Hardwood Conversion Study Summary Report

By:
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Washington State Forest Practices Adaptive Management Program

The Washington State Forest Practices Board (FPB) has established an Adaptive Management Program (AMP) by rule in accordance with the Forests & Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

> *Provide science-based recommendations and technical information to assist the FPB in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives. The board may also use this program to adjust other rules and guidance.* (Forest Practices Rules, WAC 222-12-045(1)).

To provide the science needed to support adaptive management, the FPB established the Cooperative Monitoring, Evaluation and Research (CMER) committee as a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with WAC 222-12-045 and Board Manual Section 22.

Report Type and Disclaimer

This technical report contains scientific information from research or monitoring studies that are designed to evaluate the effectiveness of the forest practices rules in achieving one or more of the Forest and Fish performance goals, resource objectives, and/or performance targets. The document was prepared for the Cooperative Monitoring, Evaluation and Research Committee (CMER) and was intended to inform and support the Forest Practices Adaptive Management program. The project is part of the Westside Type F Riparian Effectiveness Program, and was conducted under the oversight of the Riparian Scientific Advisory Group (RSAG).

This document was reviewed by CMER and was assessed through the Adaptive Management Program's independent scientific peer review process. CMER has approved this document for distribution as an official CMER document. As a CMER document, CMER is in consensus on the scientific merit of the document. However, any conclusions, interpretations, or recommendations contained within this document are those of the authors and may not reflect the views of all CMER members.

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Full Reference

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Hardwood Conversion Study (HCS) Summary Report

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CONTENTS

Executive Summary 5

Introduction 3

Background 3

Purpose 4

Study Objectives 4

Methods 5

Study Sites 5

- Site Selection 6
- Monitoring 7
- Landowner Objectives 8
- Site Characteristics 8
- Pre-harvest Stocking 9
- Harvest Practices 10
- Post-harvest Stocking 15
- Post-harvest Overstory Cover 17
- Regeneration Practices 18

Monitoring .... **Error! Bookmark not defined.**

- Silvicultural Performance 23
- Economic Performance 25

Results 26

Silvicultural Performance 26

- Shrubs, Forbs, and Grass 26
- Volunteer Hardwoods .... **Error! Bookmark not defined.**
- Conifer Height Growth 32
- Conifer Survival 35
- Free-to-Grow 37

Economic Performance 42

- Harvest Economics 43
- Regeneration Economics 43

Residual Value ... 44
Discussion ... 46
Qualitative Interpretation of Stocking Trends ... 46
Site-level Effects of Investment on Stocking ... 50
Factors Explaining Free-to-Grow Status ... 50
Technical Recommendations ... 51
Potential Management Implications ... 52
References ... 53
Appendix A: Competing Vegetation Response ... 55
Appendix B: Volunteer Hardwood Response ... 57
Appendix C: Conifer Height Growth Response ... 58
Appendix D: Conifer Survival Response ... 59

List of Figures

Figure 1: Location of Hardwood Conversion Study sites. ... 7
Figure 2. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 5. Aerial imagery collected in 2016. ... 11
Figure 3. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 8. Aerial imagery collected in 2016. ... 12
Figure 4. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 11. Aerial imagery collected in 2016 ... 12
Figure 5. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 12. Aerial imagery collected in 2016 ... 13
Figure 6. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 13. Aerial imagery collected in 2016 ... 13
Figure 7. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 14. Aerial imagery collected in 2016 ... 14
Figure 8. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 15. Aerial imagery collected in 2016 ... 14
Figure 9. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 23. Aerial imagery collected in 2016 ... 15
Figure 10. Average shrub, forb, and grass cover on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest ... 28
Figure 11. Average shrub, forb, and grass height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest ... 29

Figure 12. Average volunteer hardwood stocking on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest 30
Figure 13. Average volunteer hardwood height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest 31
Figure 14. Average height growth of conifers, by species, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers) 33
Figure 15. Average height growth of conifers from year 4 to year 10, by leader position at year 4, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers) 34
Figure 16. Tree status (live, dead) of planted conifers, by species, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest 36
Figure 17. Tree status (live, dead) of planted conifers, by species and leader status at year 4, on regeneration plots within hardwood conversion areas measured ten years post-harvest ... 37
Figure 18. Diameter distributions of planted conifers by dbh class and site on regeneration plots within hardwood conversion areas measured ten years post-harvest................................. 40
Figure 19: Comparison of residual value and regeneration costs for the conversion and upland areas in each study site.. 46
Figure 20. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average competing brush height, on regeneration plots within hardwood conversion areas measured four years post-harvest. Planted conifer bars are truncated for sites 11 and 12 in order to highlight relationships in other sites. 48
Figure 21. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average competing brush height, on regeneration plots within hardwood conversion areas measured ten years post-harvest 49
Figure 22. Relationship between total regeneration costs and conifer stocking at year 10, for all conifers and for conifers with their leaders above the brush (free-to-grow) 50

List of Tables

Table 1. Landowner management objectives for the Hardwood Conversion Study sites............. 8
Table 2. Landscape and stream characteristics at the Hardwood Conversion Study sites............ 9
Table 3. Pre-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are percent 10
Table 4. Extent of harvest unit, upland, combined core and inner zones, and hardwood conversion areas. 15
Table 5. Post-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are the percent of basal area remaining after harvest............................. 16
Table 6. Post-harvest riparian stand characteristics within the hardwood conversion areas. Values in parentheses are percentages. 16
Table 7. Post-harvest overstory tree cover within the hardwood conversion areas. Values in parentheses are standard deviation 17

Table 8. Summary of regeneration practices employed within hardwood conversion areas...... 20
Table 9. Summary of trees per acre (TPA) planting density in hardwood conversion areas........ 21
Table 10. Summary of planted tree heights, in inches, in hardwood conversion areas. 21
Table 11. Analytical metrics used to address selected Questions of Interest in the Hardwood Conversion Study Plan 22
Table 12: Sampling plot summary including the number of plots, sampling intensity, and percent area sampled at each site. 25
Table 13. Conifer stocking (trees per acre, TPA) at year 4 by leader position, species, and site[1]. 38
Table 14. Conifer stocking by trees per acre (TPA) and leader position relative to competing brush (above, within, or overtopped) at year 10 by leader position, species, and site[1] 41
Table 15. Factors influencing tree growth and survival to free-to-grow status (leader above the brush) at year 10 selected by stepwise logistic regression... 42
Table 16. Area, harvest volume, and adjusted stumpage values of timber harvest in upland areas and hardwood conversion areas, by site. 43
Table 17. Total and per-acre regeneration costs in upland areas, by site. 44
Table 18. Total and per-acre regeneration costs in hardwood conversion areas, by site. 44
Table 19. Summary of total residual values in uplands and hardwood conversion areas, and in total, by site. 45

EXECUTIVE SUMMARY

Since 2003, the Cooperative Monitoring, Evaluation, and Research Committee (CMER) has conducted the Hardwood Conversion Study to evaluate the effectiveness of hardwood conversions conducted in riparian areas of western Washington under the Washington Administrative Code (WAC) 222-30-021(1)(b)(i). Monitoring was conducted at eight study sites to evaluate the effectiveness and the operational and economic feasibility of hardwood conversion treatments in reestablishing conifers in hardwood-dominated riparian stands. This report summarizes the conditions and trends of regeneration response that has occurred, summarizes revenues and costs associated with hardwood conversion treatments, and summarizes factors strongly related to meeting stocking standards and the feasibility of doing so.

Hardwood conversion treatments were implemented on a total of 20.5 acres across eight study sites located in lowland forests of western Washington. Treatments are generally described, as follows, in the Case Study Report (Brown 2106):

> "Harvest and regeneration prescriptions were left to the discretion of landowners with the following requirements: no harvest within 25' feet of the edge of bank-full or CMZ [channel migration zone]; retain residual conifers in the core and inner zones; and, where reforestation was required, after harvesting, the goal was to successfully re-establish conifer, and that conifer be on track to dominate the converted [Riparian Management Zone]."

Treatments are recorded in the Case Study Report for each site and a summary is provided in the Harvest Practices and Regeneration Practices sections of this summary report. Overall there is no experimental design across the case studies with each landowner using treatments that fit the conditions of the case study site.

Generally, harvest values and harvest costs in hardwood conversion areas compared favorably to upland areas—average per-MBF stumpage values were higher in hardwood conversion areas ($333, SD = $49) than in adjacent uplands ($277, SD = $63) and average per-acre conversion costs were lower in hardwood conversion areas ($528, SD = $369) than in adjacent uplands ($575, SD = $625). But, because more volume could be harvested from upland areas (about 26 MBF per acre, on average, SD = 10 MBF) compared to that from the hardwood conversion areas (about 14 MBF per acre, on average, SD = 5 MBF/ac), the overall profitability of operations in the adjacent upland areas ($6,257 per acre, on average, SD = $1,448/ac) was greater than in hardwood conversion areas ($4,148 per acre, on average, SD = $1,627/ac).

As of the latest monitoring—10 years after planting—hardwood conversion areas have not yet met stocking standards prescribed under WAC 222-30-021(1)(b)(i)(D)—that is, 150 trees per acre greater than 8 inches dbh. Though all eight sites had more than 150 conifer trees per acre, no tree had yet reached 8 inches dbh. Three sites appear to be on track (sites 8, 11, and 12). These three sites were planted heavily with Sitka spruce, which has persisted at higher rates than any other species planted over a range of site conditions. The robust performance of Sitka spruce and the high numbers of this species planted at these three sites increase the likelihood of meeting the stocking standard. Where other sites were planted with Douglas-fir, which is less shade-tolerant and less persistent under shade than other species, the likelihood of meeting the stocking standard appears lower.

There is some evidence supporting a positive relationship between brush control and regeneration performance. However, because sites with the greatest brush control also had the highest levels of Sitka spruce, this relationship is masked by the persistence of Sitka spruce, which was observed across a range of brush competition. Yet, it *is* clear that seedlings with leaders above the brush were more likely to grow faster and survive. Therefore, the absence of competing vegetation or the act of reducing competing vegetation, where needed, has apparent value. But, because brush control was not performed at those sites that are also depauperate of Sitka spruce, some of which had inherently low brush levels, it is unclear whether a greater investment in brush control would have improved the growth and survival of the other species planted at those sites.

Finally, we were unable to discern the relationship between animal control or animal damage and regeneration performance. Though sites with the greatest animal control also had the highest populations of animals to control, these sites also have the highest levels of Sitka spruce, which are not preferred by browsers. This masked the relationship between animal control and conifer survival. Compounding matters, field crews were unable to reliably discern the cause of mortality during monitoring. All that is known is that a seedling died—the cause is unknown—further complicating our ability to interpret the relationship between animal damage and conifer survival.

Overall, the authors stress that the results summarized in this report are from case studies that, though they were established professionally and monitored rigorously, were not designed experimentally. This limits the inferences that can be drawn from them and the application of any findings beyond these sites. Therefore, the findings summarized herein are relationships observed in the monitoring data that serve as indicators of "success," and "failure," and should only be considered as such in rule deliberations.

INTRODUCTION

Background

The Washington Administrative Code (WAC) contains several rules governing a landowner's decision to convert hardwood-dominated stands in the inner zone[1] of the riparian management zone (RMZ)[2] to conifer-dominated stands:

- When projected stand development of the existing stands in the combined core and inner zone falls short of attaining the desired future condition of 325 square feet per acre basal area conifers by 140 years, WAC 222-30-021(1)(b)(i) stipulates that no harvest is permitted in the inner zone, except in connection with hardwood conversion[3].

- The landowner may elect conversion of hardwood-dominated stands in the inner zone if the core and inner zone meets specified conditions outlined in WAC 222-30-021(1)(b)(i)(A) for contiguous ownership, pre-conversion stocking, pre-harvest stream shade, likelihood of conversion success, and prior conversion success.

- When hardwood conversion occurs in the inner zone, it must be implemented under WAC 222-30-021(1)(b)(i)(B) through (D) which prescribes: limitations due to land ownership, retention of conifers during harvesting, requirements for conifer reforestation, and requirements for post-conversion monitoring.

These WACs were adopted in in 2001, and it was recognized that they would need to be validated using an adaptive management framework which involves monitoring to evaluate: a) the effectiveness of hardwood conversion treatments in reestablishing conifers; b) the economic and operational feasibility of hardwood conversion; and, c) the effects of the hardwood conversion on shade, stream temperature, and instream large wood.

In December 2003, the Forest Practices Board authorized the "Riparian Research Pilot Study" to achieve these adaptive management monitoring objectives. Now known as the Hardwood

[1] The "inner zone" of the RMZ is immediately upslope of a 50-foot stream-adjacent "core zone." The width of the inner zone varies under the WACs according to the site class in and stream width along the RMZ.
[2] The "riparian management zone" is the combined core, inner, and outer zones within an RMZ. The width of the riparian management zone varies under the WACs according to the site class in and stream width along the RMZ.
[3] When the case study sites were harvested in 2006, the DFC target adopted in 2001 ranged from 190 - 285 square feet per acre basal area conifers by 140 years depending on site class (Fairweather 2001).

Conversion Study, this study was designed to evaluate the effectiveness of hardwood conversions under the WACs, specifically to describe and quantify costs and benefits of implementing hardwood conversions in riparian areas of western Washington.

Shortly afterward, eight study sites were selected for monitoring. In 2006, hardwood conversion practices were implemented through alternative plans developed under the WACs. Monitoring has occurred on three occasions since: during planting, four years post-harvest, and ten years post-harvest[4]. A Case Study Report (Brown 2016) was published describing hardwood conversion treatments, silvicultural performance, and economic performance.

This report presents a summary of the findings of the hardwood conversion study to date—synthesizing information presented in the Case Study report—and provides further understanding of the silvicultural and economic performance of the hardwood conversions.

Purpose

The purpose of this report is to summarize conditions and trends from post-harvest monitoring, four and ten years since harvesting. Specifically, it addresses the following Rule Group Critical Questions outlined in Table 19 of the 2014 CMER workplan:

- How effective are different hardwood conversion treatments in reestablishing conifers in hardwood-dominated riparian stands?
- Is hardwood conversion in riparian stands operationally feasible, and what are the economic costs and benefits of the hardwood conversion treatments?

Though partially addressed by the Hardwood Conversion Study Plan, the following Rule Group Critical Questions are not addressed in this report:

- What effects do hardwood conversion treatments in riparian stands have on shade, stream temperature, and large woody debris (LWD) recruitment?
- What is the effect of hardwood conversion practices on stream temperature as a function of buffer width and length of stream treated?

A summary report of the shade and temperature study was prepared by Hunter (2010).

Study Objectives

This report addresses the following Questions of Interest posed in the Hardwood Conversion Study Plan, answering the two Rule Group Critical Questions carried forward in this report:

[4] There is some variance among sites in the length of time between harvesting and planting. In some cases, planting occurred in the same year as harvest. In others, planting occurred year(s) after harvest. Therefore, for consistency, we refer to "post-harvest" measurements for consistency in this report and with other reports.

Silvicultural Performance:

- What were the survival rates of planted seedlings in the RMZ?
- What were the growth rates of planted seedlings in the RMZ?
- What regeneration strategies did landowners use to ensure successful conifer regeneration in the RMZs?
- What were the primary problems that landowners faced regenerating the RMZs with conifers?

Economic Performance:

- What additional harvest costs resulted from adding hardwood conversion treatments to the harvest prescription?
- How much wood (volume, board feet) was harvested from the riparian management zones [the converted area including the inner zone and portions of the core zone of the RMZ]?
- How much wood (volume, board feet) was harvested from the upslope portions of the units [the outer zone of the RMZ and the remainder of the harvest unit]?
- What were the cost differences between successfully regenerating conifers in the riparian area [the converted area including the inner zone and portions of the core zone of the RMZ] versus successfully regenerating conifers in the adjacent, upslope areas [the outer zone of the RMZ and the remainder of the harvest unit]?
- What were the net financial gains (or losses) that resulted from adding riparian hardwood conversion treatments to the harvest prescriptions?
- What were the primary reasons for different costs (if any) between regenerating conifers in riparian areas versus regenerating conifers in adjacent, upslope areas?

Though the 2016 Hardwood Conversion Case Study Report addresses these questions on a site-by-site basis, this report addresses these Questions of Interest on a summary basis.

Additionally, this report addresses one Question of Interest posed by the CMER Policy Committee which provided the impetus for the latest round of monitoring:

- How many conifers are free-to-grow in the [converted core and inner zone portions of the] RMZ?

This report also addresses this Question of Interest on a summary basis.

METHODS

Study Sites

Site Selection

Eight riparian study sites were selected from a pool of twenty sites volunteered by participating landowners (see **Error! Reference source not found.**) that met the following selection criteria:

- Hardwoods must dominate over conifers (WAC 222-30-023(1)(i)),
- There is evidence (such as conifer stumps, historical photos, or a conifer understory) that the conversion area can be successfully reforested with conifers and support the development of conifer stands (WAC 222-30-023(1)(i)(A)), and
- Landowners must be willing to participate in the study and share information about their sites and silvicultural practices to meet overall project objectives.

Harvest and regeneration prescriptions were left to the discretion of landowners. However, they were given the following guidelines to regulate their treatment activities: no harvest could occur within 25' feet of the edge of bank-full or channel migration zone; conifers must be retained in the core and inner zones; and, conifers must be adequately stocked and free-to-grow and be on track to dominate the converted RMZ, regardless of cost.

The site selection criteria did not require any physical characteristics. Therefore, stream and buffer widths varied among sites with 6 of 8 sites along large streams (bankfull width over 10 feet) and 7 of 8 sites along low gradient streams (Table 2). Sites are primarily high productivity with 4 sites being DNR Site Class II, 2 sites being DNR Site Class III, and 2 sites being DNR Site Class V resulting in most sites having wider overall buffers. Sites also tend to be near the coast with 3 sites located on the northwest part of the Olympic Peninsula, 3 sites in southwest Washington in the Willapa Hills, 1 site on the northeast Olympic Peninsula, and 1 site in the southwest Washington Cascade foothills (Figure 1).

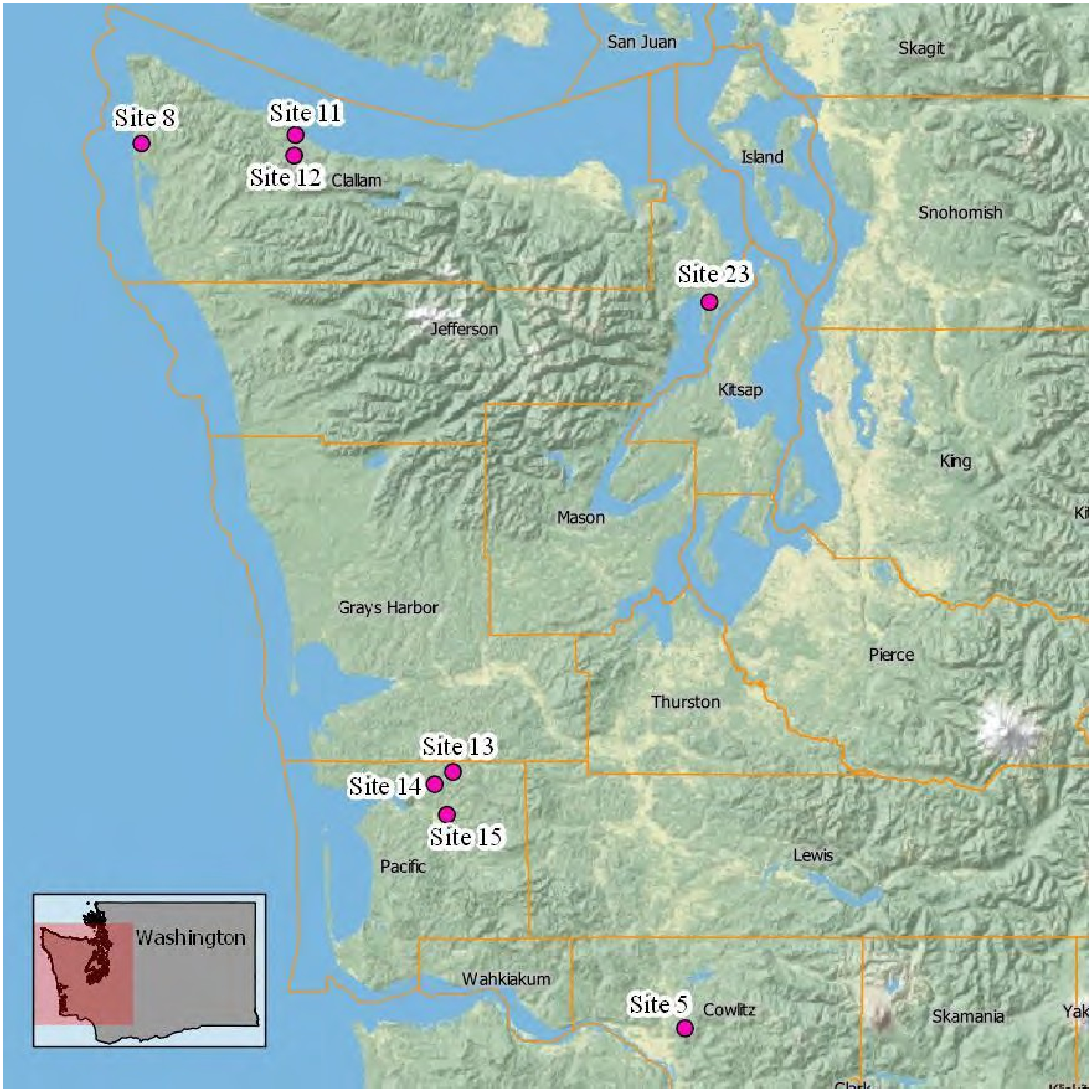

Figure 1: Location of Hardwood Conversion Study sites.

