide some additional insight (Table III-XII). HUC level-10 watershed regions were aggregated into larger regions: Stanwood, Pilchuck, Arlington, north Fork, and South Fork. When tested, the Pilchuck subwatershed tested as statistically significant with a negative coefficient. When tested on its own, the coefficient and significance remained, suggesting that respondents in the Pilchuck subwatershed were less likely to select one of the conservation program choices compared to all other subwatersheds. However, when the environmental identity score was introduced into the model, the statistical significance of the Pilchuck subwatershed fell into insignificant levels. This indicates that the environmental identity score absorbed, or better explained, the variance explained by the Pilchuck subwatershed, suggesting that the spatial difference may have been more related to attitudinal beliefs.

Prior participation in restoration was also tested in the model. However, unexpectedly, prior participation in restoration did not produce a significant result. Similarly, riparian status did not produce a significant result. Acreage bins were tested resulting in a statistically significant positive coefficient of the 11-20 acreage bin, using less than half an acre as the reference group. When tested by itself, 11-20 acres remain statistically significant and positive. However, when incorporating the longevity variable to the model, the 11-20 acreage bin lost its significance, suggesting a potential relationship between acreage size and ownership length in the Stillaguamish Watershed.

Table III-XII: WTA Hypothesis Table Post-Model Creation Results

Variable	Hypothesized Sign	Interaction Model Estimate
Willingness-to-Accept Model		
ASC – Vegetative Enhancement	-	-
ASC – Conservation Easement	-	-
Payment to Landowner	+	+
Contract Length	-	-
Monitoring Frequency	-	-
Environmental Identity Score	+	+
Prior Conservation Participation	+	~
Subwatershed Location	~	~ ¹
Riparian Status	~	~
Acreage	+	~
Age	+/-	-

+ denotes a positive and statistically significant sign.

- denotes a negative and statistically significant sign.

~ for hypothesized sign denotes an unsure coefficient but expected significance; for model estimate denotes insignificance.

¹ Subwatershed location was expected to be significant to reflect the political leanings of different communities in the watershed. However, this result was not found in the developed model.

Considerations from the Willingness-to-Pay

For the WTP scenarios, the model suggests that there are attitudinal drivers behind individuals selecting “yes” in scenarios that are captured in the environmental identity score for each respondent. The addition of respondent level data (i.e., age, acreage, ownership tenure,

location) did explain some of the heterogeneity found in the WTP model through the estimated standard deviation of programmatic attributes. However, additional respondent level data added minimally to variance explained. These results suggest there are additional variables that were not considered in this analysis that could improve the model and its prediction power.

Generally, framing and purpose of the funding mechanism is a significant driver in how respondents decided on their vote selection. Actions that may be perceived as improving environmental conditions, such as salmon habitat and water quality enhancements, appear to have a more positive association with voting “yes” compared to more recreational-oriented objectives. These associations may indicate that respondents are more supportive of actions that may have a more direct benefit to their lands compared to actions that may be perceived as beneficial to others (i.e., sports fishing).

Selected rationale for why respondents selected “no” on the choice referendum suggests that landowners are currently burdened with other taxes and are experiencing tax-fatigue (59.0%). Nevertheless, other rationale associated with the burden of additional financial stress, such as the referendum payment being too high (31.9%) and believing a by-acreage system is unfair (28.5%), are lower than the perceived tax-fatigue. Additionally, a small portion of respondents believed that there does not need to be funding for restoration in the Stillaguamish watershed (8.7%), suggesting that individuals may support or believe there does need to be a funding mechanism, just not in the form of an additional tax on landowners. Another barrier aspect is trust, with 39.0% of WTP respondents selecting not trusting the government with their money as part of their rationale. This may suggest that some landowners may be more receptive to a third-party handling restoration compared to state entities.

The high heterogeneity in the alternative specific constant for a “yes” vote suggests that respondents who typically vote “yes” once will vote “yes” again and vice versa for voting “no”. For the data and model, there may be some structural biases from the status quo keepers within the respondent group.

Barriers to Engage in Willingness-to-Pay

If a respondent ever selected “no” on a choice task, they were presented with a question to state their rationale. Out of the 701 responses, 414 selected the option “I already pay too much in various taxes,” being the most common rationale for voting “no” on a task choice. The least common selected option was “I do not think there is a need for funding restoration in the Stillaguamish Watershed” with 61 responses.

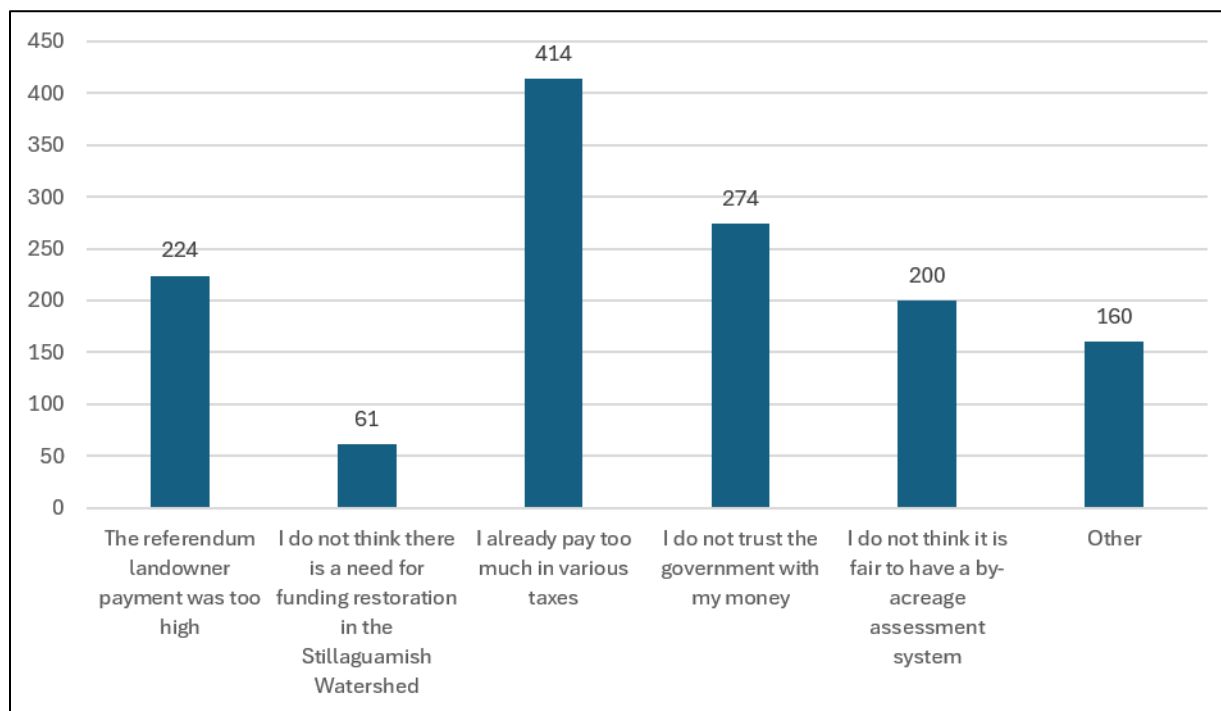


Figure XX: Willingness-to-Pay Respondents Rationale for Voting “No” on Referendum (n=701)

Respondents were additionally asked if they would be willing to donate to support restoration in the watershed. Generally, respondents were unsure (39.6%) or would not (31.5%)

donate to support restoration in the watershed. Those that would (20.9%) are the smallest group, less than the number of times respondents typically voted “yes” across the referendum choices (30.3%).

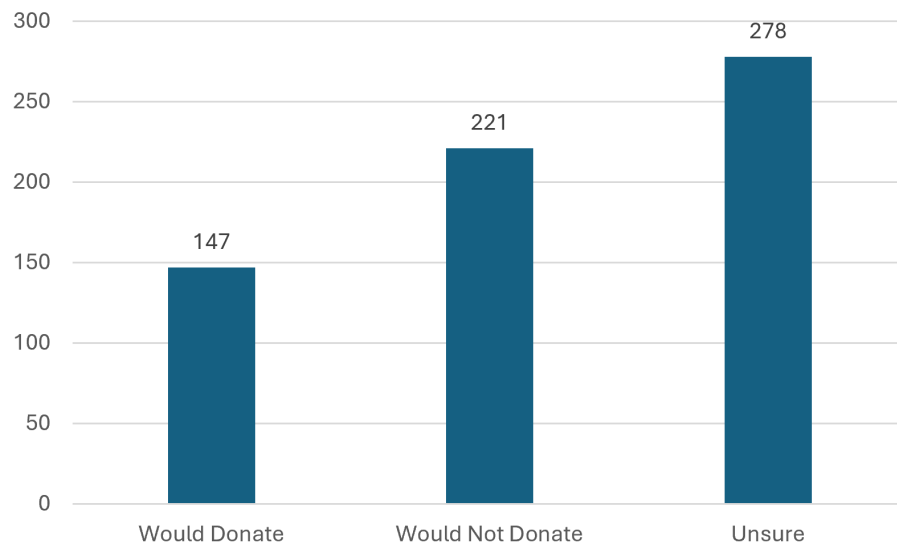


Figure XXI: Willingness-to-Pay Respondents on Willingness-to-Donate for Watershed Restoration (n=701)

Excluded Variables in Willingness-to-Pay Model

Excluded variables in the final interaction mixed logit do provide insight into the model development (Table III-XVI). To address the spatial hypothesis, HUC level-10 watershed regions were aggregated into larger regions: Stanwood, Pilchuck, Arlington, North Fork, South Fork. These added categories to the finalized structural model as the first interaction testing resulted in no statistically significant coefficients ($p \geq 0.05$) resulting in failing to reject the null hypothesis. Categorizing the watershed regions to Main Stem, North Fork, and South Fork also resulted in statistically insignificant coefficients ($p \geq 0.05$). Whether the respondent characterized their property as riparian was added as a binary category to the model and resulted in statistically insignificant results ($p \geq 0.05$). These results suggest there is no evidence to support spatial factors that influence WTP from this study sample.

To test demographic hypotheses, age, longevity in watershed, acreage size, and residency were added to the model individually. The model iteration included the scaled environmental identity score when the demographic hypotheses were tested. Age was converted to a continuous variable to avoid added parameter penalization, assuming the mid-value of the age category, then centered. Adding age results in a negative, statistically significant coefficient but did not significantly add to the model. This does suggest that older individuals are less likely to be in favor of the referendum when all else is constant. Since the model fit did not significantly improve, the variable was removed from further analysis.

Next, place attachment was added to the model in the term of longevity to the watershed. Longevity was collected as a categoric variable in the bins of less than a year, 1-5 years, 6-10 years, 11-20 years, 21 and more, or not a resident. For model development, not a resident was considered the reference. The longest tenure resident category was the only statistically significant category against the reference with a negative coefficient. To understand if this is a longevity effect or a resident effect, the longevity variable was recoded into two binary variables: resident versus non-resident and long-term resident. The resident variable was statistically significant with a negative coefficient suggesting that non-residents are more likely to support the referendum compared to residents. However, the variable addition did not improve model fit measures in a significant manner and was removed from the model. The long-term resident category resulted in a statistically significant, negative coefficient, suggesting that long-term residents are less likely to support the referendum compared to all other landowners. However, similarly, the variable did not improve model fit measures in a meaningful way.

Table III-XVI: WTP Hypothesis Table Post-Model Creation Results

Variable	Hypothesized Sign	Model Estimate
Willingness-to-Pay Model		
ASC – Yes Vote	-	-
Payment from Landowner	-	-
Program Length	-	~
Funding Purpose	~	Mixed ¹
Environmental Identity Score	+	+
Prior Conservation Participation	+	+
Subwatershed Location	~	~ ²
Riparian Status	~	~ ²
Acreage	-	_ ³
Age	+	~ ⁴

+ denotes a positive and statistically significant sign.

- denotes a negative and statistically significant sign.

~ for hypothesized sign denotes an unsure coefficient but expected significance; for model estimate denotes insignificance.

¹ Funding purpose was statistically significant. The ranking of these variables make it difficult to express in positive or negative form. From positive to negative coefficients: salmon habitat enhancement, water quality improvements, recreation enhancement, sport fishing opportunities.

² Subwatershed location was expected to be significant to reflect the political leanings of different communities in the watershed. However, this result was not found in the developed model.

³ Only large landowners (21+ acres) reported a coefficient on the ASC with other acreage categories significant on their interaction with the payment variable. A continuous acreage variable may have resulted in a different output.

⁴ The age variable did produce a statistically significant and negative result, counter to much of the literature. However, the variable did not meaningfully add to the model and was dropped for the final model.

Pseudo-Policy Scenarios Significance

From the policy scenarios, referendum framing appears to be a key component in developing a fee system that would be supported by landowners. By running the model to determine a majority support intersect, results find that framings around salmon habitat enhancement and water quality are the only ones with a positive WTP at an estimated 50% support. While the framings presented in the WTP instrument were limited, these results highlight the need for further investigation into how respondents view and weigh framings differently. The estimated heterogeneity on purpose framings do suggest that some landowners would be more willing to pay for recreational purposes; however, the respondents here were more supportive of environmentally coded purposes. This may be reflective of those who are willing to engage in surveys about watershed restoration. Such motivations may provide insight

into how decision-makers can develop fee systems or other types of programs and garner the most support.