Monitoring

Monitoring hardwood conversion case study sites was performed with a combination of information provided by landowners through written surveys along with pre- and post-harvest vegetation surveys. Briefly, Landowners provided information about these sites—landowner objectives, harvest practices, and regeneration practices—in answers to a series of questionnaires. Pre-harvest vegetation surveys used a transect plot design while post-harvest surveys used a combination of a 100% survey of standing trees, snag, and stumps within the riparian zone and a grid of monumented 1/50th acre circular plots at 60-by-60-foot spacing to sample planted trees, volunteer hardwoods, and competing vegetation. Post-harvest monitoring occurred the year of planting followed by approximately 4 and 10 years after harvest. Complete information about survey methods can found in the WDNR Hardwood Conversion Procedures Manual[5] for pre-harvest surveys, the Post-Harvest 100% and Stump Procedures Manual (Versions 1.1 – 2.0, Duck Creek Associates 2007a, 2007b, 2015a) for overstory trees, and the Post-Harvest Regeneration Survey Procedures Manual (Versions 1.3 – 2.1, Duck Creek Associates 2006, 2007c, 2009, 2015b) for regeneration and vegetation surveys.

The following sections summarize the findings of these landowner questionnaires and field surveys, characterizing pre- and post-harvest conditions at the eight riparian study sites. The Case Study Report provides detailed assessments on a site-by-site basis.

Landowner Objectives

At the beginning of the study, management of the eight study sites was distributed amongst five landowners. Since then, Weyerhaeuser acquired lands owned by Longview Fibre (see Table 1) and now manages half (4) of the study sites. All landowners were motivated by financial objectives to consider hardwood conversion practices. Environmental stewardship objectives guided only two landowners—Green Crow (site 8) and Merrill and Ring (sites 11 and 12).

Table 1. Landowner management objectives for the Hardwood Conversion Study sites.

Landowner	Site Number	Immediate Financial Gain	Increase Conifer Acreage (Future Gain)	Ecological Stewardship
Weyerhaeuser/ Longview Fiber	5, 13, 14, 15	X	--	--
Green Crow	8	X	--	X
Merrill and Ring	11, 12	X	X	X
Pope Resources	23	X	--	--

Site Characteristics

Various site attributes, derived from GIS data layers, were downloaded from WDNR and USDA spatial data clearinghouses. Climate data were obtained from National Weather Service and NOAA National Climate Data Center climate stations (Western Regional Climate Center 1971 - 2000). Soils information was compiled from digital soils data obtained from the Natural Resources Conservation Service Web Soil Survey website (Soil Survey Staff).

[5] From Brown 2016: "Pre-harvest vegetation surveys, and initial post-harvest surveys, done at 4 sites, were conducted using a transect plot design. After review of the variability in the initial post-harvest transect data, the Riparian Scientific Advisory Group (RSAG) decided to discontinue its use for collecting post-harvest vegetation data. In place of the transect survey post-harvest, a 100-percent RMZ survey was used to collect large tree data (≥ 5.5" DBH), including stumps, snags, and fallen/windthrown trees, and a 1/50th acre circular plot design to collect regeneration and lesser vegetation data in the planted RMZ. Although the two methods are not directly comparable, the pre-harvest survey data offers insights into the small tree and lesser vegetative composition and percent cover. Furthermore, the 100-percent data is used to reconstruct both pre and post-harvest condition for large trees, while circular plot data can be compared to assess changes in lesser vegetation composition and percent cover, and seedling growth and survival post- harvest."

Landscape characteristics reflect lowland forest conditions on the Olympic Peninsula and along the Washington coast (see Table 2). All sites are rain-dominated, below 650 feet elevation. Average precipitation ranges from 48 to 103 inches per year. Generally, the highest precipitation levels occur at the coastal sites, the lone exception being coastal site 13 where the climate more closely resembles that of the two leeward sites (5 and 23).

Six of the eight sites (8, 11, 12, 14, 15, and 23) occur along low gradient streams and are wider than 10 feet; four of these six sites are along relatively unconfined, softrock channels. The other two sites (5, 13) occur along streams narrower than 10 feet. Site 5 is along a high gradient, confined hardrock stream. Site (13) is along a low gradient, confined, colluvial stream.

Table 2. Landscape and stream characteristics at the Hardwood Conversion Study sites.

	Landscape Characteristics			Riparian Management Zone Characteristics		
Site	**Mean elevation (ft)**	**Parent material**	**Mean annual precipitation (in)**	**Slope (mean %, % range)**	**Mean bankfull width (ft)**	**Mean stream gradient (%)**
5	643	Basalt	48	39 (20–80)	7.6	17
8	185	alluvium	103	4 (0– 35)	23.9	2
11	340	basalt	95	<2 (0–10)	13.9	1
12	270	colluvium	95	30 (20-40)[1]	34.5	1
13	460	colluvium	53	51 (10–110)	5.9	3
14	383	colluvium	83	23 (5–85)	10.9	1
15	219	colluvium	83	22 (2–50)	18.0	1
23	249	alluvium & basalt	55	8 (0–45)	21.4	2

[1]Estimate provided by the landowner.

Pre-harvest Stocking

A 100-percent survey was conducted within the combined core and inner zones to collect large tree data (> 5.5 inches dbh) including stumps, snags, and fallen trees. The 100-percent surveys were used to characterize both pre- and post-harvest stocking for large trees; however, stocking specific to the conversion areas, which includes the inner zone and the outer portion of core zone up to 25 feet of the stream, areas cannot be extracted from the 100-percent surveys.

Based on the landowner's professional judgement, it was determined that all eight study sites lacked sufficient stocking in the combined core and inner zones to be on track to meet the desired future condition of 190 - 285 square feet per acre of conifer basal area by 140 years depending on site class (

Table 3). Hardwoods, mostly red alder, dominated on all sites on both basal area and trees-per-acre bases.

Though conifer stocking was limited, average conifer diameters were the same or larger than the dominant hardwoods. Nearly all sites had one or more of the following conifer species: Douglas-fir, western hemlock, and western redcedar. Sitka spruce occurred on half of the coastal sites (sites 8, 11, and 14) and was the only conifer species observed on site 14.

Table 3. Pre-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are percent.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	109	90 (83)	93 (83)	12.9	19 (17)	19 (17)	12.3
8	239	177 (74)	175 (78)	13.1	62 (26)	48 (22)	13.2
11	236	174 (74)	122 (72)	15.6	62 (26)	48 (28)	13.7
12	229	148 (65)	133 (76)	13.7	81 (35)	43 (24)	16.7
13	150	82 (55)	88 (70)	12.4	68 (45)	38 (30)	15.7
14	162	128 (79)	111 (94)	13.7	34 (21)	7 (6)	27.0
15	152	135 (89)	123 (96)	13.4	16 (11)	5 (4)	22.2
23	200	177 (89)	133 (92)	14.9	23 (11)	11 (8)	16.4

Harvest Practices

Figure 2 through Figure 9 depict the spatial extents of the harvest units, hardwood conversion areas, and no-cut harvest riparian buffers. Hardwood conversion areas are located within the area of the core zone and the inner zone not included in the no-cut harvest buffers. Several trends in harvest layout and practice are notable among the study sites.

Generally, harvest units on lands managed by larger industrial landowners (Weyerhaeuser, Longview Fibre, and Pope Resources) are larger than those on lands managed by smaller industrial landowners (Merrill and Ring and Green Crow). For example, sites 5, 13, 14, 15, and 23 include relatively larger proportion of the harvest units in upland[6] areas while sites 8, 11, and 12 have a higher proportion of their harvest unit in the RMZ.

Hardwood conversion prescriptions were approved under a “Feasibility/Pilot Study” alternate plan. Relative to standard rules, these prescriptions more than doubled the harvestable areas in the core and inner zones. The alternate plan used in the study allowed landowners to harvest up to 25 feet from the stream bank—half of the width of the core zone. Rules protecting “sensitive sites” still applied and landowners were expected to leave all conifers.

Hardwood conversion areas tend to be variable in width depending on many factors, including: the location of accessible and commercially valuable hardwoods; presence of sensitive sites, typically seeps; un-harvestable pockets of dense vine maple or other shrubs; areas with low

[6] Upland refers to the harvested area encompassed by the outer zone of the RMZ plus all harvested areas outside the RMZ. These are areas that would be harvested without hardwood conversion.

probability of successful conifer regeneration; patches of conifers which did not represent an obstruction or hazard; and, other inaccessible areas of the core/inner zone.

Despite these differences in unit layouts, all sites had relatively small (that is, less than 5 acres) hardwood conversion areas (Table 4). In total, only 20.5 acres were converted during this pilot study. Hardwood conversion areas were largest, both in total extent and relative extent, at sites managed by Green Crow and Merrill and Ring. In comparison, hardwood conversion areas were smaller where the overall unit size was greater.

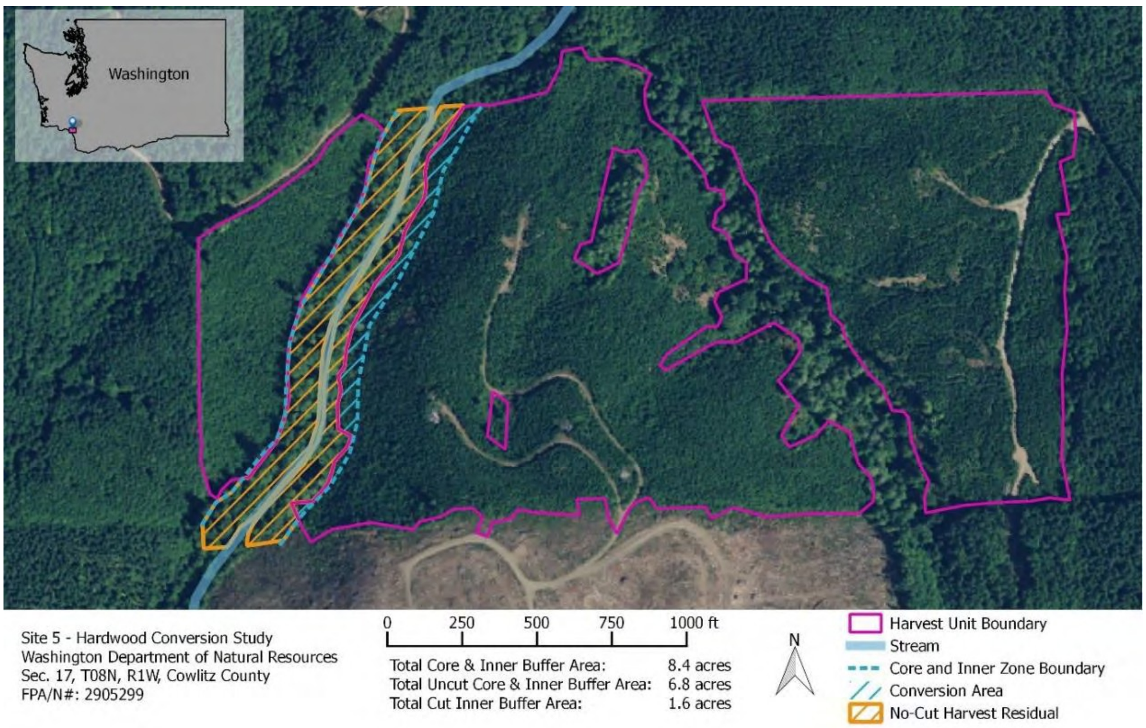

Figure 2. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 5. Aerial imagery collected in 2016.

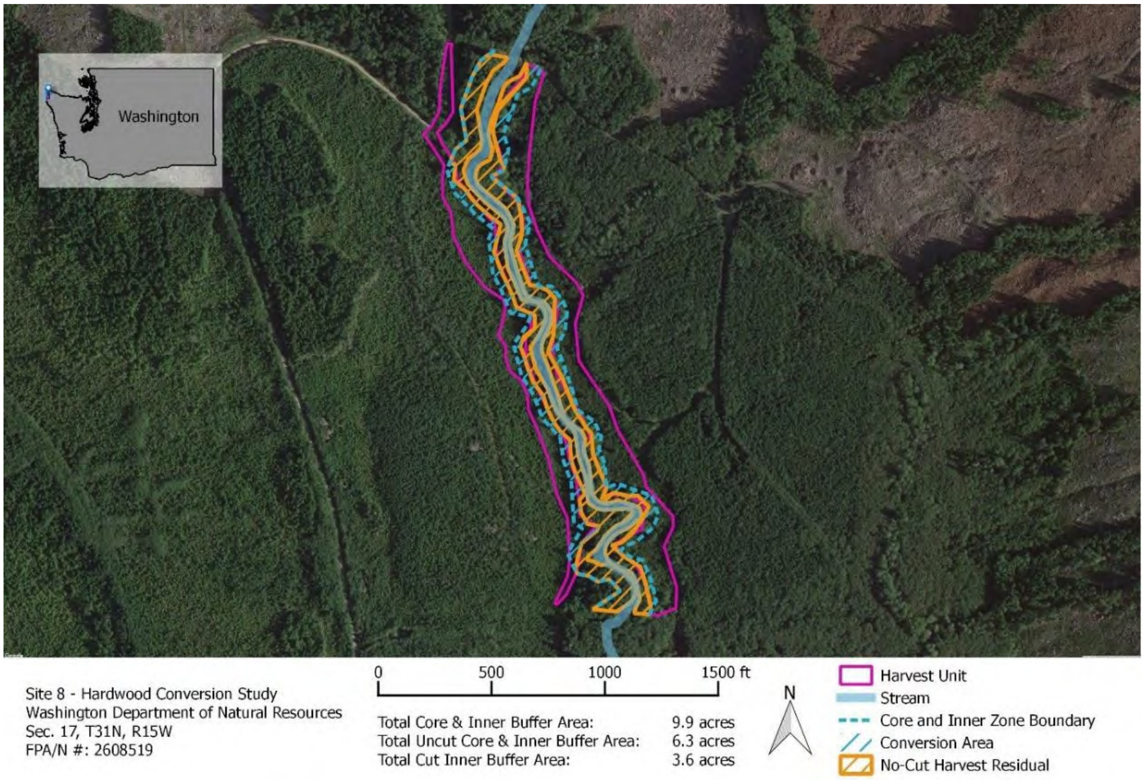

Figure 3. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 8. Aerial imagery collected in 2016.

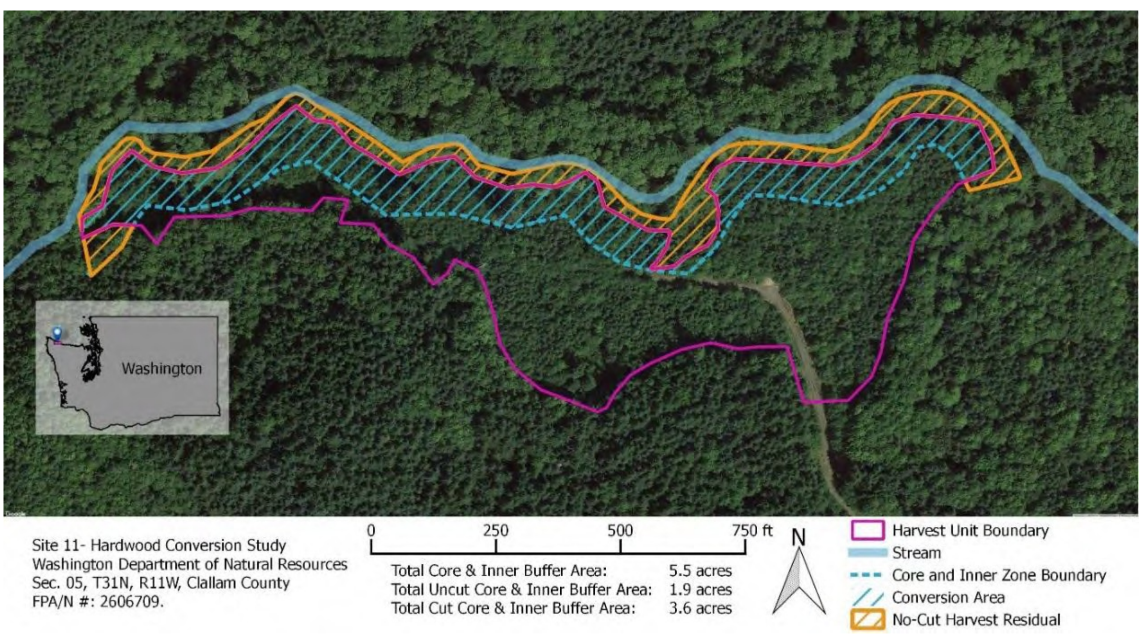

Figure 4. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 11. Aerial imagery collected in 2016.

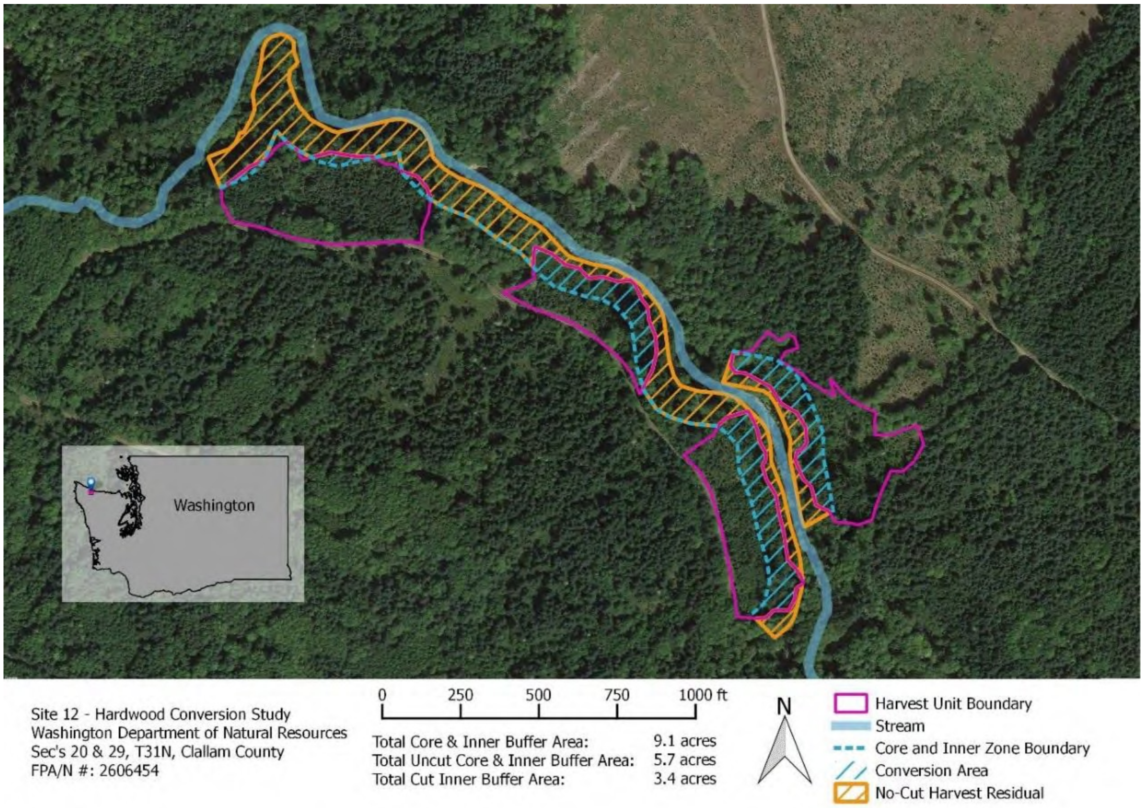

Figure 5. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 12. Aerial imagery collected in 2016.