This study only considers a per-acre per-year fee system through the WTP instrument. In part, results indicate that larger landowners, especially those greater than 20 acres, are less likely to vote “yes” on the WTP instrument. The pseudo-policy simulation indicated that these larger landowners would not reach a majority 50% support on any positive fee amount for any framing. Selected barriers to the WTP also indicate that roughly 28% of WTP respondents indicated that the by-acre assessment system seemed unfair. Other researchers incorporated questions that gauge respondents’ support for different funding mechanism, including, for example, taxes on different items and added fees to permits in the case of gray wolf conservation (van Eeden et al., 2021). Future studies could expand on split-samples that offer different funding mechanisms to support decision-making applications.

Policy scenarios indicate that, under certain conditions, supply of land to restore is greater than the total expected revenue in the most favorable WTP scenario. Nevertheless, a program could be modeled under these conditions that would match the modeled WTP frontier. Further, for managers, WTA scenarios could be modeled to create contract bundles that meet, or exceed, certain restoration goals. However, how those programs are funded may be limited to the willingness-to-pay by the regional population.

Future work could expand by matching WTP programmatic designs and WTA programmatic designs to allow for policy scenarios more akin to one another and comparable. Further WTP and WTA outcomes could help provide the basis of future studies that project WTP and WTA scenarios into the future, incorporating discounting and restoration degradation.

Longitudinal studies of watersheds could test how WTP and WTA outcomes are affected by the passage of time and time-series variables, such as economic conditions.

Both WTA and WTP models are strongly influenced by the developed environmental identity score, suggesting that attitudinal variables may be more influential than typical demographic variables. These variables are difficult to observe by program managers and policy makers without systematic surveying over time. Future work in conservation WTP and WTA should consider how to incorporate attitudinal factors and how to identify observable proxies.

Overall, these findings are limited to the Stillaguamish Watershed and may not be reflective of other nearby communities or similar watersheds. Further work on other watersheds may illustrate if these trends are similar to residential landowners.

Management Implications

The findings reinforce the notion that landowners can be incentivized to participate in conservation. Managers and decision-makers can incentive all landowners to participate in conservation programs through higher payments, shorter contracts, and less monitoring. However, focused marketing efforts may be difficult as landowner characteristics that contributed to enrollment probability are hard to observe on the landscape.

The work also supports that landowners are willing-to-pay for restoration. Generally, managers and policy-makers can garner more support through funding mechanisms that have less financial impact on landowners. In this specific watershed, the findings do support that landowners are supportive salmon habitat restoration and water quality improvements.

The pseudo-policy simulations highlight that there is a mismatch between the number of acres landowners are willing to enroll and the amount of revenue that can be generated in the

watershed. However, the findings do demonstrate that collective action can generate more support than individual action. The pseudo-policy simulations demonstrated that a referendum style mechanism can force the entire population to fund restoration rather than just willing individuals through the democratic tyranny of the majority (Tocqueville 2000).

While there is a mismatch between generated revenue and number of acres that could be enrolled, the tyranny of the majority could still meet restoration goals. For the Stillaguamish, the goal by 2055 is to restore 8,000 acres. The policy simulations demonstrate that majority-vote referendums result in enough funding to support upwards of 10,000 acres of restoration at the lowest level of payments presented to landowners, with a number of acres still likely to want to enroll.

Limitations

One expected limitation of this study was a limited response rate. However, the response rate came to roughly 13%, far greater than the expected 5-7%, resulting in 1,373 usable responses. The randomization of respondents to the WTA and WTP survey tools gave 672 and 701 respondents respectively. With a lengthy survey and the expected hesitant population, these results are promising for further survey work and possible expansion of survey tools. However, more favorable response rates could allow for additional variable inclusion and more complex modeling.

As is common with stated-preference studies, choice experiments face issues with hypothetical bias, consequentiality, and non-attendance. The survey design addresses hypothetical bias by employing cheap talk prior to the task choices to encourage respondents to take the choices seriously (Cummings & Taylor, 1999). The study addressed consequentiality by

ensuring that the program is realistic and familiar with the potential respondents, using payment vehicles and program types that are already used in the region. Each choice experiment includes the follow-up of certainty and rationale for status quo to further check for robustness (Carson & Groves, 2007). Additionally, respondents may not always acknowledge or process every attribute presented to them in a choice experiment, producing attribute non-attendance bias (Scarpa et al., 2009).

To further understand non-response bias, response rate by subwatershed was reviewed. Response rate varied significantly, ranging from 0% to 54.3%. Some 0% response rates were expected from subwatersheds, as the survey was not weighted by location, so subwatersheds such as North Fork Canyon Creek, Headwaters North Fork, Upper Deer Creek, and Headwaters South Fork did not receive a survey. However, other subwatersheds had unexpectedly low response rates, such as Boulder Creek (0%), Canyon Creek (4.7%), Jim Creek (6.3%), and Squire Creek (8.1%). Others had unexpectedly high response rates, such as Upper South Fork (50.0%), Upper Pilchuck Creek (53.9%), and Lower Deer Creek (54.2%). The subwatersheds that received the largest number of surveys were near the overall response rate: Lower South Fork (10.6%), Stillaguamish River – Frontal Port Susan (16.0%), and Armstrong Creek (18.9%). The low and high response rates in other subwatersheds may be due to low sample size; however, Jim Creek and Canyon Creek had several hundred surveys mailed, 300 and 411 respectively, to the subwatershed with some of the lowest ranking response rates. See Supplemental III-XXXVIII for a map of response rates across the watershed.

The split-sample WTA and WTP are not directly comparable to determine if WTP is equivalent to WTA to address the WTA-WTP gap literature. Rather, the split sample allows for

the construction of policy mechanisms to compare willingness to provide local funding from landowners to address the number of acres landowners are willing to put into restoration activities. This creates a pseudo-budget model for policy action that can be represented at different funding levels and differing program attributes. These scenarios and respondent-based and extrapolated to consider the watershed in its entirety. A combined sample could better empower these findings and solidify extrapolation.

Without a pilot survey, the instruments do not have the optimal D-efficient designs that would help negate issues with the sample size. However, naïve designs are known to not be as effective as other designs. Using a near-Bayesian design should increase efficiency and mitigate against the small sample size (Ferrini & Scarpa, 2007).

The models developed could be improved through survey designs that include more continuous variables that were not employed here, such as total acreage and age. Tracking individual surveys to the parcel level can provide more continuous spatial data that could allow spatial correlation analysis or examinations of proximity to certain natural features. Location data could further introduce possible environmental effects, such as pollution, regional habitat degradation, and other available socio-economic conditions.

Conclusions

The choice experiment presented demonstrates how split sample WTA and WTP can provide meaningful data to program managers and policymakers. Programmatic framing for both willingness-to-pay mechanisms and willingness-to-accept programs are influential to respondent decision-making. Attitudinal factors, though unobservable through most public data, are important predictors of respondent choices, suggesting that program development

includes attitudinal research within the target area. Joint creation of WTP and WTA models can help tailor mechanisms and programs to achieve funding and enrollment goals for agencies. However, models are limited to the respondent data and to the hypothetical bias of research studies.

The results presented here demonstrate that local communities can support local restoration. While local funding may not provide for all the acres that could be enrolled, local funding can make significant headway towards restoration goals, in some cases could even meet restoration goals. To this, tailored conservation programs that meet the needs of landowners and community specific funding mechanisms are required and should be developed in context of the local community.

This research extends the discrete choice literature by highlighting joint WTA and WTP studies to develop management applicable findings. This study further indicates that more research is needed in developing attitudinal proxies and developing more rigorous discrete choice experiments in the natural resource field. Additionally, the work supports the residential WTP and WTA literature on restoration and conservation, adding to the literature beyond that of agricultural and forest landowners.

References

- Armstrong, A., & Stedman, R. C. (2012). Landowner willingness to implement riparian buffers in a transitioning watershed. *Landscape and Urban Planning*, 105(3), 211–220.
<https://doi.org/10.1016/j.landurbplan.2011.12.011>
- Bell, K. P., Huppert, D., & Johnson, R. L. (2003). Willingness to Pay for Local Coho Salmon Enhancement in Coastal Communities. *Marine Resource Economics*, 18(1), 15–31.
<https://doi.org/10.1086/mre.18.1.42629381>
- Carson, R., & Groves, T. (2007). Incentive and informational properties of preference questions. *Environmental & Resource Economics*, 37(1), 181–210.
- ChoiceMetrics. (2025). *Ngene* [Computer software].
- Cochran, W. (1977). *Sampling Techniques* (3rd ed.). John Wiley & Sons, Inc.
- Coleman, S., Hurley, S., Rizzo, D., Koliba, C., & Zia, A. (2018). From the household to watershed: A cross-scale analysis of residential intention to adopt green stormwater infrastructure. *Landscape and Urban Planning*, 180, 195–206.
<https://doi.org/10.1016/j.landurbplan.2018.09.005>
- Comte, L., Olden, J. D., Littlefield, C., Dickson, B. G., Zablocki, J., & Moryc, D. (2026). National assessment of river protection in the United States. *Nature Sustainability*.
<https://doi.org/10.1038/s41893-025-01693-8>
- Cummings, R. G., & Taylor, L. O. (1999). Unbiased Value Estimates for Environmental Goods: A Cheap Talk Design for the Contingent Valuation Method. *The American Economic Review*, 89(3), 649–665.
- Diffendorfer, J. E., Loomis, J. B., Ries, L., Oberhauser, K., Lopez-Hoffman, L., Semmens, D., Semmens, B., Butterfield, B., Bagstad, K., Goldstein, J., Wiederholt, R., Mattsson, B., & Thogmartin, W. E. (2014). National Valuation of Monarch Butterflies Indicates an Untapped Potential for Incentive-Based Conservation. *Conservation Letters*, 7(3), 253–262. <https://doi.org/10.1111/conl.12065>
- Dillman, D., Smyth, J., & Christian, L. (2014). *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method* (4th ed.). John Wiley & Sons, Inc.
- Ferrini, S., & Scarpa, R. (2007). Designs with *a priori* information for nonmarket valuation with choice experiments: A Monte Carlo study. *Journal of Environmental Economics and Management*, 53(3), 342–363. <https://doi.org/10.1016/j.jeem.2006.10.007>
- Greiner, R. (2023). Examining Participation in and Supply of Private Land for Voluntary Conservation in Australia’s Tropical Savannas: A Discrete-Continuous Choice Experiment. *Land*, 12(7). <https://doi.org/10.3390/land12071310>
- Halton, J. H. (1960). On the efficiency of certain quasi-random sequences of points in evaluating multi-dimensional integrals. *Numerische Mathematik*, 2, 84–90.
- Hensher, D., Rose, J., & Greene. (2015). *Applied Choice Analysis* (Second Edition). Cambridge University Press. <https://doi.org/10.1017/CBO9781216136232>

- Hess, S., & Palma, D. (2019). *Apollo: A flexible, powerful and customisable freeware package for choice model estimation and application (Version 0.3.8). *Journal of Choice Modelling*, 32(100170). <https://doi.org/10.1016/j.jocm.2019.100170>
- Kim, S.-I., & Haab, T. C. (2009). Temporal insensitivity of willingness to pay and implied discount rates. *Resource and Energy Economics*, 31(2), 89–102. <https://doi.org/10.1016/j.reseneeco.2008.09.006>
- Knoot, T. G., Schulte, L. A., & Rickenbach, M. (2010). Oak Conservation and Restoration on Private Forestlands: Negotiating a Social-Ecological Landscape. *Environmental Management*, 45(1), 155–164. <https://doi.org/10.1007/s00267-009-9404-7>
- LeVert, M., Stevens, T., & Kittredge, D. (2009). Willingness-to-sell conservation easements: A case study. *Journal of Forest Economics*, 15(4), 261–275. <https://doi.org/10.1016/j.jfe.2009.02.001>
- Li, L., & Ando, A. W. (2023). Early Exposure to Nature and Willingness to Pay for It: The Value of Tallgrass Prairie Grassland Restoration. *Land Economics*, 99(4), 509–527. <https://doi.org/10.3368/le.99.4.070822-0054R>
- Lizin, S., Brouwer, R., Liekens, I., & Broeckx, S. (2016). Accounting for substitution and spatial heterogeneity in a labelled choice experiment. *Journal of Environmental Management*, 181, 289–297. <https://doi.org/10.1016/j.jenvman.2016.06.038>
- Luther, Z. R., Swinton, S. M., & Deynze, B. V. (2022). Potential Supply of Midwest Cropland for Conversion to In-Field Prairie Strips. *Land Economics*, 98(2), 274–291. <https://doi.org/10.3368/le.98.2.082020-0129R1>
- Ma, S., Swinton, S., Lupi, F., & Jolejole-Foreman, C. (2012). Farmers' Willingness to Participate in Payment-for-Environmental-Services Programmes. *Journal of Agricultural Economics*, 63(3), 604–626. <https://doi.org/10.1111/j.1477-9552.2012.00358.x>
- Ma, Z., Butler, B., Kittredge, D., & Catanzaro, P. (2012). Factors Associated with Landowner Involvement in Forest Conservation Programs in the U.S.: Implications for Policy Design and Outreach. *Land Use Policy*, 29(1), 53–61. <https://doi.org/https://doi.org/10.1016/j.landusepol.2011.05.004>
- Montgomery, C. A., & Helvoigt, T. L. (2006). Changes in attitudes about importance of and willingness to pay for salmon recovery in Oregon. *Journal of Environmental Management*, 78(4), 330–340. <https://doi.org/10.1016/j.jenvman.2005.05.002>
- Mueller, J. M. (2014). Estimating willingness to pay for watershed restoration in Flagstaff, Arizona using dichotomous-choice contingent valuation. *Forestry: An International Journal of Forest Research*, 87(2), 327–333. <https://doi.org/10.1093/forestry/cpt035>
- Mueller, J. M., Springer, A. E., & Lima, R. E. (2018). Willingness to pay for forest restoration as a function of proximity and viewshed. *Landscape and Urban Planning*, 175, 23–33. <https://doi.org/10.1016/j.landurbplan.2018.03.006>