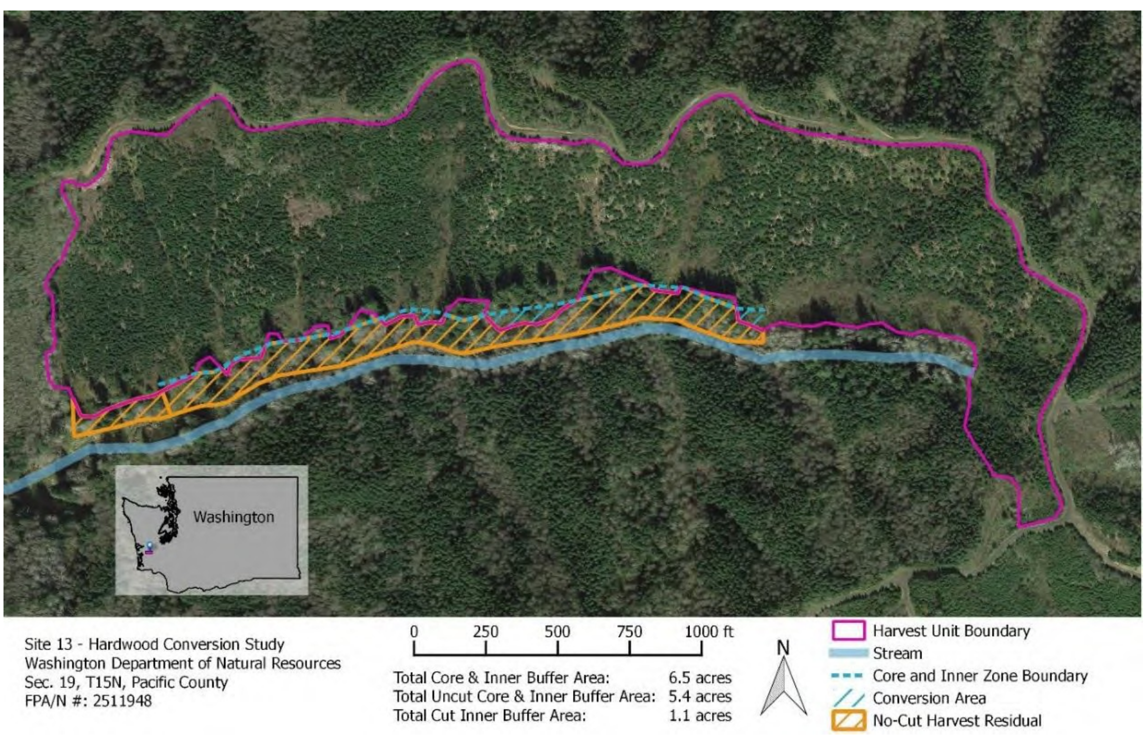

Figure 6. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 13. Aerial imagery collected in 2016.

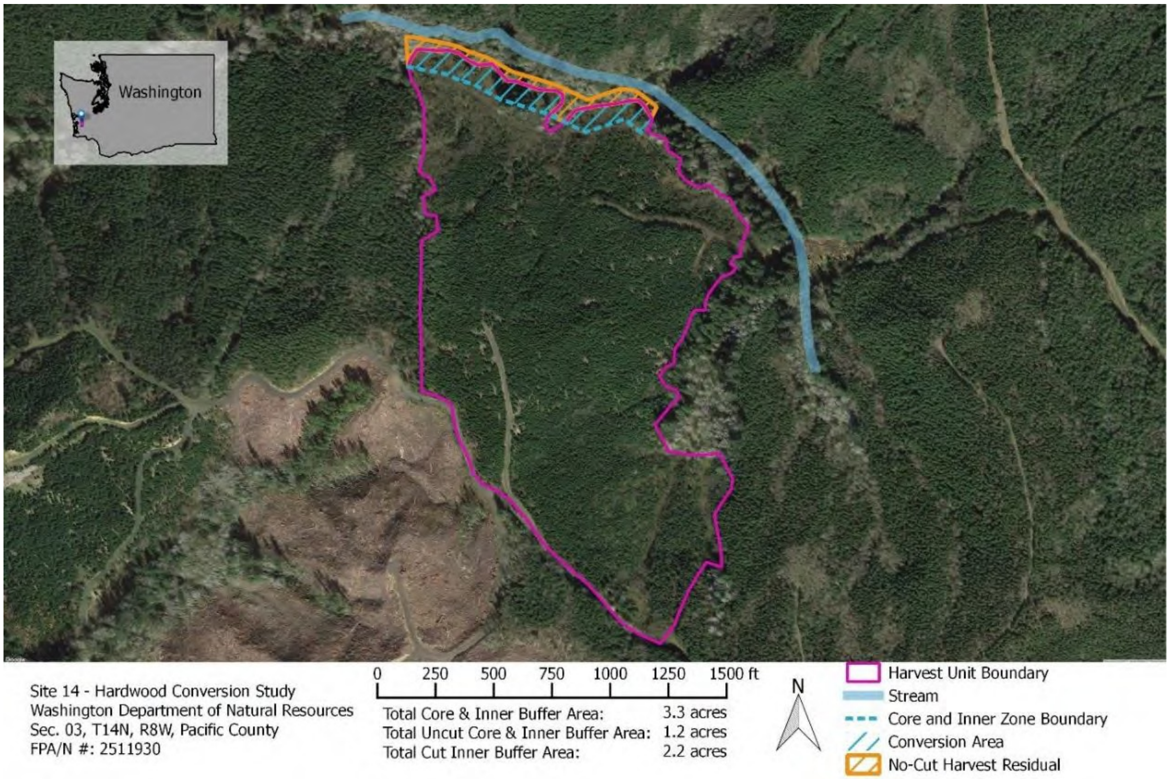

Figure 7. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 14. Aerial imagery collected in 2016.

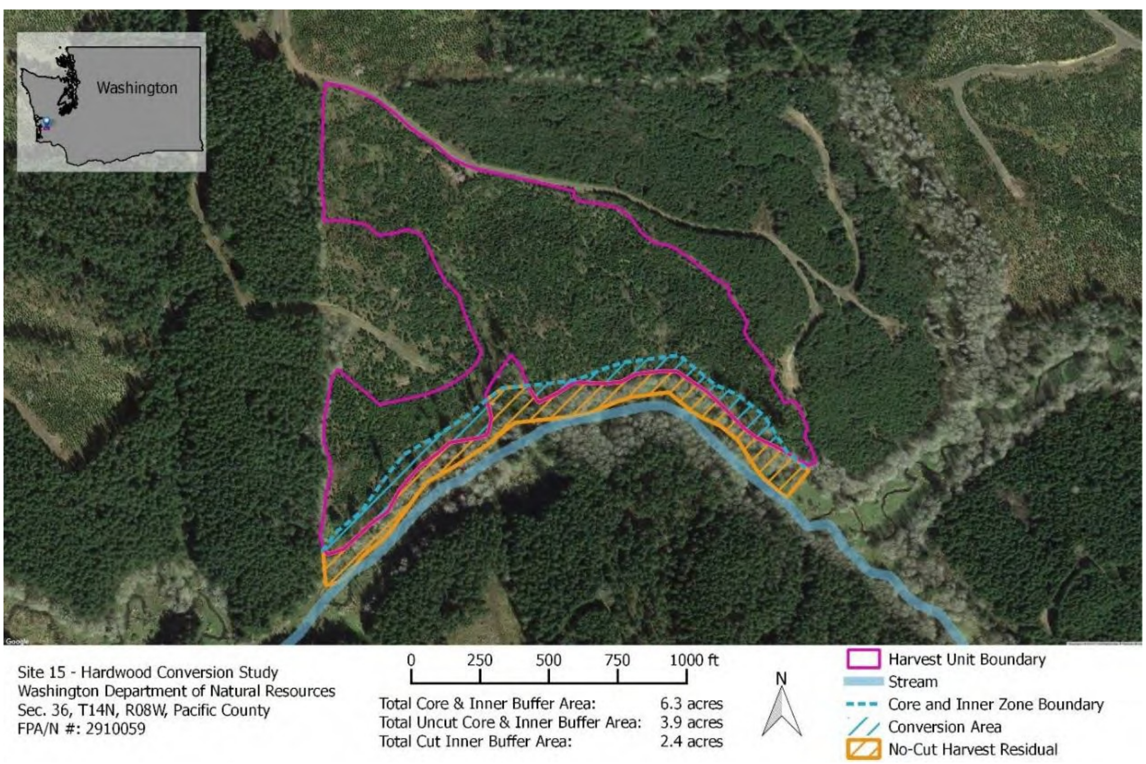

Figure 8. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 15. Aerial imagery collected in 2016.

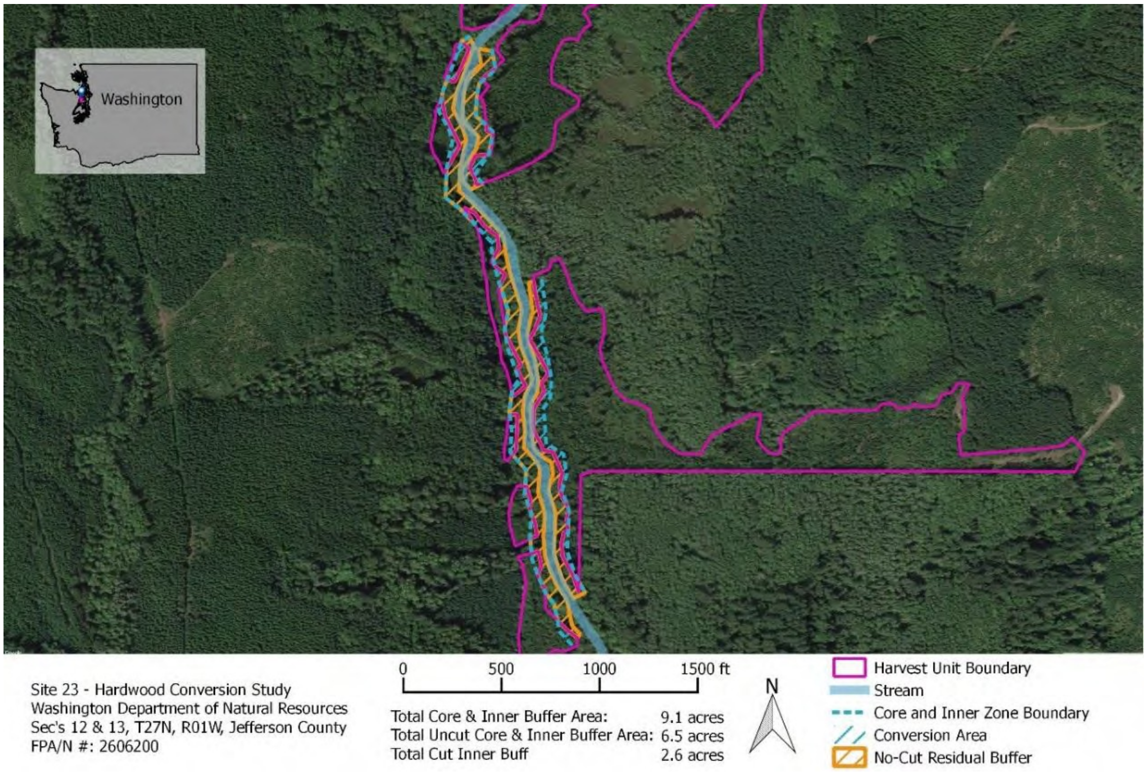

Figure 9. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 23. Aerial imagery collected in 2016.

Table 4. Extent of harvest unit, upland, combined core and inner zones, and hardwood conversion areas.

Site	Harvest Unit Area (ac)	RMZ Width (ft)	Stream Segment Length (ft)	Upland Area (ac)	Combined Core and Inner Zone Area (acre)	Hardwood Conversion Area (ac)
5	68.0	113	1,800	66.4	8.4	1.6
8	14.0	68	2,970	10.4	9.9	3.6
11	8.5	105	2,200	4.9	5.5	3.6
12	15.0	105	3,500	11.6	9.1	3.4
13	62.0	128 -- 113	2,600	60.9	6.5	1.1
14	51.0	128	1,150	48.8	3.3	2.2
15	33.0	128	2,100	30.6	6.3	2.4
23	62.7	68	3,100	60.1	9.1	2.6

Post-harvest Stocking

Post-harvest stocking (nominally, Year 0) was determined for both the combined core zone and inner zone as well as for the hardwood conversion areas within the combined core zone and inner zone. Post-harvest stocking in the combined core zone and inner zones could be summarized directly from post-harvest plot measurements (Table 5). Compared to pre-harvest levels in the combined core zone and inner zone (

Table 3), post-harvest stocking was between about 50 and 80 percent of pre-harvest stocking levels.

Post-harvest stocking in the hardwood conversion areas (Table 6) was estimated by applying ratios calculated at year 10 (stocking in hardwood conversion area to stocking in the combined core zone and inner zone) to the Year 0 values reported in the combined core zone and inner zone (Table 5). Compared to pre-harvest levels in the combined core zone and inner zone (

Table 3), post-harvest stocking in the hardwood conversion areas is substantially lower. Little to no hardwood stocking remains and very little conifer was removed.

Table 5. Post-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are the percent of basal area remaining after harvest.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	84 (77)	72 (80)	72	13.2	12 (63)	8	14.4
8	182 (76)	125 (71)	118	13.4	57 (92)	41	13.7
11	118 (50)	87 (50)	48	17.8	31 (50)	24	13.7
12	154 (67)	77 (52)	66	14.1	77 (95)	39	17.0
13	124 (83)	58 (71)	61	12.5	67 (99)	36	15.9
14	85 (52)	62 (48)	52	13.9	23 (68)	4	30.8
15	107 (70)	91 (67)	70	14.6	16 (100)	5	22.7
23	129 (65)	109 (62)	82	15.0	20 (87)	9	16.9

Table 6. Post-harvest riparian stand characteristics within the hardwood conversion areas. Values in parentheses are percentages remaining after harvest.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	6	6 (100)	80 (94)	0.9	0 (0)	5 (6)	1.9
8	64	15 (23)	110 (72)	1.7	41 (77)	43 (18)	9.8
11	27	1 (4)	57 (71)	0.1	23 (96)	23 (29)	11.1
12	65	7 (11)	57 (58)	1.7	55 (89)	41 (42)	10.8
13	41	0 (0)	-- (0)	0.0	37 (100)	47 (100)	5.3
14	36	0 (0)	-- (0)	0.0	28 (100)	4 (100)	35.5
15	28	1 (4)	67 (93)	0.2	22 (96)	5 (7)	26.8
23	5	0 (0)	-- (0)	0.0	4 (100)	7 (100)	5.5

Post-harvest Overstory Cover

Post-harvest overstory cover[7] in the hardwood conversion areas is calculated two ways in Table 7—the percent of all regeneration plots where overstory cover existed and the average percent overstory cover over all plots. Overstory cover could occur from residual conifers and hardwoods as well as from adjacent, overhanging hardwood or conifer trees. Though the percent of regeneration plots with some overstory cover could be relatively high—most sites had nearly 50 percent or more plots with some cover—the overall average percent overstory cover at these sites was relatively low—most sites had less than 15 percent cover.

Table 7. Post-harvest overstory tree cover within the hardwood conversion areas. Values in parentheses are standard deviation.

	Overstory Above Sample Plots	
Site	Percent of regeneration plots with overstory cover (%)	Average percent overstory cover (%)
5	7	1 (2.7)
8	32	4 (5.9)
11	47	8 (13.1)
12	50	10 (15.7)
13	46	5 (6.3)
14	45	13 (22.0)
15	84	22 (23.5)
23	83	11 (10.9)

[7] Overstory cover sampling methodologies were not specified in field protocols provided for this summary report, which introduces an unknowable level of uncertainty in these values. Values reported in this section come from Brown (2016).

Regeneration Practices

Regeneration practices employed at the eight study sites are summarized in

Table 8. Key practices included site preparation, animal control, planting, and vegetation control that occurred after planting. Additional information about planting histories and the planted tree heights are summarized in

Table 9 and Table 10. Detailed accounts of the regeneration practices employed are provided in the Case Study Report. A brief synthesis is provided here.

Though all sites were treated with what most foresters would consider standard regeneration practices for the region, hardwood conversion areas managed by Merrill and Ring (sites 11 and 12) received the most intensive regeneration management:

- Only the sites managed by Merrill and Ring (11 and 12) received site preparation. This consisted of shovel-piling slash and shrubs—notably including large vine maple plants—in the conversion areas outside the equipment exclusion zone prior to planting, and then burning the debris before or during the planting period.
- Mountain beavers were trapped three times at these two sites, each trapping associated with each of the three different plantings that occurred—one initial planting with two follow-up interplantings to "fill" stocking. The six other study sites received one trapping, at most, after the initial planting.
- Western redcedar planting densities were higher at these two sites than at other sites. To minimize browse damage, Sitka spruce was planted in the same planting hole as western redcedar so that the prickly needles of the spruce would deter deer- and elk-browse. (The landowner plans to remove the Sitka spruce when western redcedar seedlings exceed browsing height.)
- When the double planting is accounted for, actual planting densities are about one-third lower than shown in

- Table 8. Even with an adjustment, planting densities are higher than at the other sites. Merrill and Ring interplanted their two sites twice.
- Less emphasis was placed on Douglas-fir planting at these two sites compared to that at all but one (site 8) of the six other study sites.
- Sites 11 and 12 were the only study sites to receive post-planting brush control. Brush was cut with a chainsaw 1 year after the initial planting at site 12 and cut with a chainsaw 2 years after the initial planting at site 11.
- Alder slashing was conducted at sites 11 and 12 to control volunteer hardwood stocking.

In comparison, the six other study sites—managed by Green Crown, Pope Resources, and Weyerhaeuser/Longview Fibre—received no site preparation prior to planting, and two sites (5 and 8) received brush control after planting. Other key differences at these other study sites include:

- Weyerhaeuser (sites 13, 14 and 15) trapped mountain beavers once: in January, after their three sites were initially planted with western hemlock. Sites 5, 8 and 23 had little if any evidence of mountain beaver, thus no mountain beaver trapping was done.
- Longview Fibre (site 5), installed paper bud caps on the planted Douglas-fir and mesh tubing on the planted western redcedar seedlings. Pope Resources (site 23) installed mesh tubing on about one quarter of the western redcedar seedlings that were interplanted 3 years after the initial planting event.
- With the exception of the site managed by Green Crow (site 8), Douglas-fir was the species of emphasis on the six other study sites. It was planted in association with, or after planting, one or more of the following species: western hemlock, Sitka spruce, western redcedar, and grand fir. In most instances, Douglas-fir was planted the year following harvest.
- Sitka spruce was the only species planted at the Green Crow site (site 8). Harry Bell, chief forester at Green Crow explained that his preference is to plant Sitka spruce in areas not susceptible to tip weevil damage when there is no expectation of future harvest (RSAG, personal communication).
- Precommercial thinning and hardwood slashing was conducted at sites 5 and 8.

Table 8. Summary of regeneration practices employed within hardwood conversion areas.

	Site							
	5	8	11	12	13	14	15	23
Site preparation:								
Mechanical slash pile & burn	--	--	Yes	Yes	--	--	--	--
Animal control:								
Mtn. beaver trappings (no.)	--	--	3	3	1	1	1	-
Seedling Protection	Y[1]	--	Y[2]	Y[2]	--	--	-	Y[3]
Planting:								
Growing seasons before planted	1	0	0	0	0	0	0	0
Initial planting (TPA)[4]	554	451	752	740	212	80	145	248
Inter-plant (TPA)	0	0	275	450	215	245	158	15
Douglas-fir (%)	86	0	4	4	50	75	52	36
Major stock type	FP+1[5]	P+1[6]	P+1	P+1	1+1[7]	1+1[7]	1+1[7]	P+1
After planting brush control:								
Hand Brushing (w/ chainsaw)	--	--	Y	Y	--	--	--	--
PCT/Slashing	Y	Y	Y	Y	--	--	--	--

[1]Paper bud caps and mesh tubing; [2]Sitka spruce planted with redcedar; [3]Mesh tubing on western redcedar at time of planting, nets with stakes on 150 of the 600 interplanted redcedar; [4] density estimates based on field data; [5]FP+1 = plug+1 seedlings transplanted early ('F' signifies fall transplanting) to increase time in nursery bed prior to outplanting at site; [6]P+1 = seedlings grown in a container (plug) for 1 year, then grown in nursery bed for 1 year; [7]1+1 = seedlings grown in nursery bed at high density for 1 year, then transplanted to a lower density and grown for 1 year.

Table 9. Summary of trees per acre (TPA) planting density in hardwood conversion areas.

Site	Planting Date	TPA Planted					Total
		DF	WH	RC	SS	GF	
5	Feb. '07	479	--	75	--	--	554
8	March '08	--	--	--	451	--	451
11	Feb. '06	31	161	288	295	--	775
	Feb. '07	2	48	92	88	--	230
	Feb. '10	--		34	30	--	64
12	Feb. '06	15	140	290	295	--	740
	Feb. '07	40	48	148	138	--	373
	Feb. '10	--		63	63	--	126
13	Spring '05	--	219	--	--	--	219
	March '06	215		--	--	--	215
14	Spring '05	--	83	--	--	--	83
	March '06	243		--	--	--	243
15	Spring '05	--	147	--	--	--	147
	Feb. '06	158	--	--	--	--	158
23	Jan. '05	94	--	38	102	15	249
	Jan. '09	--	--	15	--	--	15

Table 10. Summary of planted tree heights, in inches, in hardwood conversion areas.

Species	Site							
	5	8	11	12	13	14	15	23
Douglas-fir	20.4	--	14.4	13.2	13.2	14.4	13.2	19.2 [2]
Western hemlock	--	--	22.8	24.0	28.8 [1]	30.0 [1]	26.4 [1]	--
Sitka spruce	--	15.6	16.8	16.8	--	--	--	18.0 [2]
Western redcedar	12.0	--	16.8	16.8	--	--	--	21.6 [2]
Grand fir	--	--	--	--	--	--	--	16.8 [2]
Mean	19.3	15.6	17.9	18.1	13.2	14.4	13.2	18.9

[1]Seedling height at the time of planting was likely shorter because heights were first measured approximately 12 months after planting.
[2]Seedling height at the time of planting was likely shorter because heights were measured approximately 16 months after planting.