- Mueller, J. M., Swaffar, W., Nielsen, E. A., Springer, A. E., & Lopez, S. M. (2013). Estimating the value of watershed services following forest restoration. *Water Resources Research*, 49(4), 1773–1781. <https://doi.org/10.1002/wrcr.20163>
- Naughton, H. T., Houghton, K. A., Raile, E. D., Shanahan, E. A., & Wallner, M. P. (2019). How much are US households prepared to pay to manage and protect whitebark pine (*Pinus albicaulis* Engelm.)? *Forestry: An International Journal of Forest Research*, 92(1), 52–61. <https://doi.org/10.1093/forestry/cpy030>
- Nielsen-Pincus, M., Sussman, P., Bennett, D. E., Gosnell, H., & Parker, R. (2017). The Influence of Place on the Willingness to Pay for Ecosystem Services. *Society & Natural Resources*, 30(12), 1423–1441. <https://doi.org/10.1080/08941920.2017.1347976>
- Norwest Indian Fisheries Commission. (2016). 2016 State of Our Watersheds: A Report by the Treaty Tribes in Western Washington. Northwest Indian Fisheries Commission. Olympia, WA. <https://nwifc.org/publications/state-of-our-watersheds/>
- Oluoch, S., Lal, P., Wolde, B., Susaeta, A., Soto, J. R., Smith, M., & Adams, D. C. (2021). Public Preferences for Longleaf Pine Restoration Programs in the Southeastern United States. *Forest Science*, 67(3), 265–274. <https://doi.org/10.1093/forsci/fxab008>
- Papenfus, M., & Weber, M. A. (2025). Valuing wild salmon and steelhead recovery in Oregon’s most urbanized watershed. *Ecological Economics*, 236, 108540. <https://doi.org/10.1016/j.ecolecon.2025.108540>
- Perry-Hill, R., & Prokopy, L. S. (2014). Comparing different types of rural landowners: Implications for conservation practice adoption. *Journal of Soil and Water Conservation*, 69(3), 266–278. <https://doi.org/https://doi.org/10.2489/jswc.69.3.266>
- Petrolia, D. R., Interis, M. G., & Hwang, J. (2014). America’s Wetland? A National Survey of Willingness to Pay for Restoration of Louisiana’s Coastal Wetlands. *Marine Resource Economics*, 29(1), 17–37. <https://doi.org/10.1086/676289>
- Rabotyagov, S., & Lin, S. (2013). Small forest landowner preferences for working forest conservation contract attributes. *Journal of Forest Economics*, 19, 307–330. <https://doi.org/https://dx.doi.org/10.1016/j.ife.2013.06.002>
- Ranjan, P., Church, S. P., Floress, K., & Prokopy, L. S. (2019). Synthesizing Conservation Motivations and Barriers: What Have We Learned from Qualitative Studies of Farmers’ Behaviors in the United States? *Society & Natural Resources*, 32(11), 1171–1199. <https://doi.org/10.1080/08941920.2019.1648710>
- Rosenberg, A. B., Newburn, D. A., & Towe, C. A. (2023). Household willingness to pay for stream restoration on private and public land: Evidence from the Baltimore metropolitan region. *JAWRA Journal of the American Water Resources Association*, 59(2), 376–395. <https://doi.org/10.1111/1752-1688.13089>

- Rosenberg, S., & Margerum, R. D. (2008). Landowner motivations for watershed restoration: Lessons from five watersheds. *Journal of Environmental Planning and Management*, 51(4), 477–496. <https://doi.org/10.1080/09640560802116962>
- Scarpa, R., Gilbride, T. J., Campbell, D., & Hensher, D. A. (2009). Modelling attribute non-attendance in choice experiments for rural landscape valuation. *European Review of Agricultural Economics*, 36(2), 151–174.
- Schneider, C., Adhikari, R. K., Randazzo, N., & Poudyal, N. C. (2025). Financial Incentives and Landowner Interest in Reforesting Open Lands in the Southeastern United States. *Society & Natural Resources*, 38(10), 1025–1043. <https://doi.org/10.1080/08941920.2025.2494015>
- Scholl, K., & Humphery, B. (2017). *2017 Dry Creek Landowner Watershed Awareness Survey*. University of Northern Iowa. <file:///C:/Users/acsol/Downloads/2017%20DRC%20Landowner%20Survey.pdf>
- Stacy, J., Ryan, R., Roy, A., & Milman, A. (2021). Homeowners' Willingness to Adopt Environmentally Beneficial Landscape Practices in an Urbanizing Watershed. *Cities and the Environment (CATE)*, 14(1). <https://doi.org/10.15365/cate.2021.140102>
- Stets, J. E., & Biga, C. F. (2003). Bringing Identity Theory into Environmental Sociology. *Sociological Theory*, 21(4), 398–423. <https://doi.org/10.1046/j.1467-9558.2003.00196.x>
- Stillaguamish Implementation Review Committee. *Stillaguamish Watershed Chinook Recovery Plan*. Snohomish County Department of Public Works, Surface Water Management, 2005. <https://www.snohomishcountywa.gov/ArchiveCenter/ViewFile/Item/2163>.
- Tocqueville, A. (2000). *Democracy in America*. Translated by Harvey C. Mansfield and Delba Winthrop. University of Chicago Press. (Originally published 1835)
- Train, K. (2003). *Discrete Choice Methods with Simulation* [Print]. Cambridge University Press.
- Trenholm, R., Haider, W., Lantz, V., Knowler, D., & Haegeli, P. (2017). Landowner preferences for wetlands conservation programs in Southern Ontario watersheds. *Journal of Environmental Management*, 200, 6–21. <https://doi.org/http://dx.doi.org/10.1016/j.jenvman.2017.05.055>
- van Eeden, L. M., Bogezi, C., Leng, D., Marzluff, J. M., Wirsing, A. J., & Rabotyagov, S. (2021). Public willingness to pay for gray wolf conservation that could support a rancher-led wolf-livestock coexistence program. *Biological Conservation*, 260, 109226. <https://doi.org/10.1016/j.biocon.2021.109226>
- Vedel, S. E., Jacobsen, J. B., & Thorsen, B. J. (2015). Contracts for afforestation and the role of monitoring for landowners' willingness to accept. *Forest Policy and Economics*, 51, 29–37. <https://doi.org/10.1016/j.forpol.2014.11.007>
- Vedel, S., Jacobsen, J., & Thorsen, B. (2015). Contracts for afforestation and the role of monitoring for landowner's willingness to accept. *Forest Policy and Economics*, 51, 29–37. <https://doi.org/http://dx.doi.org/10.1016/j.forpol.2014.11.007>

Supplemental III-I: Near-Bayesian Efficient Experimental Design Blocks for the Willingness-to-Accept Experiment

		Annual Payment to Landowner (\$USD/acre)		Longevity of Contract (years)		Monitoring Frequency (visits/year)	
		Vegetation Enhancement	Conservation Easement	Vegetation Enhancement	Conservation Easement	Vegetation Enhancement	Conservation Easement
Block 1	Task 1	700	1050	20	10	4	1
	Task 2	1400	1400	40	5	1	4
	Task 3	350	350	10	20	2	2
	Task 4	700	700	10	20	1	4
	Task 5	1050	1050	40	5	4	1
	Task 6	700	350	40	5	2	2
Block 2	Task 1	1050	1400	10	20	4	1
	Task 2	1400	1400	20	5	1	4
	Task 3	1050	700	10	20	1	4
	Task 4	700	350	10	20	2	2
	Task 5	1050	1050	5	40	1	4
	Task 6	350	700	5	40	2	2
Block 3	Task 1	350	350	20	10	2	2
	Task 2	700	1050	20	10	2	2
	Task 3	700	700	5	40	4	1
	Task 4	1050	1400	5	40	1	4
	Task 5	1050	1400	40	5	1	4
	Task 6	1050	700	10	20	4	1
Block 4	Task 1	350	350	20	10	4	1
	Task 2	1400	1050	40	5	1	4
	Task 3	350	700	20	10	2	2
	Task 4	1400	1050	40	5	4	1
	Task 5	1400	1050	5	40	2	2
	Task 6	350	700	20	10	1	4

Supplemental III-II: Near-Bayesian Efficient Experimental Design Blocks for the Willingness-to-Pay Experiment

		Annual Payment from Landowner (\$USD/acre)	Longevity of Fee System (years with vote for renewal)	Funding Purpose
Block 1	Task 1	25	20	Improve sport fishing opportunities
	Task 2	10	20	Enhance salmon habitat
	Task 3	100	5	Enhance salmon habitat
	Task 4	50	10	Enhance recreation in the watershed
	Task 5	10	20	Improve sport fishing opportunities
	Task 6	50	5	Improve water quality
Block 2	Task 1	50	5	Improve sport fishing opportunities
	Task 2	25	10	Improve sport fishing opportunities
	Task 3	100	5	Enhance recreation in the watershed
	Task 4	10	20	Enhance recreation in the watershed
	Task 5	100	10	Enhance salmon habitat
	Task 6	50	5	Enhance salmon habitat
Block 3	Task 1	25	20	Enhance salmon habitat
	Task 2	50	10	Improve sport fishing opportunities
	Task 3	25	20	Enhance recreation in the watershed
	Task 4	100	5	Improve sport fishing opportunities
	Task 5	10	10	Enhance salmon habitat
	Task 6	50	5	Enhance recreation in the watershed
Block 4	Task 1	25	20	Improve water quality
	Task 2	100	10	Improve water quality
	Task 3	100	5	Improve water quality
	Task 4	25	10	Enhance recreation in the watershed
	Task 5	10	10	Improve water quality
	Task 6	10	20	Improve water quality

Supplement III-III: Sample Structure of the Willingness-to-Accept Survey Instrument

The Stillaguamish Watershed has the most at-risk Chinook salmon run along the Pacific Coast, so it is a critical area for this culturally and economically important species

Washington State is reviewing incentive programs for the Stillaguamish Watershed to improve the environmental quality of the Stillaguamish River. The State believes that this will increase recreational opportunities, increase salmon runs, improve habitat and increase water quality.

Page Break

For the next section, you will be asked to choose between three options for the given scenario. These scenarios ask you to choose different restoration programs that will pay you to enroll a portion of your land in the program. These scenarios are hypothetical and involve money. No one will actually be paid money based on the decisions you make. However, please consider these scenarios as though you would receive the money presented for the program you choose and the restoration program would actually be implemented on your land.

For the following sets of options:

- All lands (no matter the size or if the land is near water), are eligible for these programs.
- You may also participate in other conservation programs.

For each scenario, you will see three options:

- **Vegetation Enhancement Project:** The State would give you money each year to add and maintain native vegetation on your land. The State would assist with the initial purchasing of materials and labor. You would be responsible for long-term monitoring and maintenance of the site.
- **Conservation Easement:** The State would pay you for the right to access and manage the portion of your land placed into the conservation easement. You would give up the development and management rights to that portion of your land to the State.
- **Status Quo:** This is how you currently manage or use your land.

Page Break

Scenario 1 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$700 per acre	\$1050 per acre	\$0
Contract length	20 years	10 years	0
Monitoring visits	4 per year	1 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Scenario 2 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$1400 per acre	\$1400 per acre	\$0
Contract length	40 years	5 years	0
Monitoring visits	1 per year	4 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Scenario 3 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$350 per acre	\$350 per acre	\$0
Contract length	10 years	20 years	0
Monitoring visits	2 per year	2 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Scenario 4 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$700 per acre	\$700 per acre	\$0
Contract length	10 years	20 years	0
Monitoring visits	1 per year	4 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Scenario 5 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$1050 per acre	\$1050 per acre	\$0
Contract length	40 years	5 years	0
Monitoring visits	4 per year	1 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Scenario 6 of 6

	Vegetation Enhancement	Conservation Easement	Status Quo
Annual payment to landowner	\$700 per acre	\$350 per acre	\$0
Contract length	40 years	5 years	0
Monitoring visits	2 per year	2 per year	None

Question: Which option would you choose?

- ☐ Vegetation Enhancement
- ☐ Conservation Easement
- ☐ Status Quo

Question: How many acres would you enroll in your choice? _____

Page Break

Question: How certain are you of your choices in these scenarios?

- ☐ Very Certain
- ☐ Somewhat Certain
- ☐ No Opinion
- ☐ Somewhat Uncertain
- ☐ Very Uncertain

Question: For the scenario(s) you selected status quo for, what was the reason: (Select all that apply)

- ☐ I do not trust receiving the payment as promised
- ☐ I do not want any monitoring activity on my land
- ☐ I do not think my land is eligible for these programs
- ☐ I do not think my land is in need of restoration
- ☐ I do not trust the State or any Government-funded program
- ☐ These programs do not provide enough funding or compensation
- ☐ I think it will decrease my income from my working land
- ☐ I am worried these programs will increase the risk of flooding or erosion on my property
- ☐ I do not think these programs will help create cleaner waters, increased salmon runs, or improved economic conditions.
- ☐ Other: _____

Supplemental III-IV: Sample Structure of the Willingness-to-Pay Survey Instrument

The Stillaguamish Watershed has the most at-risk Chinook salmon run along the Pacific Coast, so it is a critical area for this culturally and economically important species.

Some state and local governments attach a fee to landowner taxes to fund river restoration programs, such as native plantings, that improve watershed health. We are interested in your opinions on such a program for the Stillaguamish Watershed.

Page Break

For the next section, you will be given a scenario of a referendum and asked to choose whether or not you would vote for each one. These scenarios are hypothetical and involve money. No one will actually be paid money based on the decisions you make. However, please consider these scenarios as though you were paying for it with your own money. In doing so, please consider that this means you will have less money to spend on other things in your life.

The watershed enhancement programs that would be funded by the annual charges...

- Are only for landowners inside of the Stillaguamish watershed.
- Are for all Stillaguamish watershed landowners, no matter how far they are from a stream or river.
- Are for all acreage sizes, no matter how small or large.

For the following scenarios of referendums, vote for the options that best reflect what you would like to see happen.

Page Break

Scenario 1 of 6

	Referendum
Yearly payment from landowner	\$25 per acre
Length of fee program	20 years with vote for renewal
Purpose of fee program	Improve sport fishing opportunities

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Scenario 2 of 6

	Referendum
--	-------------------

Yearly payment from landowner	\$10 per acre
Length of fee program	20 years with vote for renewal
Purpose of fee program	Enhance salmon habitat

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Scenario 3 of 6

	Referendum
Yearly payment from landowner	\$100 per acre
Length of fee program	5 years with vote for renewal
Purpose of fee program	Enhance salmon habitat

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Scenario 4 of 6

	Referendum
Yearly payment from landowner	\$50 per acre
Length of fee program	10 years with vote for renewal
Purpose of fee program	Enhance recreation in the watershed

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Scenario 5 of 6

	Referendum
Yearly payment from landowner	\$10 per acre
Length of fee program	20 years with vote for renewal
Purpose of fee program	Improve sport fishing opportunities

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Scenario 6 of 6

	Referendum
Yearly payment from landowner	\$50 per acre
Length of fee program	5 years with vote for renewal
Purpose of fee program	Improve water quality

Question: Would you vote in favor of this referendum?

- ☐ Yes
- ☐ No

Page Break

Question: How certain are you of how you voted in the scenarios?

- ☐ Very Certain
- ☐ Somewhat Certain
- ☐ No Opinion
- ☐ Somewhat Uncertain
- ☐ Very Uncertain

Question: For the scenario(s) you voted “no” on, what is the reason: (Select all that apply)

- ☐ I do not trust the government with my money
- ☐ I already pay too much in various taxes
- ☐ I do not trust the government would use these funds for their intended purposes
- ☐ I do not think it is fair to have a by-acreage assessment system
- ☐ I do not think there is a need for funding restoration in the Stillaguamish Watershed
- ☐ The referendum landowner payment was too high
- ☐ Other: _____

Question: Would you be willing to donate money in order to support restoration programs in the watershed?

- ☐ Yes
- ☐ No
- ☐ I don't know

Question: How many total acres do you own in the Stillaguamish Watershed? _____

Supplemental III-V: Results from the WTA MNL Model

Results from the MNL model, only including structural variables (n = 672)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC Vegetative Enhancement	-0.36995	0.097889	-3.77932
ASC Conservation Easement	-1.39922	0.116097	-12.0522
Payment to Landowner	0.054506	0.006555	8.315641
Contract Length	-0.19267	0.025892	-7.44118
Monitoring Visit Frequency	-0.05734	0.01448	-3.95971
Pseudo-r ²			0.0166
Log Likelihood			-3864.56
AIC			7739.11
BIC			7770.62

Rationale:

All structural variables are significant and with coefficient signs as expected.

Decision:

Keep for coefficients.

Supplemental III-VI: Results from the WTA Structural Mixed Logit Model I

Results from the WTA Mixed Logit Model I, only including structural variables, error terms on contract, monitoring, and overall ASC (n = 672)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC Vegetative Enhancement	-1.11766	0.324395	-3.44537
ASC Conservation Easement	-2.50565	0.342016	-7.32612
Payment to Landowner	0.150476	0.018037	8.342765
Contract Length	-0.39565	0.04666	-8.47936
Estimated Standard Deviation	0.567976	0.053269	10.66245
Monitoring Visit Frequency	-0.09708	0.021101	-4.6006
Estimated Standard Deviation	0.000686	0.003029	0.226296
ASC Estimated Standard Deviation	6.61339	0.462011	14.31435
Pseudo-r ²			0.3781
Log Likelihood			-2439.8
AIC			4895.61
BIC			4946.02

Rationale:

Strong heterogeneity is detected in all variables other than monitoring visit frequency. This indicates that monitoring frequency is consistently negative for all respondents. Remove the error term on monitoring visit frequency.

Decision:

Keep for further analysis.

Supplemental III-VII: Results from the WTA Structural Mixed Logit Model II

Results from the WTA Mixed Logit Model II model, only including structural variables, error terms on contract, payment, and overall ASC (n = 672)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC Vegetative Enhancement	-1.14176	0.369726	-3.08812
ASC Conservation Easement	-2.5987	0.390213	-6.65968
Payment to Landowner	-2.20521	0.155595	-14.1727
Estimated Standard Deviation	0.820175	0.050077	16.37837
Contract Length	-0.41539	0.050108	-8.29002
Estimated Standard Deviation	-0.60513	0.05994	-10.0956
Monitoring Visit Frequency	-0.10301	0.022272	-4.62499
ASC Estimated Standard Deviation	6.999454	0.563669	12.41766
Pseudo-r ²			0.3814
Log Likelihood			-2426.87
AIC			4869.73
BIC			4920.15

Rationale:

Strong heterogeneity is detected in all variables other than monitoring visit frequency. This indicates that monitoring frequency is consistently negative for all respondents.

Decision:

Keep for further analysis.

Supplemental III-VIII: Results from the WTA Interaction Mixed Logit Model III

Results from the WTA Mixed Logit Model III, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with subwatersheds (5 categories, effects coded, Stanwood reference) (n = 672)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-1.00272	0.570697	-1.75701
ASC Conservation Easement	-2.483	0.597323	-4.15688
Payment to Landowner	-2.3684	0.177639	-13.3327
Estimated Standard Deviation	1.023235	0.084009	12.18005
Contract Length	-0.42698	0.05169	-8.26046
Estimated Standard Deviation	-0.61699	0.061248	-10.0737
Monitoring Visit Frequency	-0.1044	0.02266	-4.60718
Subwatershed (5) – Pilchuck	-2.3266	1.168787	-1.99061
Subwatershed (5) – Arlington	0.007593	0.844199	0.008995
Subwatershed (5) – North Fork	0.250246	0.912563	0.274224
Subwatershed (5) – South Fork	0.173245	0.863124	0.200719
ASC Estimated Standard Deviation	-6.95887	0.536952	-12.96
Pseudo-r ²			0.3819
Log Likelihood			-2421.11
AIC			4866.22
BIC			4941.84

Rationale:

When adding the first interactions on the subwatersheds, only the Pilchuck watershed is different from the reference. Other subwatersheds appear to have very weak differences. Combine to only one variable to reduce parameter loading.

Decision:

Keep for further analysis.

Supplemental III-IX: Results from the WTA Interaction Mixed Logit Model IV

Results from the WTA Mixed Logit Model IV, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with subwatershed (Pilchuck, effects coded, all others reference) (n = 672)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-0.91263	0.358776	-2.54374
ASC Conservation Easement	-2.39313	0.381315	-6.27599
Payment to Landowner	-2.37158	0.177153	-13.3872
Estimated Standard Deviation	1.025592	0.083909	12.22273
Contract Length	-0.42715	0.051529	-8.28938
Estimated Standard Deviation	-0.61745	0.061149	-10.0975
Monitoring Visit Frequency	-0.10444	0.02266	-4.60915
Subwatershed (5) – Pilchuck	-2.41725	1.073854	-2.25101
ASC Estimated Standard Deviation	-6.96377	0.531822	-13.0942
Pseudo-r ²			0.3826
Log Likelihood			-2421.16
AIC			4860.33
BIC			4917.04

Rationale:

Model slightly improves with the collapsed variable. Keep for further analysis.

Decision:

Keep for further analysis.

Supplemental III-X: Results from the WTA Interaction Mixed Logit Model V

Results from the WTA Mixed Logit Model V, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with subwatershed (Pilchuck, effects coded, all others reference), riparian status (n = 672)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-1.44338	0.508791	-2.83688
ASC Conservation Easement	-2.92203	0.526155	-5.55355
Payment to Landowner	-2.35829	0.178028	-13.2468
Estimated Standard Deviation	1.010443	0.084622	11.94062
Contract Length	-0.4272	0.051568	-8.28428
Estimated Standard Deviation	-0.61662	0.061557	-10.0171
Monitoring Visit Frequency	-0.10428	0.022639	-4.60643
Subwatershed (2) – Pilchuck	-2.45389	1.175533	-2.08747
Riparian Owner	0.885786	0.63502	1.394895
ASC Estimated Standard Deviation	-6.94238	0.536072	-12.9505
Pseudo-r ²			0.3826
Log Likelihood			-2420.19
AIC			4860.37
BIC			4923.39

Rationale:

Riparian status is not significant. Remove from the analysis.

Decision:

Discard from further analysis.

Supplemental III-XI: Results from the WTA Interaction Mixed Logit Model VI

Results from the WTA Mixed Logit Model VI, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with subwatershed (Pilchuck, effects coded, all others reference), environmental identity (n = 672)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-0.95753	0.371827	-2.57521
ASC Conservation Easement	-2.44399	0.394556	-6.19426
Payment to Landowner	-2.42243	0.243356	-9.95426
Estimated Standard Deviation	1.110207	0.210865	5.265013
Contract Length	-0.43317	0.053191	-8.14365
Estimated Standard Deviation	-0.62046	0.059853	-10.3665
Monitoring Visit Frequency	-0.10489	0.022653	-4.63013
Subwatershed (2) – Pilchuck	-1.69775	0.940508	-1.80514
Environmental Identity	1.975335	0.398208	4.960554
ASC Estimated Standard Deviation	-6.60769	0.506111	-13.0558
Pseudo-r ²			0.387
Log Likelihood			-2402.95
AIC			4825.89
BIC			4888.91

Rationale:

It appears that much of the variance explained by the geolocation of Pilchuck is explained by environmental identity. This may suggest that attitudinal variables are more important than place-based variables. Drop Pilchuck from further analysis.

Decision:

Keep for further analysis.

Supplemental III-XII: Results from the WTA Interaction Mixed Logit Model VII

Results from the WTA Mixed Logit Model VII, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity (n = 672)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC Vegetative Enhancement	-1.15164	0.352711	-3.26512
ASC Conservation Easement	-2.63815	0.378158	-6.97631
Payment to Landowner	-2.41212	0.189027	-12.7607
Estimated Standard Deviation	1.099315	0.110994	9.904246
Contract Length	-0.43482	0.053325	-8.15412
Estimated Standard Deviation	-0.6235	0.060773	-10.2595
Monitoring Visit Frequency	-0.10501	0.02279	-4.60799
Environmental Identity	2.049296	0.373479	5.487047
ASC Estimated Standard Deviation	-6.59265	0.489365	-13.4718
Pseudo-r ²			0.3869
Log Likelihood			-2404.48
AIC			4826.97
BIC			4883.68

Rationale:

Model performance is not greatly affected by the removal of the subwatershed variable. Keep as is with only environmental identity on the overall ASC.

Decision:

Keep for further analysis.

Supplemental III-XIII: Results from the WTA Interaction Mixed Logit Model VIII

Results from the WTA Mixed Logit Model VIII, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity (n = 672)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC Vegetative Enhancement	-1.71159	0.506191	-3.38132
ASC Conservation Easement	-3.19585	0.530226	-6.02734
Payment to Landowner	-2.42453	0.186138	-13.0254
Estimated Standard Deviation	1.104113	0.096069	11.49295
Contract Length	-0.43253	0.052666	-8.2128
Estimated Standard Deviation	-0.61987	0.060012	-10.329
Monitoring Visit Frequency	-0.10479	0.022763	-4.60359
Environmental Identity	1.886304	0.348032	5.419912
Prior Restoration Participation	1.058526	0.653551	1.619653
ASC Estimated Standard Deviation	-6.63218	0.495695	-13.3796
Pseudo-r ²			0.387
Log Likelihood			-2403.08
AIC			4826.16
BIC			4889.18

Rationale:

Prior Restoration participation does have a weak effect on the model with minor improvements. However, it is not significant. Remove and continue with other variables.