Evaluation

Table 11 summarizes metrics used to answer Questions of Interest posed in the Hardwood Conversion Study Plan that are being addressed in this report. Generally, silvicultural performance is evaluated by survival, height growth, and free-to-grow status. Economic performance is evaluated by harvest and regeneration costs. Factors related to silvicultural and economic performance are evaluated using modeling described in the Discussion section.

Table 11. Analytical metrics used to address selected Questions of Interest in the Hardwood Conversion Study Plan.

Question of Interest	Analytical Metrics
Silvicultural Performance	
What were the survival rates of planted seedlings in the RMZ?	Survival at year 4 and year 10.
What were the growth rates of planted seedlings in the RMZ?	Height growth at year 4 and year 10.
How many conifers are free-to-grow in the RMZ?	Number of conifers greater than 8 inches dbh, number of seedlings and saplings above brush, number of seedlings and saplings above natural hardwood regeneration, and percent stocking of conifers seedlings and saplings at year 4 and year 10.
What regeneration strategies did landowners use to ensure successful conifer regeneration in the RMZs?	Correlation of stocking, survival, growth rate, free-to-grow, at year 4 and year 10, to selected landowner cultural practices (such as animal control, brush control, and alder control).
What were the primary problems that landowners faced regenerating the RMZs with conifers?	Correlation of stocking, survival, growth rate, free-to-grow, at year 4 and year 10 to selected site factors (such as habitat type group, overstory cover, understory cover, landform, distance to stream, need for animal control).
Economic Performance	
What additional harvest costs resulted from adding hardwood conversion treatments to the harvest prescription?	Harvest costs.
How much wood (volume, board feet) was harvested from the riparian management zones?	Harvest volumes.
How much wood (volume, board feet) was harvested from the upslope portions of the units?	Harvest volumes.
What were the cost differences between successfully regenerating conifers in the riparian area versus successfully regenerating conifers in the adjacent, upslope areas?	Regeneration costs.
What were the net financial gains (or losses) that resulted from adding riparian hardwood conversion treatments to the harvest prescriptions?	Residual value.
What were the primary reasons for different costs (if any) between regenerating conifers in riparian areas versus regenerating conifers in adjacent, upslope areas?	Correlation of regeneration costs to cultural factors and site factors listed above.

Silvicultural Performance

Metrics used to answer questions regarding silvicultural performance are based on regeneration surveys that have been conducted following the procedures outlined in a series of Post-Harvest Regeneration Survey Procedures Manuals (Versions 1.3 thru 2.1). These procedures include plot layout, data collection, and data reduction protocols:

- Regeneration plot layout – Planted tree and competing vegetation data have been collected on monumented, 1/50–acre circular plots (33.3 feet in diameter) installed on a grid pattern within the hardwood conversion areas. Plot-center spacing is approximately 60 by 60 feet. The number of plots and realized sampling intensity varied by site (Table 12) with an average of approximately 22 plots used covering approximately 18% of the hardwood conversion areas.

- Tree data collection – During each sampling event, the number of live and dead planted and natural seedlings are recorded by species, along with tree attributes including height, diameter at breast height, and live-crown ratio. Tree surveys are conducted either in the spring, prior to conifer "budbreak" and seasonal height growth, or in late fall after most seasonal conifer height growth had occurred.

  The concept of a "Growth Year" was used to establish the period that the data represent. We define growth year as a one-year period starting July 1, and use the year associated with the July 1 start date to designate the growth year (e.g., a survey conducted on April 15, 2006 would be in the 2005 Growth Year).

  Though field crews could reliably observe conifer mortality—including missing trees presumed dead, as well as extant dead trees—field crews were not able to reliably assign specific causes of mortality. This confounds data interpretation, particularly the interpretation of the relationships with animal-browse and of the relationships with animal control.

  Likewise, crews were not able to readily identify damage or causes of damage to seedlings resulting in some trees losing height between measurements, which would not occur without damage to the tree. These "shrinking" trees were not used in height growth calculations because these trees would introduce bias to the analysis. However, these trees were used in other analyses.

- Competing vegetation data collection – During each sampling event, the mean percent cover of residual trees, shrubs, ferns, grasses, and herbs are visually estimated within each plot. These surveys are conducted at the same time as the planted tree surveys. Though these shoulder seasons increased the visibility of conifer while brush was not leafed-out, they are not the ideal time to observe some vegetation species because many have not emerged, have not leafed out, or have already receded since their peak.

- Data reduction – Field data are recorded in a Microsoft Access database and reduced following standard forest biometrics practices. Database schemas are documented via Post-Harvest Regeneration Survey Procedures Manuals (Versions 1.3 thru 2.1). Data reduction routines were implemented using R software (R Core Team 2017). R code for this report is documented in the R project distributed with this report.

- Statistical modeling – To identify factors statistically explaining free-to-grow status of planted trees in the hardwood conversion areas, we created a generalized linear model using logistic regression in the R statistical software (R Core Team 2017). Free-to-grow status is dichotomous variable specifying whether tree was alive and did, or did not, have its leader above the brush at 10 years after planting. Stepwise regression was used to sequentially select the most influential factors explaining the likelihood of a tree surviving and having its leader above the brush 10 years after planting. Factors considered in the stepwise regression included:
  - Site-level (N = 8):
    - Site number as a surrogate for all unmeasured site variables
    - Site preparation occurrence
    - Brush control occurrence
    - Planted trees per acre for each species
  - Plot-level (N = 94):
    - Year 0 post-harvest cover and mean height of shrubs, ferns, herbs, and grasses
    - Year 4 post-harvest cover and mean height of shrubs, ferns, herbs, and grasses
    - Year 0 post-harvest volunteer hardwood basal area and trees per acre
    - Year 4 post-harvest volunteer hardwood basal area and trees per acre
    - Year 0 post-harvest retained overstory cover
    - Landform - hill slope or grouped fluvial terrace/floodplain
    - Slope
    - Aspect
    - Plot center distance from the stream
  - Tree-level (N = 2,122 unique trees):
    - Tree species
    - Interplanting status – whether the tree was planted initially or in one of the interplantings.

Parameters were selected in stepwise regression using the stepAIC function starting with a null model with only an intercept parameter and then sequentially adding parameters keeping only those that reduce the resulting model's AIC score. Significance of terms in the final model were evaluated relative to an *a priori* five percent level of significance (i.e., P-value <= 0.05).

In this report, metrics are calculated for nominal time periods "Year 0" (post-harvest), "Year 4" (four years since timber harvest), and "Year 10" (ten years since timber harvest). However, because timber harvest and planting occurred on different schedules, the actual time periods vary site-to-site as reported within tables and figures.

Table 12: Sampling plot summary including the number of plots, sampling intensity, and percent area sampled at each site.

Site	Hardwood Conversion Area (ac)	Plots	Sampling Intensity (plots/ac)	Percent Area Sampled
5	1.6	14	8.8	17.5
8	3.6	38	10.6	21.1
11	3.6	32	8.9	17.8
12	3.4	20	5.9	11.8
13	1.1	13	11.8	23.6
14	2.2	20	9.1	18.2
15	2.4	19	7.9	15.8
23	2.6	23	8.8	17.7

Economic Performance

To assess the cost/benefit of adding hardwood conversion to the harvest unit prescription, the following study-specific definitions are used in evaluating economic performance:

- Upland refers to the harvested area encompassed by the outer zone of the RMZ plus all harvested areas outside the RMZ. These are areas that would be harvested without hardwood conversion.

- Conversion area refers to the area within the core and inner zones of the RMZ that is being converted to conifer-dominated stands under WAC 222-30-021(1)(b)(i).

This area distinction permits comparison of the economic performance of site operations with hardwood conversion areas to economic performance without hardwood conversion. Without hardwood conversion, it is assumed that riparian harvest would only have occurred in the outer zone. Thus, the designation of the outer zone as “upland” is made solely to support the economic analysis—this designation does not presume any ecological meaning.

This report summarizes, at a unit level, the detailed economics analyses presented in the Case Study Report. Briefly, economic analyses use stumpage values published by the Washington Department of Revenue for the period when harvesting occurred (2005 – 2007 when red alder log prices were relatively consistent), which includes mill-gate log prices, harvest system-based stump-to-truck costs, and location-based haul costs. Additional costs, including site preparation and planting, unit layout, and administrative costs provided by landowner are deducted from the overall stumpage to arrive at a net residual value. For details of the economic analysis see the Case Study Report for economic data sources, methods, assumptions, and limitations underlying its evaluation of economic performance.

Study Limitations

Because this study was a collection of case studies there is no overarching experimental design. Conditions on the site do not span the range of conditions that may be encountered across the population of sites that may be encountered in areas that may be candidates for hardwood conversions. Further, site-specific prescriptions were developed by landowner to fit site conditions and operability within the limitations of the general prescription guidelines resulting in unique site-specific prescriptions. While the lack of experimental design can preclude inference about the larger population of potential hardwood conversion sites, the data can be qualitatively evaluated to elucidate overarching patterns across the sites.

RESULTS

Silvicultural Performance

Shrubs, Forbs, and Grass

Appendix A, Figure 10, and

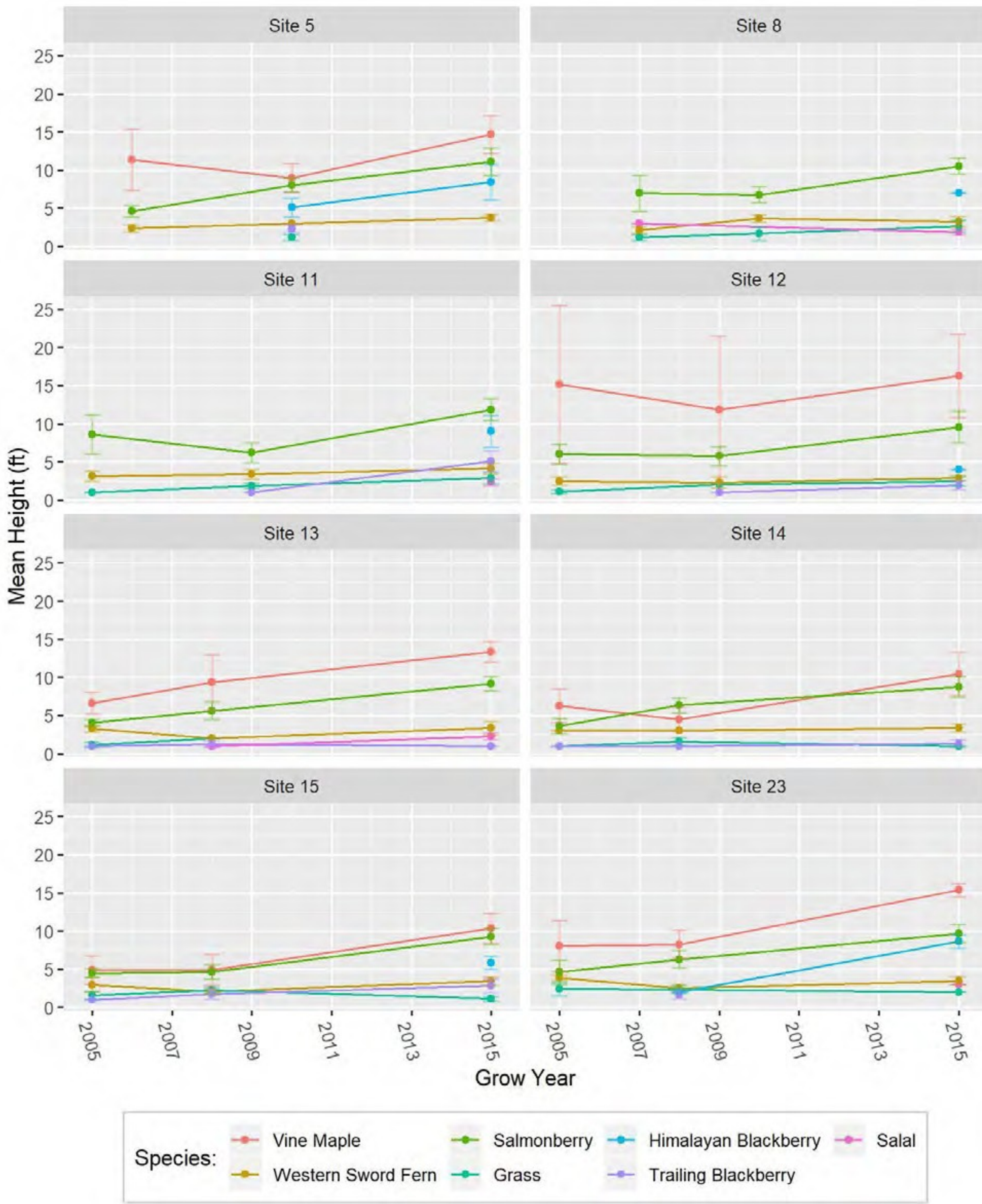

Figure 11 summarize the average shrub (including vine maple (*Acer circinatum*), salmonberry (*Rubus spectabilis*), salal (*Galtheria shallon*), trailing blackberry (*Rubus ursinus*), and Himalayan blackberry (*Rubus armeniacus*)), forb (primarily western sword fern (*Polystichum munitum*)), and grass cover and height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Where mechanical site preparation within the hardwood conversion areas was conducted to reduce shrub cover prior to planting (sites 11 and 12), year 0 shrub cover was less than 20 percent and remained below 20 percent four years post-harvest, presumably because of hand-brushing that occurred after the initial planting. Elsewhere, shrub cover exceeded 20 percent, often by a large amount, at year zero- and four-years post-harvest. By year 10 shrub cover exceeded 20 percent within regeneration plots on all eight study sites.

Salmonberry was the most common shrub at all but one site (site 15) by year 4 and remained the most common shrub at most sites 10 years post-harvest. By year 4, mean heights of salmonberry ranged between about 5 to 8 feet. By year 10, mean heights of salmonberry ranged between about 9 and 16 feet—near its maximum height potential of about 13 feet (Barber 1976). Other notable shrubs observed at the study sites included vine maple (3 sites), trailing blackberry (3), Himalayan blackberry (1), and salal (1). Vine maple and Himalayan blackberry tended to be as tall as salmonberry where they co-occurred; trailing blackberry and salal were significantly shorter, with average heights of less than 3 feet.

Grass and forbs (predominantly western sword fern) also occurred in various combinations at all study sites, but they occurred at relatively lower average percent covers compared to the predominant shrub cover (average combined cover at most sites was less than 30 percent) and at relatively lower average heights compared to the predominant shrub cover (average height was less than 4 feet). Percent cover of grass and forbs has decreased over time, presumably as shade from shrub cover has increased.

Volunteer Hardwoods

Appendix B, Figure 12, and Figure 13 summarize the average trees per acre stocking and the average height of volunteer hardwoods on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Though absent from most sites immediately post-harvest, red alder has been recorded at all sites since then. Though trends in red alder stocking over time are mixed—stocking is decreasing at some sites, while stocking is increasing at others—by year 10, red alder stocking was low to moderate—ranging between about 20 trees per acre and 200 trees per acre—at all but site 11 (about 500 trees per acre).

At year 0, the average height of red alder was less than 3 feet when it was found. By year 4, the average height of red alder ranged between about 3 and 7 feet. After year 4, height growth ranged between 2 and 3 feet per year at most sites. By year 10, the average heights of red alder were about 20 feet at most sites. Red alder height growth was very high at site 23 (about 4 feet per year) yielding an average height of nearly 40 feet—about twice the average height of red alder at all other sites.

Other volunteer hardwood species recorded at these sites were present at lower stocking levels and/or lower canopy positions compared to those of red alder. Cascara has been recorded at six of the eight study sites and has predominated on the three study sites converted by Weyerhaeuser (sites 13, 14, and 15). Where cascara occurred, average heights were always lower than those of red alder. Big leaf maple and bitter cherry have occurred on some sites, but at relatively low stocking levels and, in the case of bitter cherry, at relatively low heights.

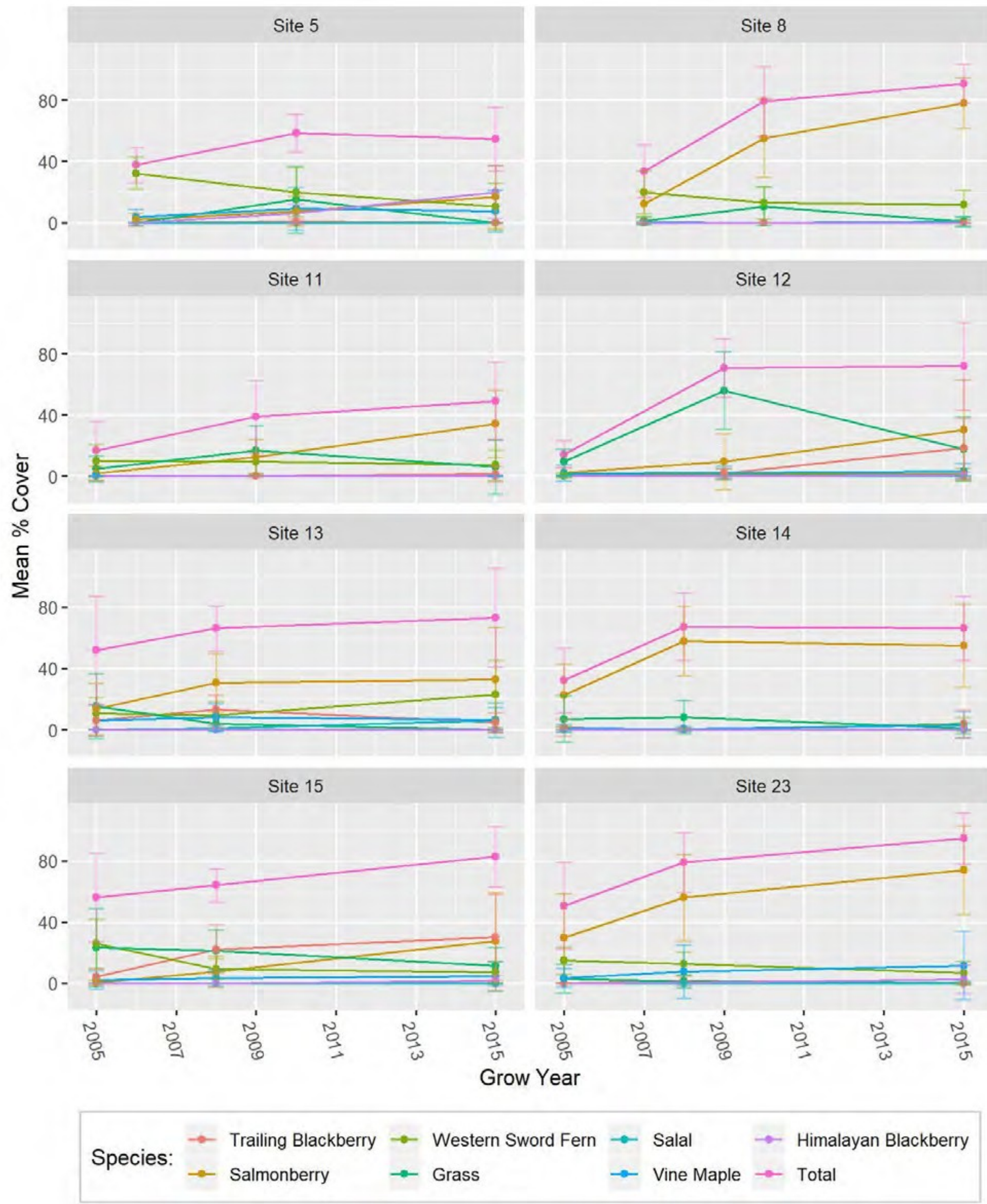

Figure 10. Average shrub, forb, and grass cover on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are one standard deviation.