Decision:

Keep for further analysis.

Supplemental III-XIV: Results from the WTA Interaction Mixed Logit Model IX

Results from the WTA Mixed Logit Model IX, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, longevity (4 categories, with non-resident as the reference) (n = 672)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-2.46925	0.791814	-3.11847
ASC Conservation Easement	-3.95487	0.807528	-4.89751
Payment to Landowner	-2.45897	0.18416	-13.3523
Estimated Standard Deviation	1.141683	0.102047	11.18777
Contract Length	-0.43322	0.052523	-8.24819
Estimated Standard Deviation	-0.62249	0.060277	-10.327
Monitoring Visit Frequency	-0.10326	0.02283	-4.52284
Environmental Identity	2.024785	0.332285	6.093512
Longevity (4) – 0 to 10	2.791689	1.161002	2.404551
Longevity (4) – 11 to 20	2.953969	0.919446	3.212769
Longevity (4) – 21+	0.096134	0.889703	0.108051
ASC Estimated Standard Deviation	-6.48441	0.481197	-13.4756
Pseudo-r ²			0.3889
Log Likelihood			-2393.25
AIC			4810.5
BIC			4886.12

Rationale:

There appears to be some differences when it comes to longevity with strong positive coefficients against the reference (dummy coded) of non-resident. Keep for now and add acreage.

Decision:

Keep for further analysis.

Supplemental III-XV: Results from the WTA Interaction Mixed Logit Model X

Results from the WTA Mixed Logit Model X, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, longevity (4 categories, with non-resident as the reference), acreage (6 categories, less than half as reference) (n = 672)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC Vegetative Enhancement	-2.60716	0.870409	-2.99532
ASC Conservation Easement	-4.08906	0.890318	-4.5928
Payment to Landowner	-2.39588	0.190008	-12.6094
Estimated Standard Deviation	1.054945	0.093607	11.2699
Contract Length	-0.43572	0.053998	-8.0691
Estimated Standard Deviation	-0.63103	0.063785	-9.89294
Monitoring Visit Frequency	-0.10454	0.022796	-4.58598
Environmental Identity	2.027315	0.371139	5.462419
Longevity (4) – 0 to 10	2.006241	1.150252	1.744175
Longevity (4) – 11 to 20	2.852141	0.940205	3.033533
Longevity (4) – 21+	-0.44543	0.889932	-0.50052
Acreage (6) – 0.5 to 1	-0.64395	0.98024	-0.65693
Acreage (6) – 2 to 5	1.191534	0.823627	1.446691
Acreage (6) – 6 to 10	0.815417	1.133282	0.719518
Acreage (6) – 11 to 20	3.84316	1.295763	2.965944
Acreage (6) – 21+	0.163184	0.954941	0.170884
ASC Estimated Standard Deviation	-6.33888	0.488926	-12.9649
Pseudo-r ²			0.3889
Log Likelihood			-2388.32
AIC			4810.64
BIC			4917.78

Rationale:

It appears that there are some weak effects from acreages 2 to 5 and a stronger effect on 11 to 20 acres. This could be associated with a certain amount of acreage needed for restoration in the minds of landowners. However, would expect that 21+ acres would have the same effect. This could be negated by what these lands are used for, like forestry or agriculture. Aggregate the acreages to decrease parameters, only 11-20 against all others.

Decision:

Keep for further analysis.

Supplemental III-XVI: Results from the WTA Interaction Mixed Logit Model XI

Results from the WTA Mixed Logit Model XI, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, longevity (4 categories, with non-resident as the reference), acreage (2 categories, 11 to 20 acres against all other aggregated) (n = 672)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC Vegetative Enhancement	-2.39586	0.78838	-3.03897
ASC Conservation Easement	-3.86816	0.7961	-4.85888
Payment to Landowner	-2.33248	0.185975	-12.5419
Estimated Standard Deviation	0.979125	0.095866	10.21351
Contract Length	-0.42975	0.051581	-8.33169
Estimated Standard Deviation	-0.62464	0.060101	-10.3931
Monitoring Visit Frequency	-0.10457	0.022628	-4.62111
Environmental Identity	1.991304	0.323324	6.158848
Longevity (4) – 0 to 10	2.2931	1.198445	1.913395
Longevity (4) – 11 to 20	2.896961	0.996054	2.908438
Longevity (4) – 21+	-0.311	0.822872	-0.37795
Acreage (2) – 11 to 20	3.700215	1.455009	2.543088
ASC Estimated Standard Deviation	-6.49521	0.507614	-12.7956
Pseudo-r ²			0.3893
Log Likelihood			-2390.73
AIC			4807.45
BIC			4889.38

Rationale:

Longevity effects are mixed for 21+years. Aggregate longevity effects.

Decision:

Keep for further analysis.

Supplemental III-XVII: Results from the WTA Interaction Mixed Logit Model XII

Results from the WTA Mixed Logit Model XII, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, longevity (2 categories, non-residents and 21+ years as reference), acreage (2 categories, 11 to 20 acres against all other aggregated) (n = 672)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC Vegetative Enhancement	-2.51667	0.418611	-6.01194
ASC Conservation Easement	-4.002	0.436138	-9.17599
Payment to Landowner	-2.44845	0.183336	-13.355
Estimated Standard Deviation	1.124228	0.112426	9.999724
Contract Length	-0.43579	0.053425	-8.15709
Estimated Standard Deviation	-0.62809	0.061017	-10.2937
Monitoring Visit Frequency	-0.10349	0.022841	-4.53074
Environmental Identity	1.980164	0.368105	5.379346
Longevity (4) – 0 to 20	2.827402	0.666449	4.242487
Acreage (2) – 11 to 20	2.725506	2.858832	0.953364
ASC Estimated Standard Deviation	-6.38915	0.496761	-12.8616
Pseudo-r ²			0.3898
Log Likelihood			-2390.98
AIC			4803.97
BIC			4873.29

Rationale:

After aggregating longevity effects, aggregated acreage loss significance. There is an apparent relationship between acreage and longevity. Drop acreage to see effects on model performance.

Decision:

Keep for further analysis.

Supplemental III-XVIII: Results from the WTA Interaction Mixed Logit Model XIII

Results from the WTA Mixed Logit Model XIII, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, acreage (2 categories, 11 to 20 acres against all other aggregated), age (forced continuous) (n = 653)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC Vegetative Enhancement	-1.96677	0.453125	-4.34045
ASC Conservation Easement	-3.43474	0.473419	-7.25519
Payment to Landowner	-2.42522	0.206324	-11.7544
Estimated Standard Deviation	1.098885	0.118237	9.293904
Contract Length	-0.42163	0.05267	-8.00519
Estimated Standard Deviation	-0.62067	0.06212	-9.99152
Monitoring Visit Frequency	-0.10019	0.02296	-4.36386
Environmental Identity	2.074132	0.408252	5.080514
Longevity (4) – 0 to 20	2.009799	0.601171	3.343139
Age	-0.05922	0.026387	-2.24415
ASC Estimated Standard Deviation	-6.40178	0.539967	-11.8559
Pseudo-r ²			0.3893
Log Likelihood			-2332.69
AIC			4687.38
BIC			4756.38

Rationale:

Age is significant. Add final model to compare without age with the same number of individuals.

Decision:

Keep for further analysis.

Supplemental III-XIX: Results from the WTA Interaction Mixed Logit Model XIV

Results from the WTA Mixed Logit Model XIV, only including structural variables, error terms on contract, payment, and overall ASC. Interactions on ASC with environmental identity, acreage (2 categories, 11 to 20 acres against all other aggregated) (n = 653)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC Vegetative Enhancement	-2.28565	0.48861	-4.67785
ASC Conservation Easement	-3.75419	0.505293	-7.42972
Payment to Landowner	-2.41897	0.220107	-10.99
Estimated Standard Deviation	1.089458	0.143949	7.568363
Contract Length	-0.42009	0.051651	-8.13323
Estimated Standard Deviation	-0.61907	0.063757	-9.70991
Monitoring Visit Frequency	-0.09997	0.022859	-4.37346
Environmental Identity	1.899311	0.396477	4.79047
Longevity (4) – 0 to 20	2.747214	0.660596	4.158691
ASC Estimated Standard Deviation	-6.49383	0.498111	-13.0369
Pseudo-r ²			0.3886
Log Likelihood			-2336.19
AIC			4692.37
BIC			4755.11

Rationale:

Age does improve the model. Keep the age model as the final interaction model.

Decision:

Keep for further analysis.

Supplement III-XX: Results from the WTP MNL Model

Results from the MNL model, only including structural variables (n = 701)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC (Yes)	-0.20346	0.115681	-1.75878
Landowner Payment (per acre per year)	-0.1693	0.012966	-13.0573
Duration of Funding Program	0.006481	0.005701	1.136832
Purpose – Salmon Habitat Enhancement	0.424582	0.05977	7.103536
Purpose – Recreation Improvement	-0.33383	0.054348	-6.14251
Purpose – Water Quality Improvements	0.408775	0.096922	4.217568
Pseudo-r ²			0.073
Log Likelihood			-2384.86
AIC			4781.72
BIC			4819.78

Rationale:

Beginning with a MNL gives starting coefficients for Apollo to derive further estimates in the mixed logit models. These results do, mostly, confirm initial hypotheses. Interestingly, Duration of Funding Program is insignificant.

Decision:

Keep for Apollo coefficients.

Supplement III-XXI: Results from the WTP EC Model I

Results from the MNL model, only including structural variables with heterogeneity terms on duration of funding program and on ASC term (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	-0.39755	0.245485	-1.61944
<i>Estimated Standard Deviation</i>	3.162871	0.215076	14.70585
Landowner Payment (per acre per year)	-0.37786	0.02855	-13.2352
Duration of Funding Program	0.001209	0.012646	0.095577
<i>Estimated Standard Deviation</i>	0.13484	0.019061	7.074289
Purpose – Salmon Habitat Enhancement	1.10668	0.126639	8.738862
Purpose – Recreation Improvement	-0.82607	0.119749	-6.89834
Purpose – Water Quality Improvements	0.809274	0.163039	4.963676
Pseudo-r ²			0.314
Log Likelihood			-1761.89
AIC			3539.77
BIC			3590.53

Rationale:

Adding the first error terms to the model on Duration of Funding Program and ASC – Yes. Initial results suggest that both added error terms are significant. This suggests that there is strong heterogeneity in the measure terms across respondents. For ASC – Yes, this likely means that those who select “yes” tend to select “yes” again and vice versa for “no”. For Duration of Funding Program, this may indicate that there are some individuals that prefer longer funding programs and others that prefer shorter programs.

Decision:

Keep for further analysis.

Supplement III-XXII: Results from the WTP Structural Mixed Logit Model II

Results from the WTP Structural Mixed Logit Model II, including structural variables with heterogeneity terms on duration of funding program, ASC term, and payment to landowner (negative log normal) (n = 701)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC (Yes)	0.552003	0.312257	1.767782
<i>Estimated Standard Deviation</i>	3.105267	0.316095	9.823843
Landowner Payment (per acre per year)	-0.59971	0.115561	-5.18955
<i>Estimated Standard Deviation</i>	1.072619	0.190558	5.628842
Duration of Funding Program	-0.00919	0.013556	-0.67794
<i>Estimated Standard Deviation</i>	0.11814	0.023155	5.102257
Purpose – Salmon Habitat Enhancement	1.07804	0.142734	7.552782
Purpose – Recreation Improvement	-0.84823	0.130244	-6.5126
Purpose – Water Quality Improvements	0.914251	0.188443	4.851618
Pseudo-r ²			0.323
Log Likelihood			-1737.6
AIC			3493.2
BIC			3550.29

Rationale:

Adds an additional error term with the payment from landowner measure. The finding is significant, with all other terms remaining significant. Suggests that some individuals may prefer higher payments while others prefer lower payments.

Decision:

Keep for further analysis.

Supplement III-XXIII: Results from the WTP Structural Mixed Logit Model III

Results from the WTP Structural Mixed Logit Model III, including structural variables with heterogeneity terms on duration of funding program, ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement” (n = 701)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC (Yes)	0.491185	0.330642	1.485548
<i>Estimated Standard Deviation</i>	3.477511	0.340254	10.22033
Landowner Payment (per acre per year)	-0.54741	0.121032	-4.52286
<i>Estimated Standard Deviation</i>	0.982557	0.157129	6.25318
Duration of Funding Program	-0.01242	0.014845	-0.83641
<i>Estimated Standard Deviation</i>	0.138027	0.026314	5.245443
Purpose – Salmon Habitat Enhancement	1.20979	0.165067	7.329086
<i>Estimated Standard Deviation</i>	1.206692	0.207824	5.806306
Purpose – Recreation Improvement	-0.87688	0.143831	-6.0966
Purpose – Water Quality Improvements	1.032845	0.210605	4.904179
Pseudo-r ²			0.327
Log Likelihood			-1727.2
AIC			3474.41
BIC			3547.85

Rationale:

Addition of an error term associated with the “Salmon Habitat Enhancement” term results in a significant estimate. This suggests that there are some individuals that may be repeated for salmon habitat enhancement compared to the reference term and vice versa.

Decision:

Keep for further analysis.