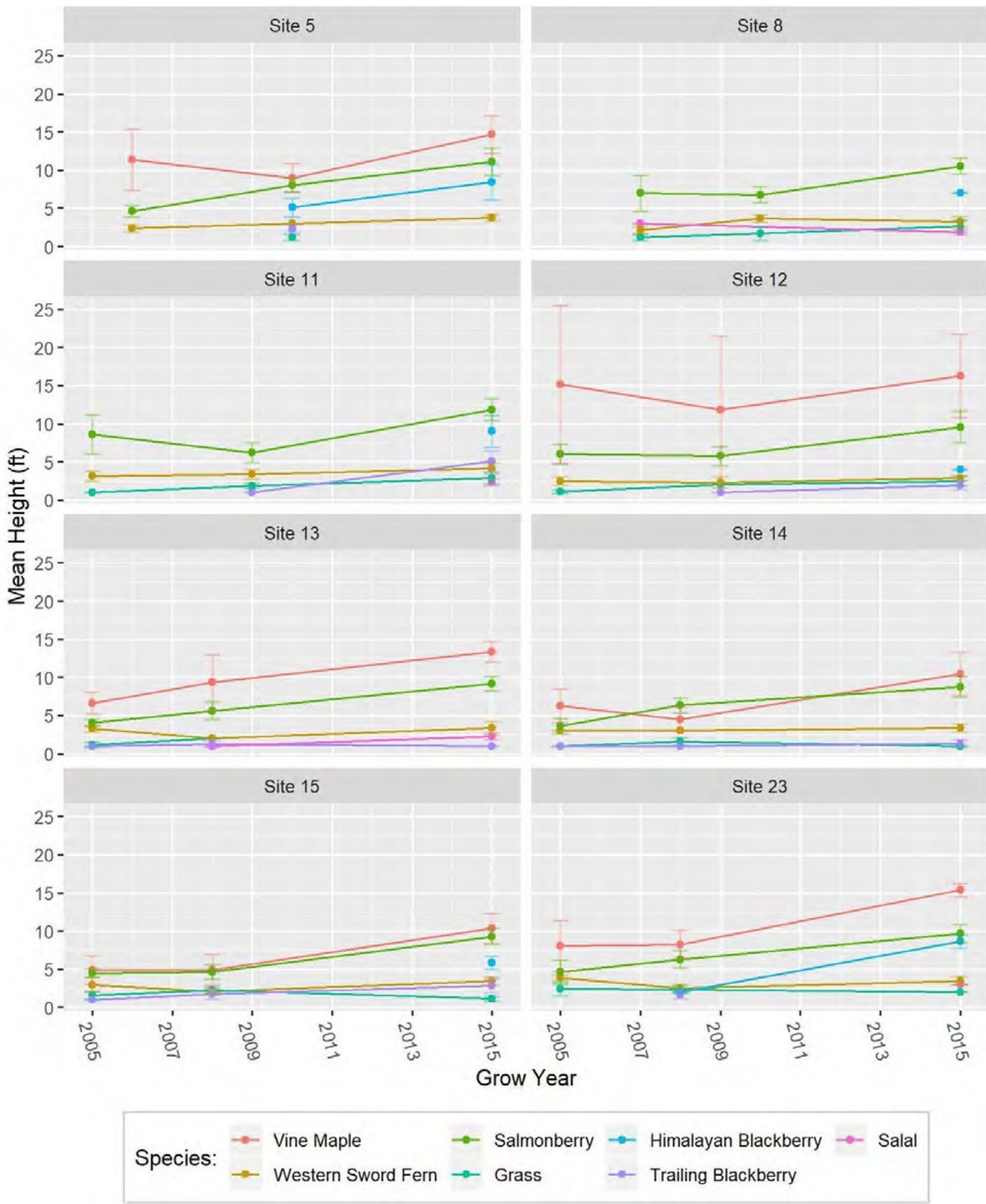

Figure 11. Average shrub, forb, and grass height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are one standard deviation.

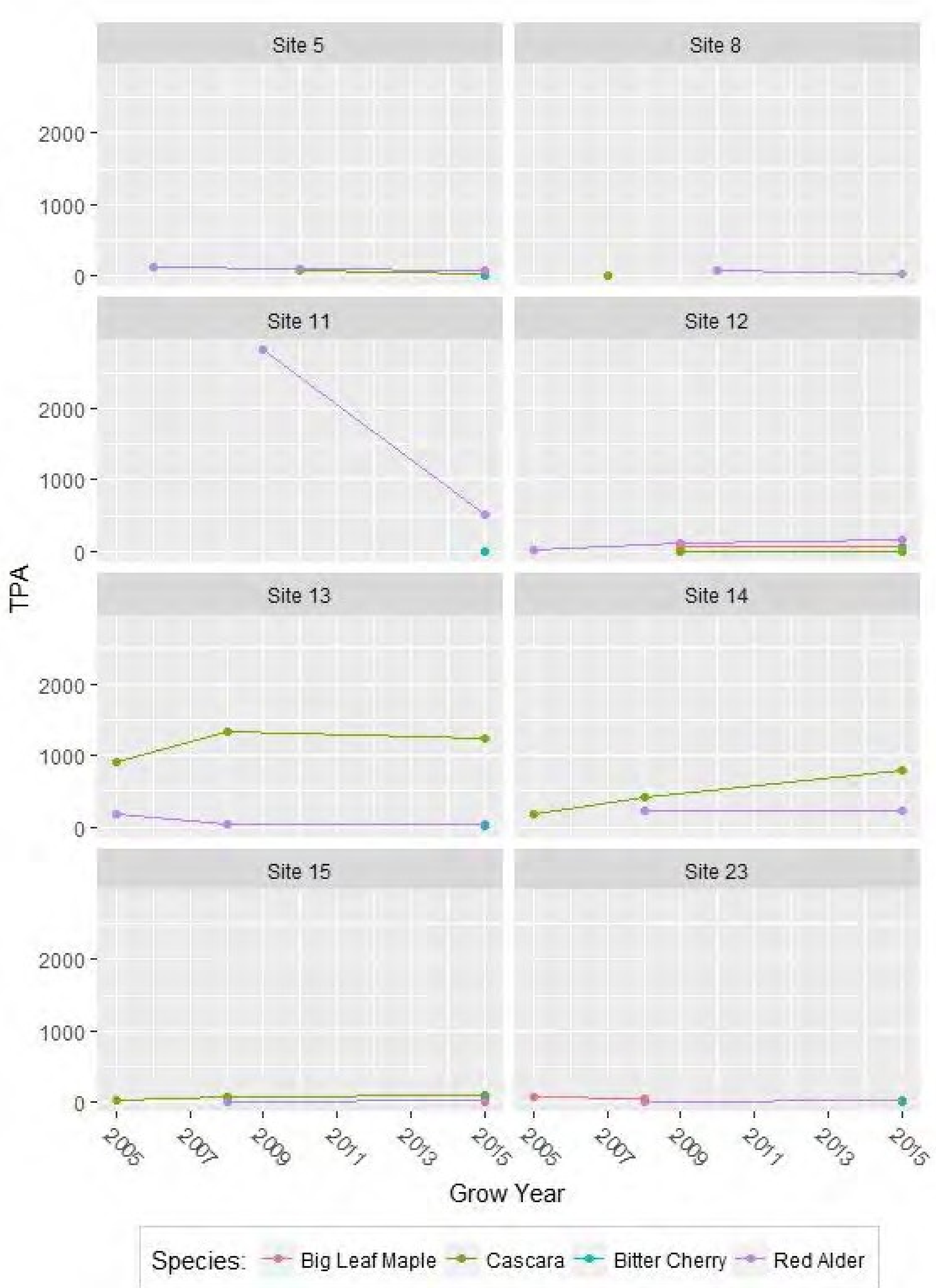

Figure 12. Average volunteer hardwood stocking on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are omitted for clarity of trends due to extremely high Coefficients of Variation.

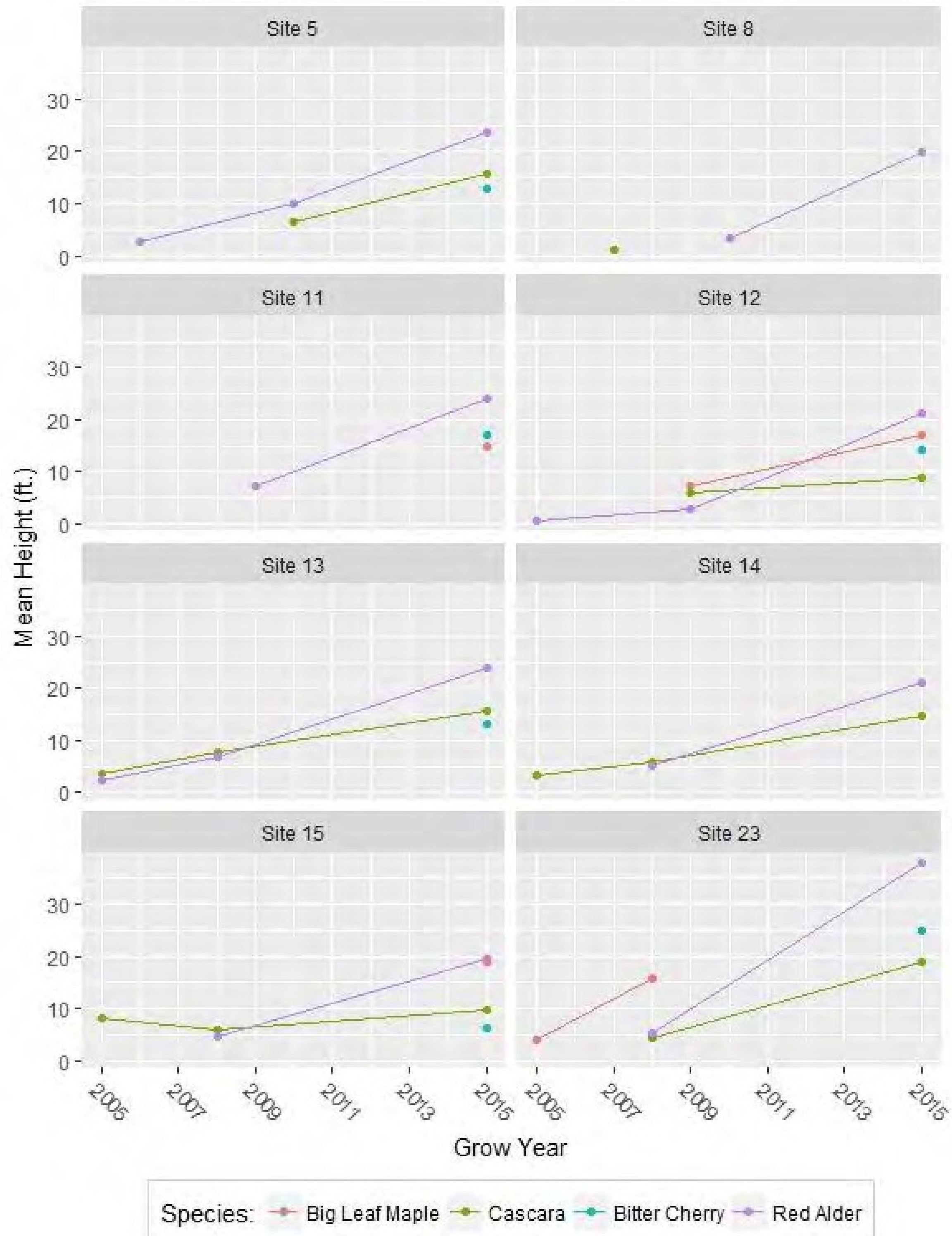

Figure 13. Average volunteer hardwood height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are omitted for clarity of trends due to extremely high Coefficients of Variation.

Conifer Height Growth

Appendix C, Figure 14, and Figure 15 summarize the average height growth of conifers, by species and by leader position, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Height growth of all species accelerated over time. Where western hemlock was planted—sites planted by Merrill and Ring (sites 11 and 12) and Weyerhaeuser (sites 13, 14, and 15)—the species usually exhibited the greatest height growth—1.9 feet per year (site14, SD = 0.27) to 2.6 feet per year (site 11, SD = 0.59) by year 10 in trees from the initial plantings. At sites were Douglas-fir was planted in the initial planting the species exhibited the height growth comparable to western hemlock—1.7 feet per year (site 11, SD = 1.15) to 2.4 feet per year (site 15, SD = 0.51) by year 10. At sites 8, 11, 12, and 23, where Sitka spruce was planted in the initial planting growth ranged from 0.6 feet per year (site 23, SD = .038) to 2.2 feet per year (site 11, SD = 0.84) by year 10. Western redcedar, which was planted in the initial planting on sites 5, 11, 12, and 23, showed the lowest growth rates—0.8 feet per year (site 23, SD = 0.42) to 1.0 foot per year (site 5, SD = 0.41) by year 10. Where trees were interplanted after the initial planting—sites 12 and 13—average height growth was lower than the trees that were planted during the initial planting.

Average height growth of trees that had their leader above the brush at year 4 consistently exceeded height growth of trees that had their leaders within the brush or overtopped by the brush. The greatest difference was realized by western hemlock at site 11—growth of trees with leaders above the brush at this site by year 4 exceeded the growth of western hemlock with leaders within or below the brush by over 2 feet per year. The difference was slightly less among Douglas-fir—the growth of trees with leaders above the brush was about 1 to 2 feet per year higher than trees with leaders within or overtopped by the brush. The difference was least among other species—western redcedar and Sitka spruce—and among western hemlock planted at sites 13, 14, and 15; the growth differential was less than 1 foot per year. On sites 11 and 12 the growth of interplanted trees was generally comparable to trees planted in the initial planting when they have comparable leader positions.

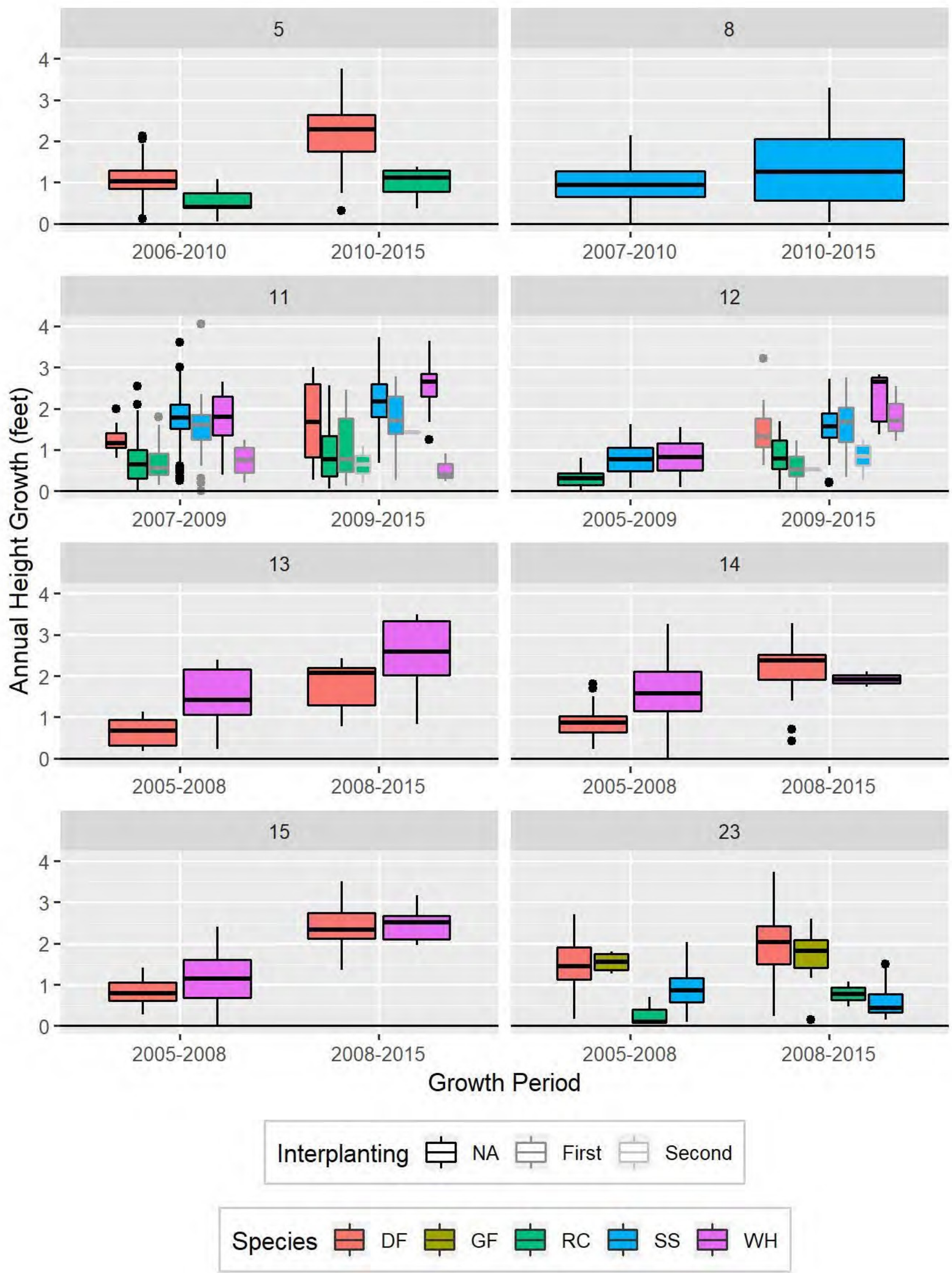

Figure 14. Average height growth of conifers, by species and interplanting, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers). Gray bar outlines signify interplanted trees.

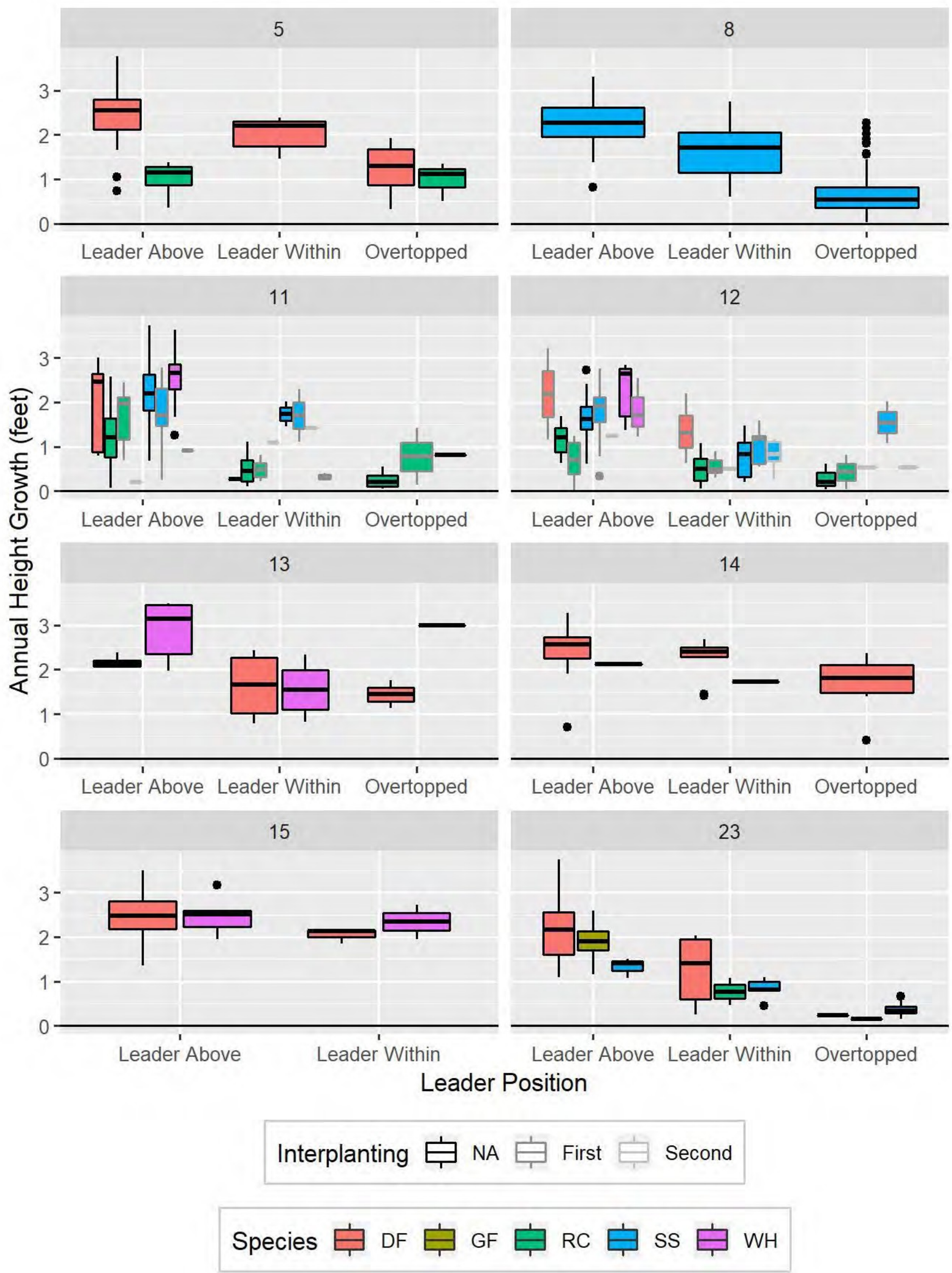

Figure 15. Average height growth of conifers, by species and interplanting, from year 4 to year 10, by leader position at year 4, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers). Gray bar outlines signify interplanted trees.

Conifer Survival

Appendix D, Figure 16, and Figure 17 summarize the survival of planted conifers, by species and leader position, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Overall survival of all species declined over time, irrespective of leader position (i.e., above, within, or below the brush). Where Sitka spruce was planted—sites planted by Green Crow (site 8), Merrill and Ring (sites 11 and 12), and Pope Resources (site 23)—the species usually exhibited the highest survival rates by year 10 (61 – 87 percent, median 74 percent). Survival rates were markedly lower (less than 50 percent) for the other planted species: western redcedar (21 - 62 percent, median 47 percent), Douglas-fir (21 - 77 percent, median 38 percent), and western hemlock (10 – 64 percent, median 36 percent). Survival of trees that had their leader above the brush at year 4 consistently exceeded the survival of trees that had their leaders within the brush or leaders overtopped by the brush. Sitka spruce had the highest survival rates regardless of leader position. Otherwise, the strongest relationship with leader position was seen in Douglas-fir—survival rate of trees with their leader above the brush was more than double the rate of trees that had their leaders within or overtopped by the brush. The difference in survival among leader positions was less for western redcedar—survival rates of trees with leaders above the brush was 74 percent higher than trees with lesser leader positions. Apart from Sitka spruce, the difference in survival among leader positions was least for western hemlock—survival rates of trees with their leader above the brush were 44 percent higher. On sites 11 and 12 interplanted trees generally had lower survivorship than trees planted in the initial planting at both 4 and 10 years after planting and regardless of leader position at year 4.