Supplement III-XXIV: Results from the WTP Structural Mixed Logit Model IV

Results from the WTP Structural Mixed Logit Model IV, including structural variables with heterogeneity terms on duration of funding program, ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement” and “Water Quality Improvements” (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.515653	0.376112	1.371008
<i>Estimated Standard Deviation</i>	3.938115	0.43798	8.991545
Landowner Payment (per acre per year)	-0.42551	0.112127	-3.79493
<i>Estimated Standard Deviation</i>	1.021734	0.179338	5.697249
Duration of Funding Program	-0.00565	0.014459	-0.39103
<i>Estimated Standard Deviation</i>	0.0708	0.080237	0.88239
Purpose – Salmon Habitat Enhancement	1.339378	0.184676	7.252587
<i>Estimated Standard Deviation</i>	-1.03058	0.264941	-3.88986
Purpose – Recreation Improvement	-0.79787	0.152798	-5.2217
Purpose – Water Quality Improvements	1.066904	0.244328	4.366683
<i>Estimated Standard Deviation</i>	2.192318	0.32427	6.760777
Pseudo-r ²			0.3314
Log Likelihood			-1714.09
AIC			3450.18
BIC			3519.97

Rationale:

Addition of an error term associated with the “Water Quality Improvements” is significant, indicating strong heterogeneity associated with the variable. With the added error term, the error term on duration of funding program becomes insignificant, suggesting that the error term purpose statement associated with water quality may be explaining some of the unobserved variance on duration. Without significance in this model, the error term on the duration of funding should be removed to improve the model through decreased parameter penalties. It is not immediately apparent the relationship between water quality improvements purpose statement and duration of funding program.

Decision:

Keep for further analysis. Remove the error term on duration of funding.

Supplement III-XXV: Results from the WTP Structural Mixed Logit Model V

Results from the WTP Structural Mixed Logit Model V, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement” and “Water Quality Improvements” (n = 701)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC (Yes)	0.434573	0.332401	1.307377
<i>Estimated Standard Deviation</i>	4.028557	0.346271	11.63411
Landowner Payment (per acre per year)	-0.45233	0.097531	-4.63778
<i>Estimated Standard Deviation</i>	0.995337	0.091191	10.91482
Duration of Funding Program	-0.00355	0.014027	-0.25279
Purpose – Salmon Habitat Enhancement	1.301292	0.177552	7.329069
<i>Estimated Standard Deviation</i>	-1.04226	0.268792	-3.87756
Purpose – Recreation Improvement	-0.79388	0.146987	-5.40099
Purpose – Water Quality Improvements	1.016328	0.233413	4.354203
<i>Estimated Standard Deviation</i>	2.116238	0.301413	7.021065
Pseudo-r ²			0.3315
Log Likelihood			-1714.97
AIC			3449.95
BIC			3513.39

Rationale:

Removal of the heterogeneity term on duration of funding program improved AIC and BIC with little impact to pseudo-r² and log likelihood. Recommend to retain removal for ease of interpretation and model performance.

Decision:

Keep for further analysis.

Supplement III-XXVI: Results from the WTP Structural Mixed Logit Model VI

Results from the WTP Structural Mixed Logit Model VI, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements,” and “Recreation” (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.502802	0.379757	1.324012
<i>Estimated Standard Deviation</i>	4.121776	0.372401	11.0681
Landowner Payment (per acre per year)	-0.4439	0.115064	-3.85787
<i>Estimated Standard Deviation</i>	-0.98029	0.111201	-8.81553
Duration of Funding Program	-0.00534	0.014396	-0.37093
Purpose – Salmon Habitat Enhancement	1.344654	0.187189	7.183405
<i>Estimated Standard Deviation</i>	-1.04262	0.280584	-3.71588
Purpose – Recreation Improvement	-0.81141	0.150941	-5.3757
<i>Estimated Standard Deviation</i>	0.6072	0.363831	1.668907
Purpose – Water Quality Improvements	1.030512	0.238877	4.313995
<i>Estimated Standard Deviation</i>	-2.19845	0.329152	-6.67912
Pseudo-r ²			0.331
Log Likelihood			-1715.12
AIC			3452.25
BIC			3522.04

Rationale:

The heterogeneity term on the “Recreation” purpose statement is not significant and does not improve any model performance metric. Recommend removal.

Decision:

Discard for further analysis.

Supplement III-XXVII: Results from the WTP Interaction Mixed Logit Model VII

Results from the WTP Structural Mixed Logit Model VII, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x subwatersheds (5). (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.262974	0.453092	0.580399
<i>Estimated Standard Deviation</i>	3.976943	0.332352	11.96606
Landowner Payment (per acre per year)	-0.45564	0.099766	-4.56706
<i>Estimated Standard Deviation</i>	0.988512	0.083216	11.87885
Duration of Funding Program	-0.00365	0.014023	-0.26036
Purpose – Salmon Habitat Enhancement	1.29922	0.174417	7.448939
<i>Estimated Standard Deviation</i>	0.981928	0.274219	3.580818
Purpose – Recreation Improvement	-0.78181	0.145338	-5.37929
Purpose – Water Quality Improvements	1.004705	0.230519	4.358454
<i>Estimated Standard Deviation</i>	2.140268	0.291271	7.348037
Subwatershed (5) – Pilchuck	0.347909	0.634822	0.548041
Subwatershed (5) – Arlington	-0.06642	0.566322	-0.11729
Subwatershed (5) – North Fork	0.74606	0.528664	1.411218
Subwatershed (5) – South Fork	0.013307	0.559086	0.023801
Pseudo-r ²			0.3305
Log Likelihood			-1713.47
AIC			3454.94
BIC			3543.76

Rationale:

Subwatersheds are not significant against the reference (dummy coded). Removal and aggregate.

Decision:

Discard for further analysis.

Supplement III-XXVIII: Results from the WTP Interaction Mixed Logit Model VIII

Results from the WTP Structural Mixed Logit Model VIII, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x subwatersheds (3). (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.268405	0.378553	0.709028
<i>Estimated Standard Deviation</i>	4.010294	0.345357	11.61204
Landowner Payment (per acre per year)	-0.45582	0.100422	-4.53902
<i>Estimated Standard Deviation</i>	0.977693	0.09773	10.00405
Duration of Funding Program	-0.00348	0.014	-0.24886
Purpose – Salmon Habitat Enhancement	1.305222	0.177772	7.342127
<i>Estimated Standard Deviation</i>	-1.03585	0.269467	-3.84406
Purpose – Recreation Improvement	-0.78703	0.145989	-5.39105
Purpose – Water Quality Improvements	1.011585	0.231622	4.36739
<i>Estimated Standard Deviation</i>	2.134201	0.302327	7.059257
Subwatershed (3) – North Fork	0.720198	0.47474	1.517034
Subwatershed (3) – South Fork	-0.02032	0.487801	-0.04166
Pseudo-r ²			0.3312
Log Likelihood			-1713.76
AIC			3451.51
BIC			3527.64

Rationale:

Subwatersheds are not significant against the reference (dummy coded). Removal and aggregate.

Decision:

Discard for further analysis.

Supplement III-XXIX: Results from the WTP Interaction Mixed Logit Model IX

Results from the WTP Structural Mixed Logit Model IX, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x riparian. (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.514867	0.437399	1.17711
<i>Estimated Standard Deviation</i>	3.987759	0.329949	12.08598
Landowner Payment (per acre per year)	-0.447	0.098407	-4.54232
<i>Estimated Standard Deviation</i>	1.007493	0.090122	11.17922
Duration of Funding Program	-0.00394	0.014062	-0.28004
Purpose – Salmon Habitat Enhancement	1.294878	0.175207	7.390547
<i>Estimated Standard Deviation</i>	0.999808	0.270794	3.692129
Purpose – Recreation Improvement	-0.78626	0.146373	-5.37165
Purpose – Water Quality Improvements	1.010946	0.232378	4.350433
<i>Estimated Standard Deviation</i>	2.133871	0.297631	7.169508
Riparian Owner	-0.05082	0.405531	-0.12531
Pseudo-r ²			0.3311
Log Likelihood			-1714.81
AIC			3451.61
BIC			3521.4

Rationale:

Riparian status is not significant. Recommend removal.

Decision:

Discard for further analysis.

Supplement III-XXX: Results from the WTP Interaction Mixed Logit Model X

Results from the WTP Structural Mixed Logit Model X, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity. (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.394381	0.348935	1.130241
<i>Estimated Standard Deviation</i>	3.671908	0.307301	11.94891
Landowner Payment (per acre per year)	-0.45906	0.108386	-4.23546
<i>Estimated Standard Deviation</i>	0.967623	0.120241	8.047383
Duration of Funding Program	-0.00462	0.013998	-0.33031
Purpose – Salmon Habitat Enhancement	1.290702	0.171682	7.517976
<i>Estimated Standard Deviation</i>	-0.97786	0.287651	-3.39946
Purpose – Recreation Improvement	-0.79095	0.14426	-5.48283
Purpose – Water Quality Improvements	1.01752	0.229266	4.43816
<i>Estimated Standard Deviation</i>	2.151548	0.307936	6.987004
Environmental Identity	1.490234	0.210147	7.091386
Pseudo-r ²			0.3428
Log Likelihood			-1684.78
AIC			3391.56
BIC			3461.35

Rationale:

Environmental identity is significant and positive, suggesting an attitudinal factor in decision making.

Decision:

Keep for further analysis.

Supplement III-XXXI: Results from the WTP Interaction Mixed Logit Model XI

Results from the WTP Structural Mixed Logit Model XI, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x longevity (4). (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	1.44191	0.633936	2.274538
<i>Estimated Standard Deviation</i>	3.610279	0.2979	12.11909
Landowner Payment (per acre per year)	-0.48482	0.105365	-4.60134
<i>Estimated Standard Deviation</i>	0.953617	0.119785	7.96107
Duration of Funding Program	-0.00436	0.013861	-0.31439
Purpose – Salmon Habitat Enhancement	1.271526	0.168751	7.534939
<i>Estimated Standard Deviation</i>	0.872867	0.296399	2.944903
Purpose – Recreation Improvement	-0.78438	0.143085	-5.48193
Purpose – Water Quality Improvements	1.002743	0.226078	4.43539
<i>Estimated Standard Deviation</i>	2.088234	0.280982	7.431915
Environmental Identity	1.484295	0.205641	7.217883
Longevity – 0 to 5 years	-0.45136	0.689652	-0.65447
Longevity – 6 to 20 years	-0.93678	0.650281	-1.44057
Longevity – 20+ years	-1.60151	0.618129	-2.59089
Pseudo-r ²			0.3433
Log Likelihood			-1680.41
AIC			3388.82
BIC			3477.64

Rationale:

The longest longevity factor against the reference (not a resident) is significant. Will test resident binary variable and long-term resident binary variable.

Decision:

Keep for further analysis.

Supplement III-XXXII: Results from the WTP Interaction Mixed Logit Model XII

Results from the WTP Structural Mixed Logit Model XII, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x longevity (resident and long-term). (n = 701)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC (Yes)	1.446206	0.631947	2.288492
<i>Estimated Standard Deviation</i>	3.618233	0.298686	12.11384
Landowner Payment (per acre per year)	-0.48192	0.104488	-4.6122
<i>Estimated Standard Deviation</i>	0.960734	0.113123	8.49281
Duration of Funding Program	-0.00411	0.013879	-0.29606
Purpose – Salmon Habitat Enhancement	1.275788	0.169117	7.543823
<i>Estimated Standard Deviation</i>	0.888706	0.294441	3.01828
Purpose – Recreation Improvement	-0.78683	0.143278	-5.49167
Purpose – Water Quality Improvements	1.00318	0.226475	4.429539
<i>Estimated Standard Deviation</i>	2.09436	0.282361	7.417327
Environmental Identity	1.476207	0.207174	7.125434
Longevity – Resident	-0.7599	0.612891	-1.23987
Longevity – 20+ years	-0.84463	0.386657	-2.18444
Pseudo-r ²			0.3435
Log Likelihood			-1680.81
AIC			3387.62
BIC			3470.1

Rationale:

While the longest-term owners in the Stillaguamish Watershed remain a negative coefficient and significant. However, the model performance indicators are worse than before the addition of longevity. Recommend removal, but note that long-term owners may have some influence on the model.

Decision:

Discard for further analysis.

Supplement III-XXXIII: Results from the WTP Interaction Mixed Logit Model XIII

Results from the WTP Structural Mixed Logit Model XIII, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x acreage (6 categories, less than 0.5 as reference – dummy coded) (n = 701)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC (Yes)	1.395215	0.467257	2.985972
<i>Estimated Standard Deviation</i>	3.513984	0.294065	11.94969
Landowner Payment (per acre per year)	-0.54543	0.107969	-5.05174
<i>Estimated Standard Deviation</i>	0.85727	0.122305	7.009254
Duration of Funding Program	-0.00221	0.013606	-0.16246
Purpose – Salmon Habitat Enhancement	1.256492	0.165183	7.606665
<i>Estimated Standard Deviation</i>	0.906964	0.266222	3.406795
Purpose – Recreation Improvement	-0.77901	0.141183	-5.5177
Purpose – Water Quality Improvements	0.99598	0.215463	4.622517
<i>Estimated Standard Deviation</i>	2.012468	0.270488	7.440145
Environmental Identity	1.486105	0.208222	7.137111
Acreage – 0.5 to 1	0.064731	0.556853	0.116245
Acreage – 2 to 5	-1.53221	0.49441	-3.09908
Acreage – 6 to 10	-2.46036	0.631878	-3.89373
Acreage – 11 to 20	-2.52322	0.746915	-3.37819
Acreage – 20+	-3.14801	0.716372	-4.39438
Pseudo-r ²			0.3483
Log Likelihood			-1665.56
AIC			3363.11
BIC			3464.62

Rationale:

Adding acreage indicates all but 0.5 to 1 category are significant against the reference (less than 0.5). Suggests that 0.5 to 1 and less than 0.5 can be combined for ease of interpretation.

Decision:

Keep for further analysis.

Supplement III-XXXIV: Results from the WTP Interaction Mixed Logit Model XIV

Results from the WTP Structural Mixed Logit Model XIV, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x acreage (5 categories, less than 1 as reference – dummy coded) (n = 701)

Measure	Robust Standard		Robust T-Ratio
	Estimate	Error	
ASC (Yes)	1.428274	0.388949	3.67214
<i>Estimated Standard Deviation</i>	3.512792	0.293312	11.97632
Landowner Payment (per acre per year)	-0.54571	0.108105	-5.048
<i>Estimated Standard Deviation</i>	0.856958	0.12272	6.98304
Duration of Funding Program	-0.00222	0.013605	-0.16346
Purpose – Salmon Habitat Enhancement	1.256293	0.165092	7.609649
<i>Estimated Standard Deviation</i>	0.906411	0.266378	3.402725
Purpose – Recreation Improvement	-0.77889	0.141104	-5.51995
Purpose – Water Quality Improvements	0.99586	0.215489	4.621386
<i>Estimated Standard Deviation</i>	2.01236	0.270642	7.435497
Environmental Identity	1.486591	0.208525	7.129089
Acreage – 2 to 5	-1.56532	0.416167	-3.76127
Acreage – 6 to 10	-2.49328	0.574527	-4.33971
Acreage – 11 to 20	-2.55625	0.700022	-3.65167
Acreage – 20+	-3.18079	0.669173	-4.75332
Pseudo-r ²			0.3487
Log Likelihood			-1665.56
AIC			3361.13
BIC			3456.29

Rationale:

All acreage categories are significant against the reference (less than 1 acre). Add former participation in restoration activities.

Decision:

Keep for further analysis.

Supplement III-XXXV: Results from the WTP Interaction Mixed Logit Model XV

Results from the WTP Structural Mixed Logit Model XV, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x acreage (5 categories, less than 1 as reference – dummy coded), x participation (binary) (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	1.01076	0.424594	2.380533
<i>Estimated Standard Deviation</i>	3.47076	0.292016	11.88551
Landowner Payment (per acre per year)	-0.55834	0.113029	-4.93979
<i>Estimated Standard Deviation</i>	0.840658	0.139076	6.044607
Duration of Funding Program	-0.00189	0.01353	-0.13998
Purpose – Salmon Habitat Enhancement	1.25078	0.165295	7.566952
<i>Estimated Standard Deviation</i>	0.890225	0.261564	3.403471
Purpose – Recreation Improvement	-0.77861	0.140481	-5.54246
Purpose – Water Quality Improvements	0.98012	0.214252	4.574604
<i>Estimated Standard Deviation</i>	1.979293	0.278731	7.101078
Environmental Identity	1.387927	0.204855	6.775169
Acreage – 2 to 5	-1.643	0.417935	-3.93123
Acreage – 6 to 10	-2.53362	0.567156	-4.46723
Acreage – 11 to 20	-2.78787	0.695316	-4.0095
Acreage – 20+	-3.27605	0.667806	-4.90569
Prior Restoration Participation	0.867942	0.35321	2.457299
Pseudo-r ²			0.3495
Log Likelihood			-1662.48
AIC			3356.97
BIC			3458.48

Rationale:

Prior restoration participation suggests higher tendency to support WTP. Add interaction of the acreages on the payment variable to see if there is a clearer explanation for the acreage interaction.

Decision:

Keep for further analysis.

Supplement III-XXXVI: Results from the WTP Interaction Mixed Logit Model XVI

Results from the WTP Structural Mixed Logit Model XVI, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x acreage (5 categories, less than 1 as reference – dummy coded), x participation (binary), payment x acreage (5 categories, less than 1 as reference – dummy coded) (n = 701)

Measure	Estimate	Robust Standard	
		Error	Robust T-Ratio
ASC (Yes)	0.574093	0.442072	1.298642
<i>Estimated Standard Deviation</i>			
Landowner Payment (per acre per year)	-0.87073	0.136642	-6.37236
<i>Estimated Standard Deviation</i>	0.832005	0.086085	9.664979
Duration of Funding Program	-0.00289	0.013576	-0.21252
Purpose – Salmon Habitat Enhancement	1.264243	0.168082	7.521602
<i>Estimated Standard Deviation</i>	0.936616	0.25268	3.706721
Purpose – Recreation Improvement	-0.78157	0.141287	-5.53176
Purpose – Water Quality Improvements	0.980069	0.216016	4.537015
<i>Estimated Standard Deviation</i>	2.015739	0.276934	7.278758
Environmental Identity	1.421299	0.211233	6.728595
Acreage – 2 to 5	-1.0009	0.503995	-1.98593
Acreage – 6 to 10	-0.81376	0.771946	-1.05417
Acreage – 11 to 20	-1.34664	1.036976	-1.29862
Acreage – 20+	-2.79182	0.880545	-3.17056
Acreage – 2 to 5 x Payment	0.464327	0.181267	2.561566
Acreage – 6 to 10 x Payment	1.048623	0.267931	3.913775
Acreage – 11 to 20 x Payment	0.889211	0.360118	2.469224
Acreage – 20+ x Payment	0.372546	0.417765	0.89176
Prior Restoration Participation	0.882154	0.355731	2.479837
Pseudo-r ²			0.3522
Log Likelihood			-1651.37
AIC			3342.75
BIC			3469.63

Rationale:

Adding payment interactions with the payment variable results in significant results other than the biggest landowners. However, the significance drops on acreages less than 20 against the reference. This appears to describe a relationship where certain acreages are more sensitive to payment rather than the ASC. Drop the insignificant acreage variables for model performance.

Decision:

Keep for further analysis.

Supplement III-XXXVII: Results from the WTP Interaction Mixed Logit Model XVII

Results from the WTP Structural Mixed Logit Model XVII, including structural variables with heterogeneity terms on ASC term, payment to landowner (negative log normal), and purpose statement “Salmon Habitat Enhancement,” “Water Quality Improvements”. Interaction of ASC x environmental identity, x acreage (1 categories, less 20 acres as reference – dummy coded), x participation (binary), payment x acreage (5 categories, less than 1 as reference – dummy coded) (n = 701)

Measure	Robust Standard		
	Estimate	Error	Robust T-Ratio
ASC (Yes)	0.181128	0.405272	0.44693
<i>Estimated Standard Deviation</i>	3.465587	0.286476	12.0973
Landowner Payment (per acre per year)	-0.97475	0.13598	-7.16828
<i>Estimated Standard Deviation</i>	0.875446	0.105236	8.318872
Duration of Funding Program	-0.00384	0.013741	-0.27962
Purpose – Salmon Habitat Enhancement	1.260057	0.170892	7.373413
<i>Estimated Standard Deviation</i>	-0.97643	0.30454	-3.20625
Purpose – Recreation Improvement	-0.77809	0.141583	-5.49567
Purpose – Water Quality Improvements	0.988128	0.21982	4.49517
<i>Estimated Standard Deviation</i>	2.067413	0.291445	7.093665
Environmental Identity	1.418713	0.21003	6.754825
Acreage – 20+	-2.30566	0.878354	-2.62498
Acreage – 2 to 5 x Payment	0.694608	0.161798	4.293069
Acreage – 6 to 10 x Payment	1.274487	0.221402	5.756446
Acreage – 11 to 20 x Payment	1.231085	0.355325	3.46467
Acreage – 20+ x Payment	0.497912	0.458317	1.086393
Prior Restoration Participation	0.80972	0.359724	2.250948
Pseudo-r ²			0.3523
Log Likelihood			-1654.35
AIC			3342.71
BIC			3450.56

Rationale:

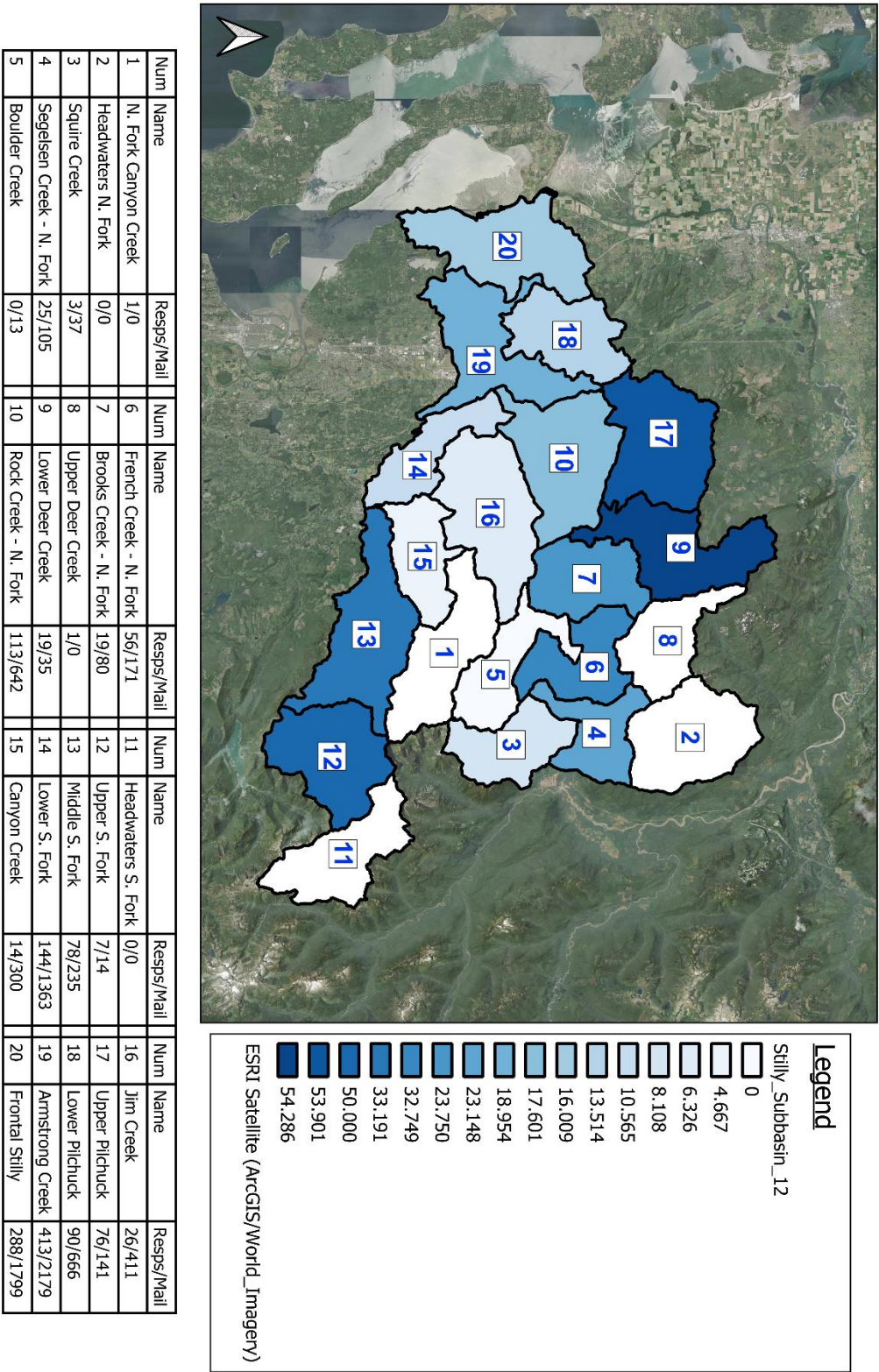
This model maintains the best performance and significance across variables. Keep as final.

Decision:

Keep as final model.

Supplement III-XXXVIII: Map of Response Rates by Subwatershed

Subwatershed Response Rate - Stillaguamish Survey



Discussion

The three chapters presented in this dissertation describe three different study contexts for working landscapes. The first chapter considered the NTFP greenery industry: a rural economy founded on the domestic holiday season demand for floral greens and evergreen boughs, trade to Europe in primarily salal, and an immigrant workforce. The second chapter considered on evergreen boughs production, that supports the NTFP greenery industry, will be affected by climate change, especially around shifting frost dates, the observable climatic indicator that trees will have hardened-off. The third chapter investigated incentives and barriers to engaging in restoration in the Stillaguamish Watershed, resulting in pseud-policy scenarios that describe the possible tyranny of the majority supporting local restoration but without enough revenue to fund all expected enrollment.

Alignment of Working Landscapes

Across these studies, working landscape outcomes were only possible through the interactions of ecological conditions, institutions, economic conditions, and engagement of the relevant agents. These interactions that were present in each study demonstrate how working landscapes require consideration of multifunctionality, adaptative management, differing scales, and agent capacity (Kremen & Merenlender 2018; Sayer et al. 2012). This makes working landscapes a product of alignment and opportunity (Figure XXII).