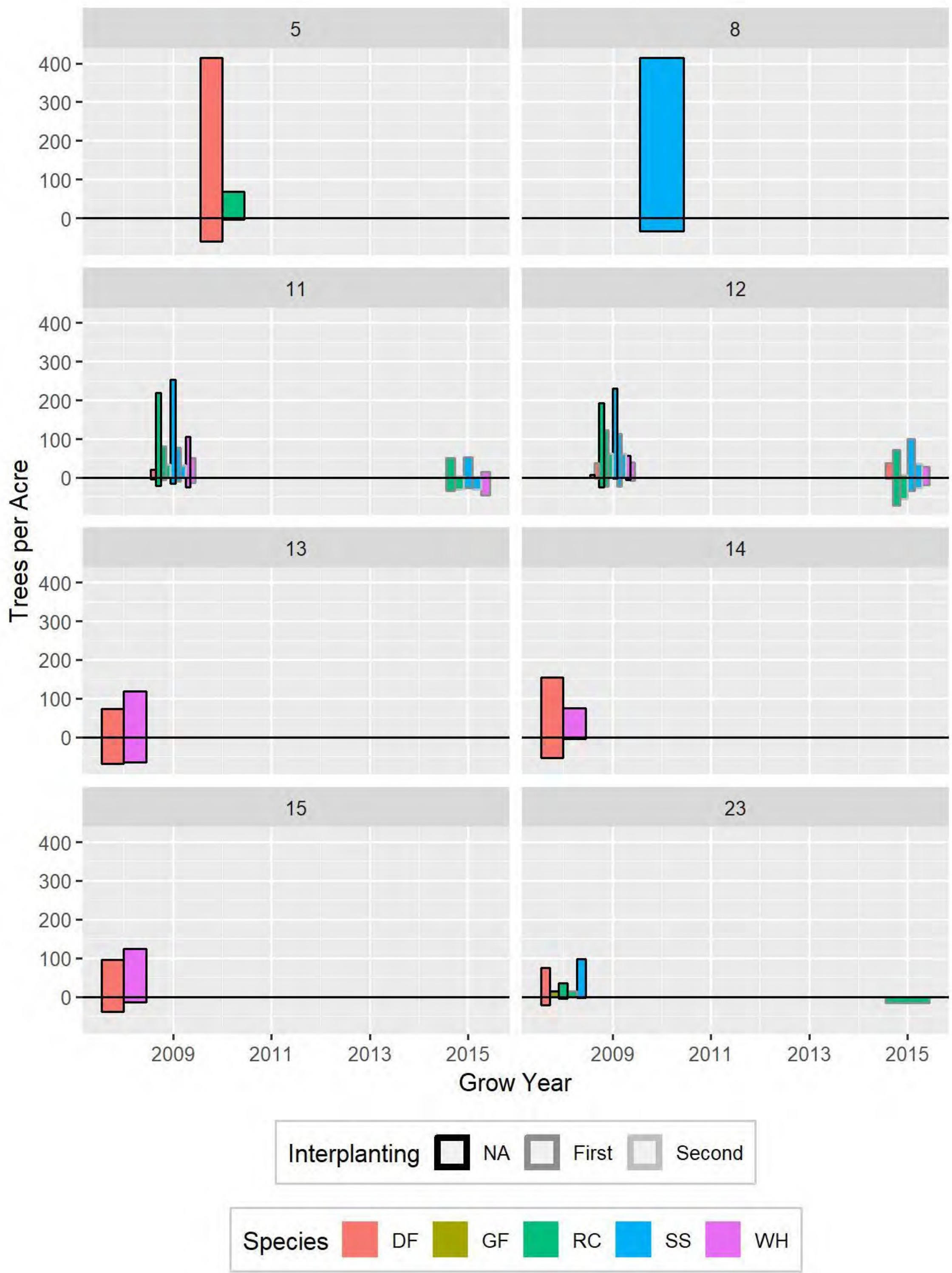

Figure 16. Tree status (live, dead) of planted conifers, by species and interplanting, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Gray bar outline signifies interplanted trees.

Figure 17. Tree status (live, dead) of planted conifers, by species, interplanting, and leader status at year 4, on regeneration plots within hardwood conversion areas measured ten years post-harvest. Gray bar outline signifies interplanted trees.

Free-to-Grow

Conifer stocking at year 4 and year 10 were compared to requirements for hardwood conversion areas in WAC 222-30-021(1)(b)(i)(D) which stipulates that:

> Following harvest in conversion areas, the landowner must: … Conduct postharvest treatment … until the conifer trees necessary to meet acceptable stocking levels in WAC 222-34-010(2) have crowns above the brush or until the conversion area contains a minimum of one hundred fifty conifer trees greater than eight inches dbh per acre.

The referenced rule, WAC 222-34-010(2), stipulates that:

> A harvested area is reforested when that area contains an average of 190 or more vigorous, undamaged commercial species seedlings per acre that have survived on the site for at least 1 growing season. Up to 20 percent of the harvested area may contain fewer than 190 seedlings per acre, but no portion of the harvested area with timber growing capacity may contain less than 150 seedlings per acre. The department may determine that less than an average of 190 seedlings per acre is acceptable if fewer seedlings will reasonably utilize the timber growing capacity of the site.

Because WAC 222-30-021(1)(b)(i)(D) stipulates conifer tree stocking, “commercial species” in WAC 222-34-010(2) was interpreted to be “conifer species,” consistent with the study’s intent. Though alder has become designated as a commercial species since these rules were written, it does not change the logical interpretation relying on WAC 222-30-021(1)(b)(i)(D). That is, from an enforcement standpoint, though a site may meet stocking requirements under WAC 222-34-010(2) by virtue of its hardwood stocking, it may not necessarily meet WAC 222-30-021(1)(b)(i)(D) because of lack of conifers. Further, because this is a hardwood conversion study, inclusion of hardwoods in a free-to-grow evaluation would be counterintuitive.

Assessment of stocking one year after planting is complicated by the multiple plantings that occurred at most sites. Therefore, our assessment of stocking relative to the rules begins at year 4, acknowledging that it represents stocking more than 1 year after most trees were planted. We evaluated year 4 stocking relative to the portion of WAC 222-30-021(1)(b)(i)(D) that, when combined with WAC 222-34-010(2), stipulates that there be 190 conifer trees with their crowns above the brush. As shown by the stocking summaries in Table 13

Factors selected as important in explaining regeneration performance in the stepwise model include species, whether a tree was interplanted, competition with volunteer hardwoods and understory vegetation, and landform (Table 15). Tree species was the first parameter selected in the stepwise regression with Sitka spruce having greater odds of having a leader above the brush at year 10 than Douglas-fir ($p < 0.001$) while the odds of western redcedar having a leader above the brush at year 10 are lower than Douglas-fir ($p < 0.001$). The odds of western hemlock having a leader above the brush at year 10 are lower than Douglas-fir but not statistically different. When trees are interplanted trees have lower odds of having a leader above the brush at year 10, especially for the second interplanting ($p < 0.001$). The influence of volunteer hardwoods and understory vegetation is mixed. Taller shrubs and grass at year 0 along with more hardwood basal area, higher shrub and herb cover all reduce the odds of trees having their leader above the brush at age 10. However, higher shrub cover and taller ferns at year 0 along with more hardwood trees per acre and taller herbs and grasses increase the odds. Landform may have a significant influence as well with trees on hillslope landforms having increased odds of having a leader above the brush than on floodplain terrace landforms. The surrogate variable for site conditions that were not measured, which may have had in influence beyond what was measured, was not selected by the stepwise regression.

Table 13, only three sites (sites 5, 11, and 12) met this standard at year 4. Of those three sites, only one (site 11) had a small portion (3 percent) of the hardwood conversion area with less than 150 trees per acre.

By year 10, all sites have passed the point in time when the seedling-oriented requirements of WAC 222-34-010(2) were relevant. Therefore, we turned our attention to evaluating conifer stocking relative to the portion of WAC 222-30-021(1)(b)(i)(D) which stipulates that the conversion area contains a minimum of 150 conifer trees greater than eight inches dbh per acre. By year 10, no conifers had attained a diameter exceeding 8 inches dbh (Figure 18). Therefore, the comparison of year 10 results serves only as an indicator of the attainability of this standard. As shown in Table 14, all sites had conifer stocking exceeding 150 trees per acre by year 10. Though we could extrapolate past performance to project future stocking levels (e.g., based on species composition and leader position), the issue of meeting regulatory regeneration standards truly remains inconclusive until conifers attain 8 inches dbh at a future monitoring event.

Factors selected as important in explaining regeneration performance in the stepwise model include species, whether a tree was interplanted, competition with volunteer hardwoods and understory vegetation, and landform (Table 15). Tree species was the first parameter selected in the stepwise regression with Sitka spruce having greater odds of having a leader above the brush at year 10 than Douglas-fir ($p < 0.001$) while the odds of western redcedar having a leader above the brush at year 10 are lower than Douglas-fir ($p < 0.001$). The odds of western hemlock having a leader above the brush at year 10 are lower than Douglas-fir but not statistically different. When trees are interplanted trees have lower odds of having a leader above the brush at year 10, especially for the second interplanting ($p < 0.001$). The influence of volunteer hardwoods and understory vegetation is mixed. Taller shrubs and grass at year 0 along with more hardwood basal area, higher shrub and herb cover all reduce the odds of trees having their leader above the brush at age 10. However, higher shrub cover and taller ferns at year 0 along with more hardwood trees per acre and taller herbs and grasses increase the odds. Landform may have a significant influence as well with trees on hillslope landforms having increased odds of having a leader above the brush than on floodplain terrace landforms. The surrogate variable for site conditions that

were not measured, which may have had in influence beyond what was measured, was not selected by the stepwise regression.

Table 13. Conifer stocking (trees per acre, TPA) at year 4 by leader position, species, and site[1].

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
5	2010	Douglas-fir	196.43	100.00	121.43	417.86
		Western redcedar	25.00	14.29	28.57	67.86
		Total	**221.43**	**114.29**	**150.00**	**485.72**
8	2010	Sitka spruce	103.95	96.05	228.95	428.95
		Western hemlock	11.84	10.53	22.37	44.74
		Total	**115.79**	**106.58**	**251.32**	**473.69**
11	2009	Douglas-fir	15.63	4.69	1.56	21.88
		Western redcedar	131.25	92.19	110.94	334.38
		Sitka spruce	298.44	35.94	46.88	381.26
		Western hemlock	120.31	18.75	32.81	171.87
		Total	**565.63**	**151.56**	**192.19**	**909.38**
12	2009	Douglas-fir	12.50	30.00	7.50	50.00
		Western redcedar	100.00	125.00	152.50	377.50
		Sitka spruce	255.00	105.00	50.00	410.00
		Western hemlock	55.00	32.50	15.00	102.50
		Total	**422.50**	**292.50**	**225.00**	**940.00**
13	2008	Douglas-fir	15.38	30.77	26.92	73.07
		Western redcedar	NA	3.85	3.85	7.70
		Sitka spruce	NA	3.85	NA	3.85
		Western hemlock	65.38	30.77	23.08	119.23
		Total	**80.77**	**69.23**	**53.85**	**203.85**
14	2008	Douglas-fir	40.00	65.00	52.50	157.50
		Sitka spruce	2.50	15.00	2.50	20.00
		Western hemlock	55.00	27.50	15.00	97.50
		Total	**97.50**	**107.50**	**70.00**	**875.00**
15	2008	Douglas-fir	63.16	23.68	7.89	94.73
		Western hemlock	86.84	28.95	15.79	131.58
		Total	**150.00**	**52.63**	**23.68**	**226.31**
23	2008	Douglas-fir	45.65	15.22	13.04	73.91
		Grand Fir	13.04	NA	2.17	15.21

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
		Western redcedar	NA	10.87	39.13	50.00
		Sitka Spruce	21.74	23.91	52.17	97.82
		Western Hemlock	4.35	NA	NA	4.35
		Total	**84.78**	**50.00**	**106.52**	**241.29**

[1]At sites 11 and 12, western redcedar and Sitka spruce were co-planted.

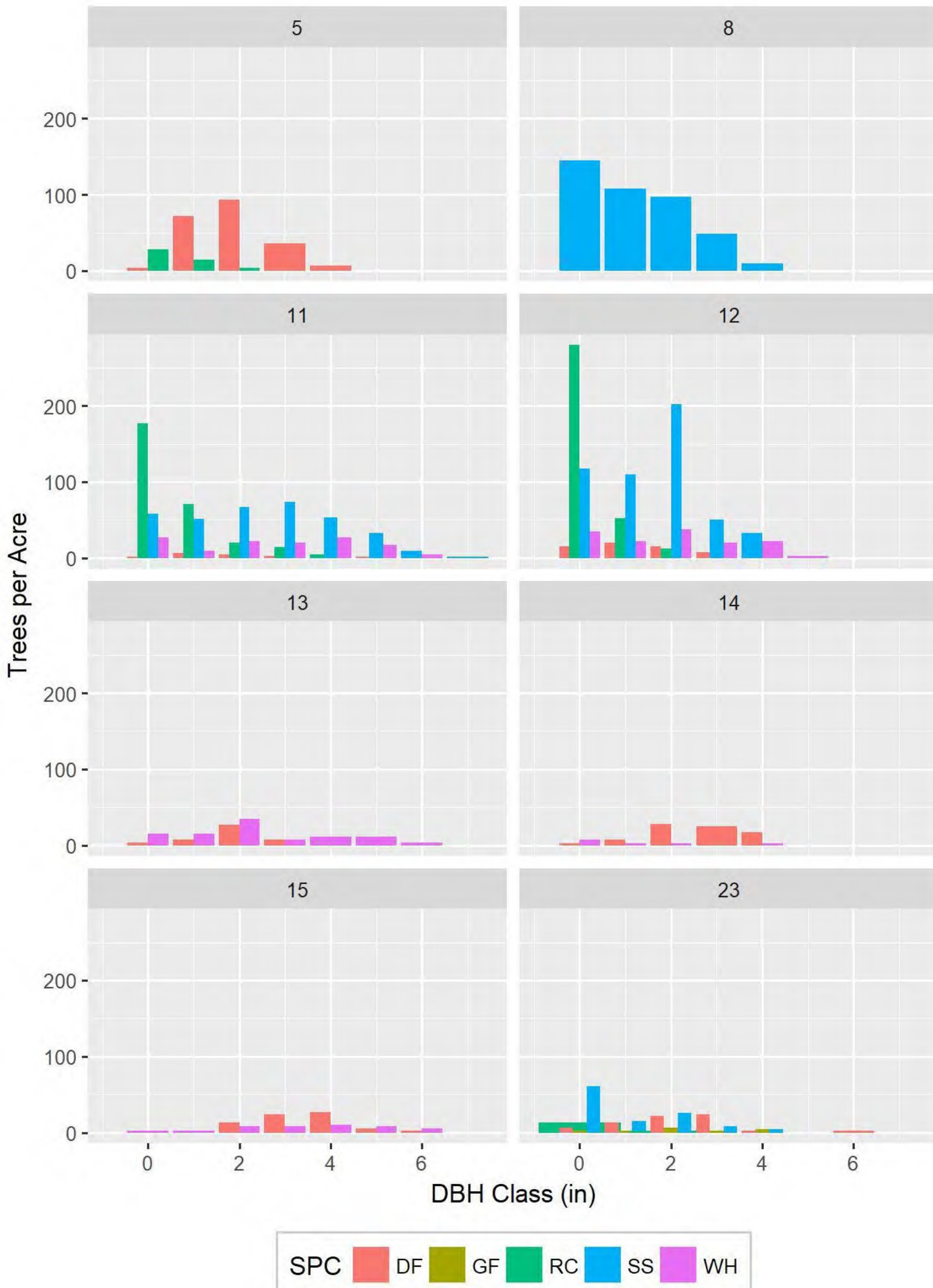

Figure 18. Diameter distributions of planted conifers by dbh class and site on regeneration plots within hardwood conversion areas measured ten years post-harvest.

Table 14. Conifer stocking by trees per acre (TPA) and leader position relative to competing brush (above, within, or overtopped) at year 10 by leader position, species, and site[1].

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
5	2015	Douglas-fir	132.14	21.43	21.43	175.00
		Western redcedar	25.00	7.14	14.29	46.43
		Total	**157.14**	**28.57**	**35.71**	**221.42**
8	2015	Sitka spruce	184.21	26.32	172.37	382.90
		Western hemlock	40.79	7.89	6.58	55.26
		Total	**225.00**	**34.21**	**178.95**	**438.16**
11	2015	Douglas-fir	6.25	NA	6.25	12.50
		Western redcedar	35.94	20.31	151.56	207.81
		Sitka spruce	153.13	31.25	78.13	262.51
		Western Hemlock	60.94	3.13	29.69	93.76
		Total	**256.25**	**54.69**	**265.63**	**576.57**
12	2015	Douglas-fir	32.50	7.50	35.00	75.00
		Western redcedar	67.50	27.50	127.50	222.50
		Sitka spruce	265.00	27.50	57.50	350.00
		Western hemlock	55.00	NA	20.00	75.00
		Total	**420.00**	**62.50**	**240.00**	**722.50**
13	2015	Douglas-fir	42.31	NA	11.54	53.85
		Western redcedar	3.85	NA	NA	3.85
		Western hemlock	69.23	23.08	34.62	126.93
		Total	**115.38**	**23.08**	**46.15**	**184.63**
14	2015	Douglas-fir	47.50	10.00	30.00	87.50
		Sitka spruce	20.00	5.00	12.50	37.50
		Western hemlock	15.00	2.50	17.50	35.00
		Total	**82.50**	**17.50**	**60.00**	**160.00**
15	2015	Douglas-fir	89.47	NA	5.26	49.73
		Sitka spruce	2.63	NA	NA	2.63
		Western hemlock	50.00	2.63	5.26	57.89
		Total	**142.11**	**2.63**	**10.53**	**110.25**
23	2015	Douglas-fir	47.83	2.17	10.87	60.87
		Grand fir	6.52	2.17	6.52	15.21
		Western redcedar	NA	2.17	8.70	10.87
		Sitka spruce	26.09	13.04	50.00	89.13
		Western hemlock	4.35	NA	NA	4.35
		Total	**84.78**	**19.57**	**76.09**	**180.43**

[1]At sites 11 and 12, western redcedar and Sitka spruce were co-planted.

Table 15. Factors influencing tree growth and survival to free-to-grow status (leader above the brush) at year 10 selected by stepwise logistic regression. Positive parameter values indicate factors that increase the odds of surviving and having a leader above the brush at year 10. Negative parameter values indicate factors that decrease the odds of surviving and having a leader above the brush at year 10. Statistically significant parameters are in bold text. *Note that Douglas-fir and fluvial terrace/floodplain are not included in the table and are the basis for species and landform comparisons*.

	Estimate	Std. Error	z value	p-value
(Intercept)	**-1.1445**	**0.2822**	**-4.0555**	**0.0001**
Western redcedar	**-1.0138**	**0.2035**	**-4.9809**	**<0.0001**
Sitka spruce	**0.9374**	**0.1677**	**5.5909**	**<0.0001**
Western hemlock	-0.3161	0.1845	-1.7130	0.0867
First interplanting	-0.2892	0.1691	-1.7103	0.0872
Second interplanting	**-1.6403**	**0.3878**	**-4.2297**	**<0.0001**
Retained overstory cover	**0.0142**	**0.0047**	**3.0333**	**0.0024**
Year 0 hardwood basal area	-0.1646	0.1138	-1.4465	0.1480
Year 0 shrub cover	**1.0453**	**0.4616**	**2.2645**	**0.0235**
Year 0 shrub height	**-0.0592**	**0.0218**	**-2.7195**	**0.0065**
Year 0 fern height	**0.2146**	**0.0458**	**4.6829**	**<0.0001**
Year 0 grass height	**-0.2585**	**0.1088**	**-2.3754**	**0.0175**
Year 4 hardwood basal area	**-0.1152**	**0.0230**	**-5.0100**	**<0.0001**
Year 4 hardwood trees per acre	**0.0011**	**0.0005**	**2.1585**	**0.0309**
Year 4 shrub cover	**-1.3012**	**0.3054**	**-4.2605**	**<0.0001**
Year 4 shrub height	-0.0402	0.0276	-1.4597	0.1444
Year 4 herb cover	**-1.9299**	**0.5583**	**-3.4566**	**0.0005**
Year 4 herb height	**0.3582**	**0.1359**	**2.6353**	**0.0084**
Year 4 grass height	**0.1860**	**0.0691**	**2.6917**	**0.0071**
Hillslope landform	**0.3468**	**0.1406**	**2.4676**	**0.0136**

Economic Performance

The summary of economic performance reported in this section is compiled from detailed site-by-site analysis reported in the Case Study Report. Note that in compiling this summary we observed that upland acres derived from GIS boundaries do not precisely match those reported in the Case Study Report. While these differences may affect per-acre economics in the upland area, the total upland area economics would not be affected. Furthermore, because the issue is isolated to the uplands, economics within the hardwood conversion areas would not be affected. Therefore, the decision was made to use values detailed in the Case Study Report.