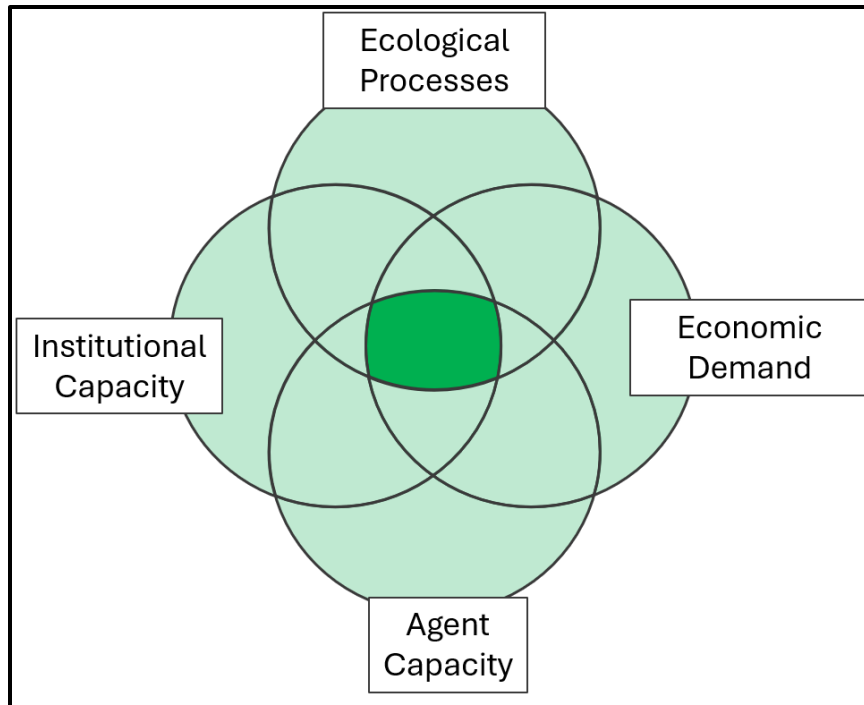


Figure XXII: A conceptual framework for understanding working landscapes as the alignment of ecological processes, institutional capacity, agent capacity, and economic demand.

The different contexts of the studies brought up the alignment of ecological processes, economic opportunity, institutional capacity, and behavioral willingness. The NTFP greenery industry is rooted in the available NTFP greenery species throughout the year. Economically, these products have demand domestically and in international markets. Findings demonstrate that NTFP greenery is harvested based on the institutional capacity, through an available workforce and development of informal networks and long-term relationships that provide access to land. The willing workforce and relationships that provide access form behavioral willingness.

The case study found that there are vulnerabilities in the current alignment that have allowed industry and market to exist. Economically, the trade decline with Europe suggests that the economic opportunity is shifting. The potential institutional threats towards the workforce with shifts in domestic immigration policy may decrease behavioral willingness. While not

suggested as a threat in the case study, the formation of access through trust and long-term relationships illustrates a gatekeeping of resources, becoming another core part of the alignment equation.

For the climatic impacts to evergreen bough production, similar alignment comes from the NTFP greenery case study, as evergreen boughs are a product for that industry. However, the chapter investigated the potential impact to the ecological process that has allowed for evergreen boughs to be part of the working landscape. As frost shifts to later in the season, processors and harvesters will have fewer days to harvest and prepare boughs for sale. As the more reliable frosts appear higher in elevation, the industry will need to rely on access to higher elevation ownerships, such as USFS. This access represents an institutional capacity misalignment as National Forests become older and management is not favored towards bough production, as suggested in the NTFP greenery case study findings. The climatic impacts to evergreen bough production study then shows potential future misalignments with institutional capacity and ecological processes.

Restoration in the Stillaguamish Watershed highlights the behavioral willingness portion of working landscapes, requiring both individuals willing to engage in restoration and willing to pay for that restoration. The pseudo policy scenarios found a mismatch between expected enrolled acres, the cost of those acres being enrolled, and how much revenue could be generated from the landowners in the watershed. The mismatch presents how behavior willingness extends to different agents and the scale that those agents are operating.

Heterogeneity and Scale in Working Landscapes

These studies demonstrated wide heterogeneity and different scales to working landscapes. Heterogeneity takes on the forms of the different agents that are on the landscape, with the studies covering residents, harvesters, agency officials, greenery processors, and industrial landowners. Additionally, there is heterogeneity in the landscape in terms of climate impacts, who is impacted, and by how much. On a finer resolution, individual preferences and decisions greatly impact the outcomes of modeled behavior at a watershed level.

There are different scales in institutions and how the working landscape is viewed. The NTFP greenery industry has economic global scale, regional scale in the supply chain, and the individual level of trust and the workforce. These different scales of institutions and the agents also impact one another as the declining trade impacts the regional economic opportunity. Individual level trust and long-term relationships govern how much of the landscape is available for access and harvest. In the climate impacts to evergreen boughs, the impacts varied by the analysis unit, whether it was ecoregions or ownerships, highlight that the lens of the research impacts findings. Restoration occurs at a regional scale but requires individuals making independent decisions about enrollment and support on their one slice of the region. Additionally, paying for restoration occurs on the regional scale, requiring collective action to fund individual decisions.

Heterogeneity and scale may limit management decisions as the scale of institutions may not match the scale of the problem (Cummings et al. 2006). The case of the NTFP industry highlights a multi-state and international supply chain, following through different jurisdictions. The impact of climate change on evergreen bough production demonstrates that different

ownerships will face different impacts. These ownerships also have different management that may not be conducive to bough production, impacting access. Restoration occurs at the regional scale, and institutions may not have the full authority of an area or where restoration needs to occur, such as on private land.

Implications

Together, the findings of these studies represent how working landscapes are diverse with several dimensions. For those wishing to understand working landscapes, the unit to research must be well defined and the processes that affect that subject mapped out. The NTFP industry was found to be a wide network of informal connections that spread from British Columbia to southern Oregon, based in secrecy and trust. Evergreen bough production was found to be based on what managers observe climatically, as a proxy to physiological processes, and making operation decisions based on those daily observations. Restoration is a function of willingness-to-engage and willingness-to-pay amongst many actors, each of whom will make independent decisions.

Opportunity must also be seen through different lens and dimensions. Combined, this research does suggest there is potential between the NTFP industry and restoration. Restoration includes the vegetative enhancement of a property through planting native plants and removing invasive ones. Should restoration include the planting of NTFP greenery species, it could increase the land base that could become accessible for greenery products to be harvested. Through restoration, or restorative forest farming, landowners may enter the NTFP greenery industry.

These studies draw attention to the need for future research and monitoring in each subject. The NTFP greenery industry still needs additional research to understand the full economic scope and size of the industry. Evergreen bough production needs to be better modeled and understood outside of climatic proxies while other NTFP greenery species may also need to be research for their response to climate change. Watershed restoration is not a one-time event and is subject to willingness changing as individual preferences and perceptions change (Montgomery & Helvoigt, 2006).

Limitations

As a product of these three studies, this dissertation does have limitations to its interpretability. First, each study has a different scale, research subject, and different dimensions explored in a working landscape. These differences make it difficult to understand the relationship between these chapters in a definitive manner, as results are not fully comparable. This difficulty is representative of the working landscape.

All the studies had difficulties with data availability and the limitations on how what data could be gathered. The NTFP greenery industry is chronic understudied and unmonitored, leaving little public data, and the industry is shrouded by secrecy and trust, making entry to investigate the industry difficult. Evergreen boughs and the hardening-off process were difficult to model without species specific data on the physiological process and climatic variables. The discrete choice experiment had to balance what could be asked for in the survey and how that data was gathered in a relatively reluctant population.

These common aspects do not detract from the dissertation, rather they inspired creativity in the research. The limitations define working landscapes as a subject that needs

interdisciplinary methods when applying research and being flexible in how research questions can be answered.

Future Research

Future research on working landscapes should follow the principles set out by others (Sayer et al. 2012). The work presented here demonstrated that the different dimensions of working landscapes are difficult to understand and incorporate in research but provide compelling evidence in how industries and cooperation on the landscape form. Each study presented the future research in each specific domain; however, future research is needed to connect:

- How are working landscapes connected through different industries, restoration activities, and achieving other environmental objectives?
- How can cooperative policies and management connect different agents and processes?
- How can research, management, and policy-making provide opportunities for monitoring, data collection, and experiments that provide appropriate frameworks and sources for future working landscape research?

Conclusion

Working landscapes are complex systems that support multiple objectives, achieving more outcomes than industrialized or solitary systems. The added complexity of working landscapes creates more dimensions to understand and include when attempting to study or manage the landscape. This dissertation set out to understand working landscapes through the lens of the NTFP greenery industry, climate risk, and watershed restoration. These studies

highlight the complexity of these systems, the insights these systems provide to working landscapes in Washington State, and the future work needed to understand these systems.

From the first and second chapters, findings indicate that natural resource industries on the working landscape form around social and institutional systems while climate change may introduce change to the resources these systems industries rely upon. The NTFP greenery industry is built on informal governance, relying on trust and long-term relationships that grant access to the harvest sites. In the near-term, the industry may experience vulnerabilities as exports to Europe decline and domestic immigration policy threatens the workforce. In the future, climate change may limit the post-frost harvesting season for boughs, introducing yet another uncertainty for the industry. Much is left to be known about the industry; however, the threats and uncertainty the industry faces present an opportunity to observe and document how a working landscape industry manages and adapts to change.

The third chapter demonstrates how restoring working landscapes takes public willingness to engage and to support. The findings demonstrate the need for incentives to balance program design and individual preferences to encourage engagement in restoration. Additionally, individual willingness to pay for restoration follows landowner characteristics and the purpose for enhancing salmon habitat and water quality over recreational objectives. Policy simulations demonstrate that through tyranny of the majority, the watershed community can support some of, but not all, those willing to engage in conservation programs, highlighting the need for external support. Here, working landscapes require coordination from different scales of the same group of individuals, in this case landowners, along with support and design from other authorities, such as the state.

In the case of working landscapes, these studies highlight that systems are dependent on alignment of opportunity. This opportunity is the alignment of ecological processes, agents and institutions, economics and industry, and a willingness to engage. This alignment is crosses through different scales, governance, and social dimensions that vary from the individual to societal level. The results presented here demonstrate the formation of that opportunity and alignment through the persistence of the NTFP greenery industry and achieving restoration goals in the Stillaguamish Watershed.

So, then, working landscapes should be understood in their formation, their alignment of opportunity, and how opportunity can be manufactured. Research will need to be interdisciplinary and work to build relationships with hard-to-observe communities. With the degree of heterogeneity on the landscape, management will need to reflect flexibility and respect for informal governance systems. Present and future vulnerabilities should be identified to support capacity building, planning, mitigation, and adaptation.

References for Introduction, Discussion, and Conclusion

- Arts, B., Buizer, M., Horlings, L., Ingram, V., van Oosten, C., & Opdam, P. (2017). Landscape Approaches: A State-of-the-Art Review. *Annual Review of Environment and Resources*, 42, 439–463. <https://doi.org/10.1146/annurev-environ-102016-060932>
- Cumming, G. S., Cumming, D. H. M., & Redman, C. L. (2006). Scale Mismatches in Social-Ecological Systems: Causes, Consequences, and Solutions. *Ecology and Society*, 11(1). <https://www.jstor.org/stable/26267802>
- Dalton, M., Mote, P., & Snover, A. (Eds.). (2013). *Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities*. Island Press.
- Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, 30, 441–473. <https://doi.org/10.1146/annurev.energy.30.050504.144511>
- Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology*, 91(3), 481–510.
- Kremen, C., & Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. *Science*, 362(6412), eaau6020. <https://doi.org/10.1126/science.aau6020>
- Lemos, M. C., & Agrawal, A. (2006). Environmental Governance. *Annual Review of Environment and Resources*, 31, 297–325. <https://doi.org/10.1146/annurev.energy.31.042605.135621>
- Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., Pell, A. N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C. L., Schneider, S. H., & Taylor, W. W. (2007). Complexity of Coupled Human and Natural Systems. *Science*, 317(5844), 1513–1516. <https://doi.org/10.1126/science.1144004>
- Montgomery, C. A., & Helvoigt, T. L. (2006). Changes in attitudes about importance of and willingness to pay for salmon recovery in Oregon. *Journal of Environmental Management*, 78(4), 330–340. <https://doi.org/10.1016/j.jenvman.2005.05.002>
- Ostrom, E. (1990). *Governing the Commons*. Cambridge University Press.
- Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, 325(5939), 419–422. <https://doi.org/10.1126/science.1172133>
- Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A. K., Day, M., Garcia, C., van Oosten, C., & Buck, L. (2013). Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences*, 110(21). <https://doi.org/10.1073/pnas.1210595110>
- Woollacott, J., Franzen, K., Taylor, N., & Austin, K. (2022). *Economic Impacts of Investing in Climate Resilience through Ecosystem Restoration in Washington State*. Washington State Department of Natural Resources. https://dnr.wa.gov/sites/default/files/2025-05/em_climateresilience_economic_impact_jan22.pdf