Harvest Economics

Table 16 summarizes the harvest area, harvest volume, and adjusted stumpage value for the upland area and the hardwood conversion area at each study site. Adjusted stumpage includes traditional elements of stumpage (log pond values minus logging and hauling cost) plus adjustments for excise tax, per-acre road costs, and per-acre administrative costs. Regeneration costs are *not* included in this stumpage adjustment. Average per-MBF stumpage value was greater in hardwood conversion areas ($333, SD = $49) than in adjacent uplands ($277, SD = $63) because the conversion areas generally had greater volumes of high-value red alder than uplands. However, because more volume could be harvested from each upland acre (about 26 MBF per acre, on average, SD = 10 MBF/ac) compared to that from the hardwood conversion areas (about 14 MBF per acre, on average, SE = 5 MBF/ac) the per-acre stumpage value was greater in upland operations ($6,257 per acre, on average, SE = $1,448/ac) than in hardwood conversion areas ($4,148 per acre, on average, SE = $1,627/ac).

Table 16. Area, harvest volume, and adjusted stumpage values of timber harvest in upland areas and hardwood conversion areas, by site. Adjusted stumpage includes stumpage value minus excise tax, per-acre road costs, and per-acre administration costs.

Site	Acres			Harvest Volume (MBF)			Adjusted Stumpage ($)		
	Upland	Conversion area	Total	Upland	Conversion area	Total	Upland	Conversion area	Total
5	66.4	1.6	68.0	1,008.5	17.3	1,025.8	301,826	6,343	308,169
8	10.4	3.6	14.0	445.3	40.3	405.0	92,039	17,801	109,840
11	4.9	3.6	8.5	182.6	60.4	243.0	33,836	19,116	52,952
12	11.6	3.4	15.0	253.6	50.4	304.0	89,176	16,247	105,423
13	60.9	1.1	62.0	1,404.9	11.4	1,416.3	410,791	3,299	414,090
14	48.8	2.2	51.0	1,686.3	29.9	1,716.2	383,787	9,086	392,873
15	30.6	2.4	33.0	515.2	24.7	539.9	158,336	7,783	166,119
23	60.1	2.6	62.7	1,192.7	66.9	1,259.6	414,250	20,901	435,151

Regeneration Economics

Table 17 and Table 18 summarize regeneration costs in the upland area and the hardwood conversion area, respectively, at each study site. On a per-acre basis, total regeneration costs were greater in upland areas than they were in hardwood conversion areas. And, because both the area treated and the per-acre regeneration costs were greater in upland areas, total regeneration costs were greater in the upland areas than they were in hardwood conversion areas. The difference was mostly due to relatively higher investments in site prep, brush control, precommercial thinning, and slashing in upland areas. Otherwise, costs for animal control and planting were consistent between upland areas and hardwood conversion areas.

Among the hardwood conversion areas, the investment in regeneration varied from less than $200 per acre to over $1,000 per acre.

Table 8 in the Site Selection section summarizes the regeneration practices that accounted for the difference in costs across sites. As was reported in that section, site 11 and site 12 had greater control of competing vegetation, more intensive animal control measures, and higher planting densities. As a result, these sites had an order-of-magnitude greater investment in site prep, animal control, planting, and brush control. Among the remaining sites (sites 5, 8, 13, 14, 15, and 23), there were minor differences in per acre-costs related to minor differences in animal control costs and planting costs.

Table 17. Total and per-acre regeneration costs in upland areas, by site.

Site	Upland Acres	Per Acre Costs						Total Regen Costs
		Site prep	Animal control	Planting	Brush control	PCT/ Slashing	Total	
5	66.4	58.88	57.53	327.94	--	110.00	554.35	36,809
8	10.4	--	--	228.29	--	73.00	301.29	3,133
11	4.9	230.81	176.97	559.58	240.89	--	1,208.25	5,920
12	11.6	228.82	219.47	557.48	118.80	--	1,124.57	13,045
13	60.9	69.00	31.00	209.00	32.00	--	341.00	20,767
14	48.8	61.00	31.00	209.00	33.00	6.15	340.15	16,599
15	30.6	104.00	27.00	209.00	48.00	4.60	392.50	12,010
23	60.1	--	10.55	268.09	6.41	59.63	344.68	20,715

Table 18. Total and per-acre regeneration costs in hardwood conversion areas, by site.

Site	Conversion Area Acres	Per Acre Costs						Total Regen Costs
		Site prep	Animal control	Planting	Brush control	PCT/ Slashing	Total	
5	1.6	--	57.53	327.94	--	110.00	495.47	793
8	3.6	--	--	228.29	--	73.00	301.29	1,085
11	3.6	230.81	176.97	559.58		191.89	1,159.25	4,173
12	3.4	228.82	219.47	557.48		49.83	1,055.60	3,589
13	1.1	--	31.00	313.50	--	--	344.50	379
14	2.2	--	31.00	313.50	--	--	344.50	758
15	2.4	--	27.00	313.50	--	--	340.50	817
23	2.6	--	9.75	166.26	--	--	183.21	476

Residual Value

Table 19 and Figure 19 calculate the total and per acre residual values, respectively, of operations at each site—in upland areas and in hardwood conversion areas—calculated as the total adjusted stumpage (from Table 16) value minus regeneration costs (from Table 17 and Table 18). On a per acre basis, residual value of upland harvests was greater than hardwood conversion areas at all sites, except site 23. Per acre residual values in upland harvest areas usually exceeded those in hardwood conversion areas because of the greater volume that could be harvested from them—upland harvests permit greater harvest of conifers than hardwood conversions—resulting in higher per-acre stumpage in upland versus conversion areas. A combination of factors account for the aberration observed at site 23, including relatively higher hardwood harvest levels and stumpage values and slightly lower conifer harvest levels and stumpage values—regeneration costs were a relatively small factor.

Table 19. Summary of total residual values in uplands and hardwood conversion areas, and in total, by site.

Site	Upland			Conversion Area			Total		
	Stumpage	Regen	Residual	Stumpage	Regen	Residual	Stumpage	Regen	Residual
5	301,826	36,809	265,017	6,343	793	5,550	308,169	37,602	270,567
8	92,039	3,133	88,906	17,801	1,085	16,716	109,840	4,218	105,622
11	33,836	5,920	27,916	19,116	4,173	14,943	52,952	10,094	42,858
12	89,176	13,045	76,131	16,247	3,589	12,658	105,423	16,634	88,789
13	410,791	20,767	390,024	3,299	379	2,920	414,090	21,146	392,944
14	383,787	16,599	367,188	9,086	758	8,328	392,873	17,357	375,516
15	158,336	12,010	146,326	7,783	817	6,966	166,119	12,828	153,291
23	414,250	20,715	393,535	20,901	476	20,425	435,151	21,192	413,959

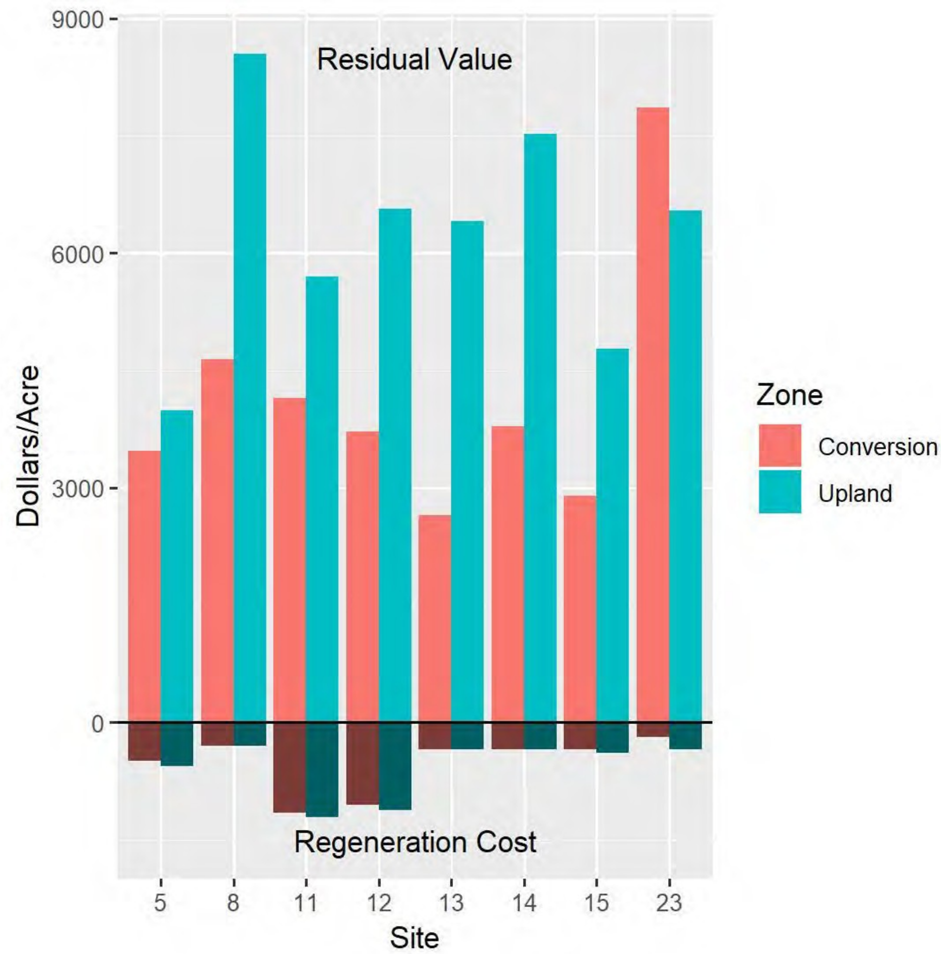

Figure 19: Comparison of residual value and regeneration costs for the conversion and upland areas in each study site.

Discussion

Qualitative Interpretation of Stocking Trends

Figure 20 and Figure 21 compare the distribution of conifers and hardwoods, relative to the average competing brush height, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest, respectively. The general trends, year 4 to year 10, are for the distributions of conifers to move to the right, keeping pace with, "catching up" with, or sometimes surpassing the distribution of hardwoods and average height of brush. This trend highlights "the race" that silviculturists "run" to improve the chances that planted conifers rise above the competing vegetation. Results thus far in the Hardwood Conversion Study provide some insight into management alternatives that can help with meeting the regulatory stocking standard.

Among the sites most on track to achieve the WAC stocking standard for hardwood conversion areas (sites 8, 11, and 12), the factors accounting for their trajectory towards this standard appear to be low levels of competing brush at year 4, relatively high overall planting densities, high planting densities of Sitka spruce, and use of P+1 nursery stock. Not explicitly evaluated, but likely a factor in the overall trajectory of these sites, is the relatively high resistance of Sitka spruce to animal predation and the resistance of Sitka spruce to spruce tip weevil when the species co-occurs with red alder (Almond 2006). Looking forward, these sites likely face challenges in the form of excessive hardwood competition and, in the case of sites 11 and 12, removal of Sitka spruce where it was planted along with western redcedar in the same hole.

Among those sites that are least on track to achieve the WAC stocking standard (sites 5, 13, 14, 15, and 23), the chances of meeting the standard rely on survival of the remaining conifers which, in the case of these sites, appears limited by the relatively high levels of Douglas-fir and the hopes that would have to be put in the survival and growth of trees within or overtopped by brush. Based on past performance, the chances of adequate growth and survival do not appear great. Yet, as argued above, though we could extrapolate past performance to project future stocking levels (e.g., based on species composition and leader position), these sites have not achieved of the stocking standard yet and it truly remains unknown if the sites will until conifers attain 8 inches dbh at some future date.

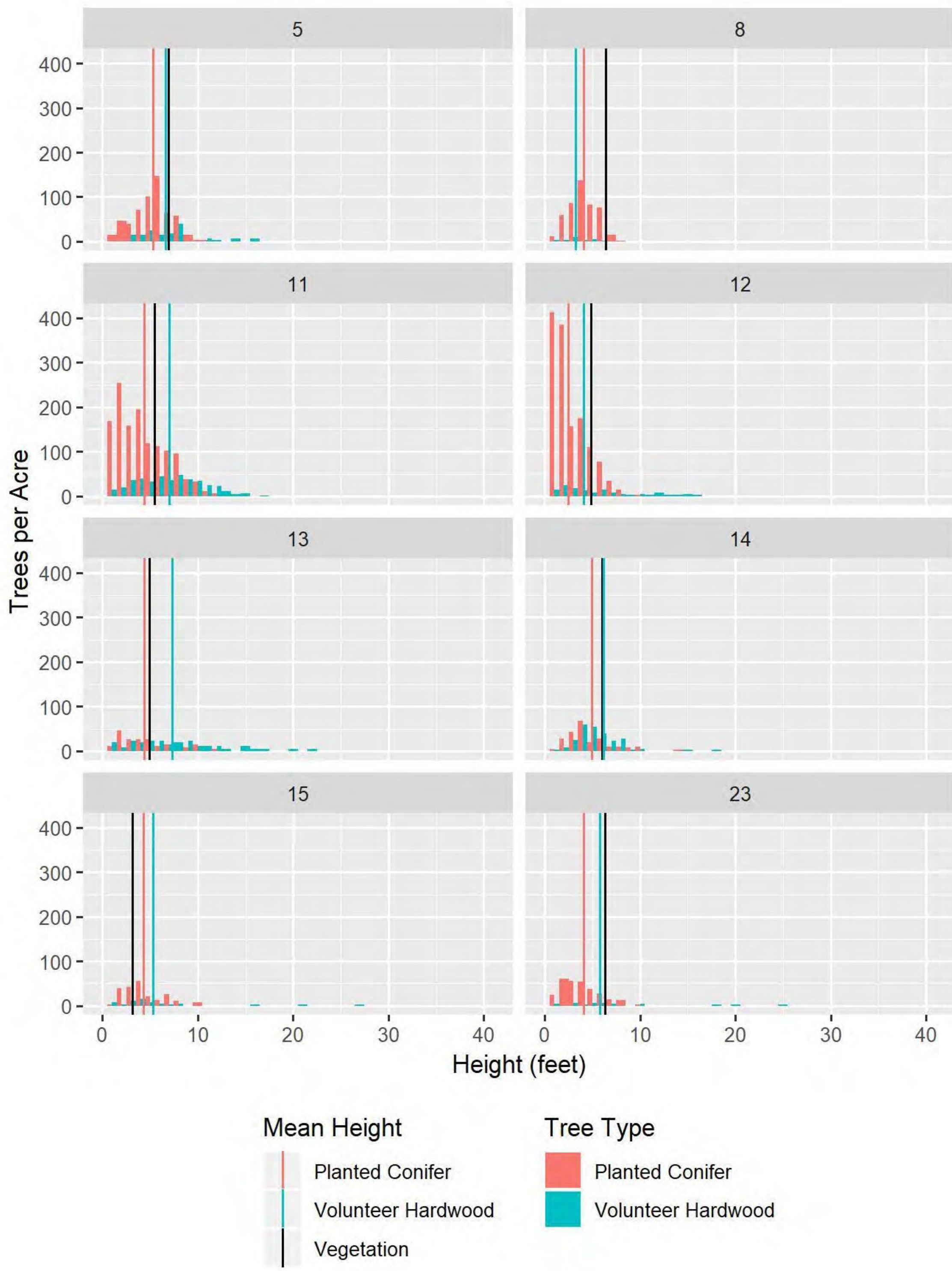

Figure 20. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average planted confer (vertical red line), volunteer hardwood (vertical blue line) and competing brush (vertical black line) heights, on regeneration plots within hardwood conversion areas measured four years post-harvest.

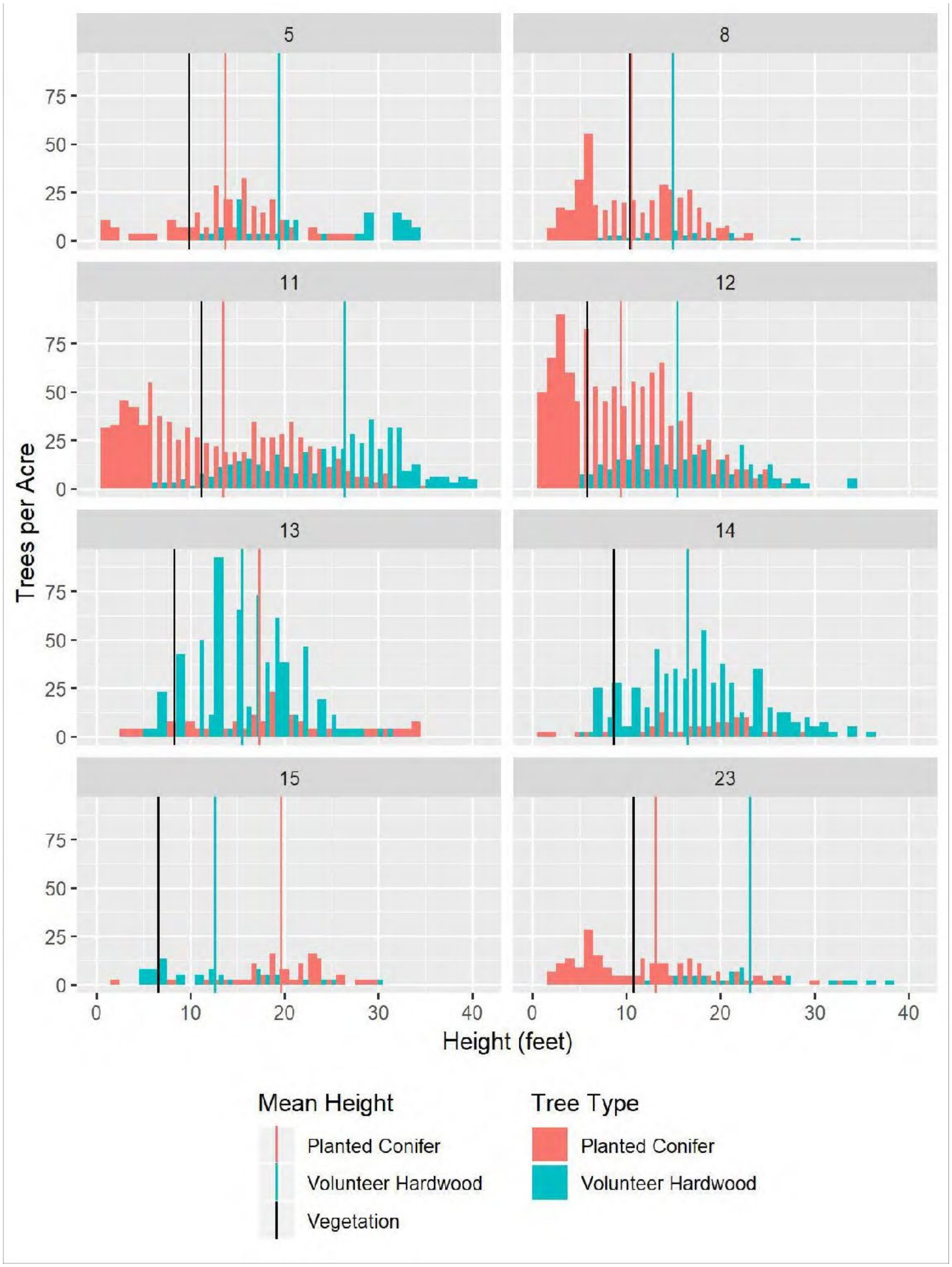

Figure 21. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average planted confer (vertical red line), volunteer hardwood (vertical blue line) and competing brush (vertical black line) heights, on regeneration plots within hardwood conversion areas measured ten years post-harvest.

Site-level Effects of Investment on Stocking

Site-to-site differences in silvicultural performance are positively related to landowner investment in regeneration activities (Figure 22). Though a small sample size, the range of investment is broad. Both total conifers and conifers above the brush are strongly correlated with regeneration costs. This correlation is largely driven by investments made at sites 11 and 12 in cultural treatments that did not occur elsewhere—site prep and brush control—or in cultural practices that occurred with greater intensity than elsewhere—animal control and planting density. The only outlier in this relationship is the other site most on track to achieve the WAC standard (site 8). The high stocking level achieved at year 10 at site 8 (greater than 400 trees per acre total, greater than 200 trees per acre with leaders above the brush) appears to have been achieved with relatively low investment, planting only Sitka spruce. Because of the small sample size and lack of an experimental design, this relationship may be coincidental.

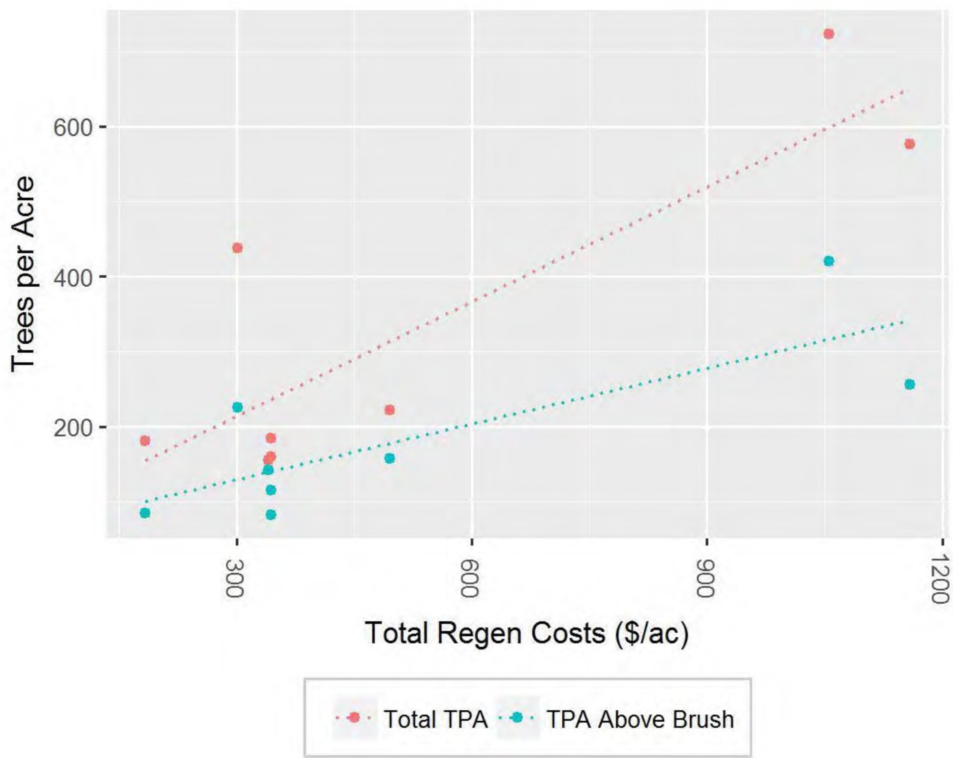

Figure 22. Relationship between total regeneration costs and conifer stocking at year 10, for all conifers and for conifers with their leaders above the brush (free-to-grow).

Factors Explaining Free-to-Grow Status

Though well-intentioned, we found that statistically significant factors in the final stepwise model (Table 15) reflect differences in hardwood conversion areas managed by Weyerhaeuser (sites 5, 13, 14, and 15) and Pope Resources (23)—where regeneration performance has *generally* been poorer—and those managed by Green Crow (8) and Merrill and Ring (11 and 12)—where regeneration performance has *generally* been better. Discernment of potentially influential factors (from a standpoint of cause-effect) required qualitative, rather than quantative, interpretation of the results.

Statistically significant factors explaining regeneration performance in the step wise model include topographic position, species selection, and competing vegetation. Weyerhaeuser plots occur predominantly on hillslopes, were planted predominantly with Douglas-fir, and generally have had lower competing vegetation. Most other landowners' plots occur predominantly on fluvial terraces and floodplains, were planted with more diverse species mixes, and generally have had greater competing vegetation. But, which of these factors are, in fact, meaningful?

Of these three factors, the effect of topographic position and competing vegetation may simply be coincidental. The lack of balance within each site (and landowner) limits the ability to discern the ecological influence of floodplain and fluvial terrace sites versus hillslope sites from the coincidental trajectory towards stocking standards on Green Crow and Merrill and Ring. Further, the better regeneration performance on these sites, despite having higher levels of competing vegetation, seems counterintuitive. Though significant, it's difficult to find meaning in these terms. Species selection, however, has both significance and meaning. Sitka spruce is statistically more likely to become free-to-grow at year 10. Likely because of Sitka spruce's shade tolerance, moisture tolerance, and resistance to animal predation, this species has had higher survival. The resistance of Sitka spruce to spruce tip weevil when the species co-occurs with red alder (Almond 2006) likely contributes to its success, however, comparative information on weevil damage was not recorded.

Though these are general trends, two sites push against this interpretation, underscoring the limitations of the data set. Site 5—a Weyerhaeuser site—has slightly better survival than the other Weyerhaeuser sites despite the predominance of Douglas-fir planting. This perhaps reflects a better matching of species to site—where site 5 occurs within a Douglas-fir zone—compared to the other Weyerhaeuser sites—which occur within a western hemlock zone.

Site 23—the Pope Resources site—has slightly poorer performance than Green Crow and Merrill and Ring sites, despite the high levels of Sitka spruce planted at the site. This perhaps reflects a poor matching of species to site—where site 23 occurs within a drier precipitation zone—compared to the Green Crow and Merrill and Ring sites—which occur in higher precipitation zones. The exceptions at sites 5 and 23 underscore the limitations of the data.

Technical Recommendations

Though some sites appear more likely than others to achieve stocking standards for hardwood conversion areas under WAC 222-30-021(1)(b)(i)(D), planted conifers have not yet achieved the 8 inches dbh size limit required to make this determination. One could extrapolate past survival and growth to project future stocking levels, or one could apply models to project stand development, but this would be fraught with uncertainty. Additional monitoring of tree growth and actual observation would provide a more definitive determination of whether this part of WAC 222-30-021(1)(b)(i)(D) is being met. CMER Policy will need to determine if such additional monitoring is a priority for the adaptive management program. If so, this could be achieved through remeasurement of vegetation monitoring plots, or by simpler stand inventory techniques focused solely on tree stocking. In either case, stocking evaluations will require waiting for enough conifer trees to reach 8 inches dbh. Based on professional judgement, this would occur at least 10 years after the year 10 remeasurement (i.e., at 20 years post-harvest).

Potential Management Implications

Though it is too soon to certify successful hardwood conversions, several factors appear to be important to putting stands on a trajectory towards the stocking standard. Most influential to growth and survival appear to be common-sense planting strategies: matching the species to the site, planting P+1 nursery stock, and planting at high densities. This trifecta is achieved at those sites most likely to succeed (Sites 8, 11, and 12), and one or more of these factors is achieved at those sites that may be marginally successful (Sites 5 and 23). None of these strategies was employed at the three Weyerhaeuser sites (13, 14, and 15) which are most likely to fall short of the stocking standard. Though these strategies comport with basic ecological and silvicultural principles, detailed recommendations beyond these general strategies remain elusive.

Because the number of monitoring sites is limited, it is more difficult to extract common-sense vegetation control strategies from the data. Though it appears important that conifers have their leaders above competing brush, it is not clear how and where or when this must be achieved. The planting strategies outlined in the previous paragraph are likely important contributors because they not only improve height growth, but they also improve the numerical odds. But, in comparison, the value of actively controlling competing vegetation appears mixed. The data suggest that it may be dependent on the site—that is, where Douglas-fir is best matched to the site, maintaining low levels of competing vegetation may be more important than where Sitka spruce is best matched. Again, this comports with basic ecological and silvicultural principles, but detailed recommendations beyond this general strategy remain elusive.

Finally, though intuition suggests that there is value in animal control, it is difficult to interpret its potential value from the data. Enough anecdotal evidence is provided in the Case Study Report to suggest that, where the potential for animal predation was observed (e.g., beaver presence, animal-browse), animal control measures were employed (e.g., trapping, barriers, deception). However, observations on animal damage are limited, making it difficult to quantify effectiveness. There are instances where animal control appears consequential (e.g., Sites 11 and 12), there are those where animal control appears inconsequential (e.g., Sites 13, 14, and 15), and there are those where it’s simply too difficult to discern (e.g., Sites 5 and 23). Therefore, we can only make the conservative recommendation—that is, that animal control measures should be employed where there is a risk for animal predation.

SUMMARY

The Hardwood Conversion Study evaluated the economic and silvicultural feasibility of converting hardwood-dominated riparian areas, which had evidence of past conifer presence, back to being conifer dominated. Eight sites were volunteered by landowners for the study that are located across western Washington but primarily near the coast in southwest Washington or on the northwest Olympic Peninsula. Across these sites there was no overarching experimental design, which limits the inference that can be made about hardwood conversions in general. However, some general patterns across these eight sites are apparent. All conversion areas were economically feasible with net-positive residual values after deducting regeneration and administration costs from the stumpage value. Success in regenerating sites varied but was facilitated when landowners invested in site preparation and competing vegetation control or planted shade- and moisture-tolerant species such as western hemlock and Sitka spruce. Growth of these species planted in riparian zones was generally better than Douglas-fir, which is less shade- and moisture-tolerant. Co-planting western redcedar with Sitka spruce to minimize browse damage appears to be successful in sustaining some of these trees where this method was used. When Sitka spruce is planted it is more likely to be free-to-grow at 10 years after planting, which may be related to its shade- and moisture-tolerance as well as very stiff leaders and shoots and sharp needles. However, after 10 years of monitoring, none of the sites have met the regulatory success criterion: 150 trees per acre with d.b.h of at least 8 inches. Additional monitoring would be needed to determine when this success criterion is met.

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Appendix A: Competing Vegetation Response

Mean height and cover of shrubs, forbs, and grasses by site and by species zero, four, and ten years post-harvest. Only species with mean cover greater than 5 percent are reported. Values in parentheses are standard deviations.

Site	Species	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover
5	Grass	2006	0.00 (0)	0.00% (0)	2010	1.21 (0.41)	15% (22.01%)	2015	0.00 (0)	0.00% (0)
	Himalayan blackberry	2006	0.00 (0)	0.00% (0)	2010	4.94 (1.31)	6.07% (6.26%)	2015	8.14 (2.58)	20% (17.1%)
	Salmonberry	2006	4.2 (1)	1.79% (4.21%)	2010	8.1 (1.16)	7.5% (9.95%)	2015	10.98 (1.85)	16.79% (20.53%)
	Vine Maple	2006	8.11 (3.45)	3.21% (5.04%)	2010	9.35 (2.14)	9.29% (13.99%)	2015	14.76 (2.68)	7.5% (13.41%)
	Western Sword Fern	2006	2.38 (0.49)	30% (13.16%)	2010	3 (0)	20% (16.05%)	2015	3.83 (0.38)	10.36% (15.25%)
8	Grass	2007	1.2 (0.4)	1.32% (2.77%)	2010	1.68 (0.87)	10.66% (12.64%)	2015	0.00 (0)	0.00% (0)
	Salmonberry	2007	6.95 (2.25)	12.11% (8.75%)	2010	6.7 (1.03)	55.26% (25.57%)	2015	10.47 (1.08)	77.87% (16.63%)
	Western Sword Fern	2007	2.2 (0.45)	19.87% (14.07%)	2010	3.68 (0.49)	13.16% (10.68%)	2015	3.13 (0.7)	11.58% (9.59%)
11	Grass	2005	1 (0)	2.97% (7.06%)	2009	1.97 (0.17)	15.63% (16.05%)	2015	2.97 (0.7)	6.09% (17.63%)
	Salmonberry	2005	6.25 (2.25)	1.25% (3.81%)	2009	6.08 (1.18)	11.56% (11.67%)	2015	12.15 (1.48)	34.22% (22.04%)
	Western Sword Fern	2005	3.04 (0.88)	6.19% (9.6%)	2009	2.91 (0.51)	8.91% (7.7%)	2015	3.85 (0.89)	7.19% (10.08%)
12	Grass	2005	1.07 (0.26)	7% (8.18%)	2009	2 (0)	56% (25.37%)	2015	2.56 (0.58)	17.75% (20.93%)
	Salmonberry	2005	4.57 (2.02)	1.75% (2.94%)	2009	5.32 (1.22)	9.5% (18.42%)	2015	9.4 (2.28)	30.25% (32.95%)
	Trailing blackberry	2005	0.00 (0)	0.00% (0)	2009	0.00 (0)	0.00% (0)	2015	2.11 (0.63)	18.5% (18.99%)
13	Salal	2005	0.00 (0)	0.00% (0)	2008	0.00 (0)	0.00% (0)	2015	2.25 (0.44)	6.15% (11.21%)
	Salmonberry	2005	4.03 (0.45)	13.46% (16.76%)	2008	5.63 (1.15)	30.77% (19.02%)	2015	9.18 (0.95)	32.69% (33.89%)
	Trailing blackberry	2005	1 (0)	6.15% (10.24%)	2008	1.24 (0.43)	13.08% (9.69%)	2015	0.00 (0)	0.00% (0)
	Vine Maple	2005	6.63 (1.46)	6.15% (10.24%)	2008	9.33 (3.62)	8.08% (8.79%)	2015	13.35 (1.33)	6.54% (8.01%)
	Western Sword Fern	2005	3.29 (0.45)	10.77% (10.17%)	2008	2 (0)	9.62% (8.77%)	2015	3.35 (0.87)	23.08% (21.94%)

Site	Species	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover
14	Grass	2005	1 (0)	7% (14.99%)	2008	1.58 (0.5)	8.25% (10.79%)	2015	0.00 (0)	0.00% (0)
	Salmonberry	2005	3.62 (0.99)	22.5% (20.55%)	2008	6.32 (0.99)	58% (22.5%)	2015	8.77 (1.36)	54.75% (27.22%)
15	Grass	2005	1.57 (0.5)	23.42% (25.61%)	2008	2.25 (0.43)	21.32% (13.63%)	2015	1.12 (0.32)	11.32% (11.88%)
	Salmonberry	2005	4.5 (0.53)	0.53% (1.58%)	2008	4.62 (0.93)	7.63% (10.05%)	2015	9.25 (1.06)	27.37% (32.03%)
	Trailing blackberry	2005	1 (0)	4.21% (5.07%)	2008	1.71 (0.68)	22.11% (15.93%)	2015	2.82 (0.89)	30.26% (28.11%)
	Western Sword Fern	2005	2.9 (0.93)	25.79% (16.01%)	2008	2.06 (0.41)	9.47% (6.64%)	2015	3.43 (0.56)	7.37% (7.14%)
23	Salmonberry	2005	4.25 (1.07)	29.57% (29.23%)	2008	6.16 (1.06)	55.87% (28.15%)	2015	15.28 (0.88)	11.52% (22.23%)
	Vine Maple	2005	7.63 (3.64)	3.48% (6.11%)	2008	8.29 (1.93)	7.61% (17.38%)	2015	9.77 (1.26)	73.7% (28.87%)
	Western Sword Fern	2005	3.84 (0.37)	14.78% (8.98%)	2008	2.48 (0.5)	12.61% (7.67%)	2015	3.39 (0.61)	6.74% (7.48%)

APPENDIX B: VOLUNTEER HARDWOOD RESPONSE

Mean height and stocking of volunteer hardwoods by site and by species zero, four, and ten years post-harvest. Values in parentheses are standard deviations.

Site	Species	Year	Mean Ht.	TPA	Year	Mean Ht.	TPA	Year	Mean HT.	TPA
5	Cascara	2006	0.00 (0)	0.00	2010	6.55 (1.5)	78.57	2015	15.8 (2.59)	17.86
	Bitter Cherry	2006	0.00(0)	0.00	2010	0.00(0)	0.00	2015	13.00 (0)	3.57
	Red Alder	2006	2.67 (0.48)	117.86	2010	10 (2.61)	107.14	2015	23.48 (8.98)	82.14
8	Cascara	2007	1.00 (0)	1.32	2010	0.00(0)	0.00	2015	0.00(0)	0.00
	Red Alder	2007	0.00(0)	0.00	2010	3.32 (1.22)	65.79	2015	19.89 (20.1)	35.53
11	Big Leaf Maple	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	15 (1.73)	4.69
	Bitter Cherry	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	17 (3.61)	4.69
	Red Alder	2005	0.00(0)	0.00	2009	7.3 (2.61)	2821.88	2015	24.1 (9.58)	523.44
12	Big Leaf Maple	2005	0.00(0)	0.00	2009	7.35 (2.5)	77.50	2015	17.11 (2.69)	70.00
	Cascara	2005	0.00(0)	0.00	2009	6.00 (0)	2.50	2015	9 (5.66)	5.00
	Bitter Cherry	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	14.11 (5.1)	47.50
	Red Alder	2005	0.50 (0)	10.00	2009	2.86 (1.98)	122.50	2015	21.27 (17.99)	157.50
13	Cascara	2005	3.67 (2.31)	915.38	2008	7.74 (3.2)	1338.46	2015	15.66 (4.32)	1234.62
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	13.00 (0)	3.85
	Red Alder	2005	2.49 (0.38)	173.08	2008	6.94 (3.69)	42.31	2015	23.9 (5.93)	38.46
14	Cascara	2005	3.29 (1.12)	170.00	2008	5.87 (2.51)	420.00	2015	14.72 (5.33)	785.00
	Red Alder	2005	0.00 (0)	0.00	2008	5.31 (1.63)	222.50	2015	21.15 (8.95)	215.00
15	Big Leaf Maple	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	19.0 (0)	2.63
	Cascara	2005	8.17 (8.09)	23.68	2008	6.03 (5.97)	73.68	2015	9.89 (5.8)	94.74
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	6.28 (3.52)	42.11
	Red Alder	2005	0.00(0)	0.00	2008	4.85 (0.64)	5.26	2015	19.44 (14.47)	23.68
23	Big Leaf Maple	2005	4.0 (0)	65.22	2008	15.86 (5.35)	60.87	2015	0.0 (0)	0.00
	Cascara	2005	0.00(0)	0.00	2008	4.25 (1.83)	17.39	2015	19.08 (2.87)	26.09
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	25.0 (0)	2.17
	Red Alder	2005	0.00(0)	0.00	2008	5.4 (1.52)	10.87	2015	38.09 (28.8)	23.91

APPENDIX C: CONIFER HEIGHT GROWTH RESPONSE

Mean annual height growth by species for all trees (Overall) and by leader position at the beginning of the growth period.

Site	Species	Growth Period	Overall	Growth Period	Overall	Leader Above	Leader Within	Overtopped
5	DF	2006-2010	1.1	2010-2015	2.2	2.4	2	1.2
	RC	2006-2010	0.5	2010-2015	0.9	1	-	0.7
8	SS	2007-2010	0.9	2010-2015	1.3	2.3	1.6	0.7
11	DF	2007-2009	1	2009-2015	1.7	2	0.3	-
	RC	2007-2009	0.6	2009-2015	0.9	1.3	0.5	0.3
	SS	2007-2009	1.7	2009-2015	2.1	2.1	1.4	0.8
	WH	2007-2009	1.3	2009-2015	2.4	2.6	0.3	
12	DF	2005-2009	0	2009-2015	1.6	2.2	1.3	-
	RC	2005-2009	0.3	2009-2015	0.7	1	0.5	0.4
	SS	2005-2009	0.7	2009-2015	1.5	1.7	0.9	1.2
	WH	2005-2009	0.7	2009-2015	2.2	2.2	-	-
13	DF	2005-2008	0.6	2008-2015	1.8	2.2	1.6	1.4
	WH	2005-2008	1.2	2008-2015	2.5	2.9	1.6	3
14	DF	2005-2008	0.9	2008-2015	2.2	2.4	2.2	1.7
	WH	2005-2008	1.5	2008-2015	1.9	2.1	1.7	-
15	DF	2005-2008	0.8	2008-2015	2.4	2.5	2.1	-
	WH	2005-2008	1.1	2008-2015	2.5	2.5	2.3	-
23	DF	2005-2008	1.4	2008-2015	1.9	2.2	1.3	0.2
	GF	2005-2008	1.5	2008-2015	1.6	1.9	-	0.2
	RC	2005-2008	0.2	2008-2015	0.3	-	0.5	0
	SS	2005-2008	0.9	2008-2015	0.6	1.3	0.8	0.4

Appendix D: Conifer Survival Response

Trees per acre and percent of planted trees (in parentheses) surviving at the 4-year and 10-year measurements, by species, for all trees and by leader position at the previous measurement.

Site	Species	Grow Year	All	Leader Above	Leader Within	Overtopped	Grow Year	All	Leader Above	Leader Within	Overtopped
5	DF	2010	414.29 (86.49)	196.43 (41.01)	96.43 (20.13)	121.43 (25.35)	2015	175.00 (36.53)	132.14 (27.59)	21.43 (4.47)	21.43 (4.47)
	RC	2010	67.86 (90.48)	25.00 (33.33)	14.29 (19.05)	28.57 (38.09)	2015	46.43 (61.91)	25.00 (33.33)	7.14 (9.52)	14.29 (19.05)
8	SS	2010	414.47 (91.90)	97.37 (21.59)	94.74 (21.01)	222.37 (49.31)	2015	356.58 (79.06)	161.84 (35.88)	23.68 (5.25)	171.05 (37.93)
11	DF	2009	20.31 (61.55)	15.62 (47.33)	3.12 (9.45)	1.56 (4.73)	2015	12.50 (37.88)	6.25 (18.94)	-	6.25 (18.94)
	RC	2009	334.38 (80.77)	131.25 (31.70)	92.19 (22.27)	110.94 (26.80)	2015	207.81 (50.20)	35.94 (8.68)	20.31 (4.91)	151.56 (36.61)
	SS	2009	362.50 (87.77)	296.88 (71.88)	31.25 (7.57)	34.38 (8.32)	2015	251.56 (60.91)	145.31 (35.18)	29.69 (7.19)	76.56 (18.54)
	WH	2009	157.81 (75.51)	118.75 (56.82)	15.62 (7.47)	23.44 (11.22)	2015	84.38 (40.37)	53.12 (25.42)	3.12 (1.49)	28.12 (13.45)
12	DF	2009	45.00 (81.82)	12.50 (22.73)	27.50 (50.00)	5.00 (9.09)	2015	42.50 (77.27)	12.50 (22.73)	5.00 (9.09)	25.00 (45.45)
	RC	2009	377.50 (75.35)	100.00 (19.96)	125.00 (24.95)	152.50 (30.44)	2015	217.50 (43.41)	65.00 (12.97)	27.50 (5.49)	125.00 (24.95)
	SS	2009	405.00 (81.65)	252.50 (50.91)	102.50 (20.67)	50.00 (10.08)	2015	342.50 (69.05)	260.00 (52.42)	27.50 (5.54)	55.00 (11.09)
	WH	2009	97.50 (51.86)	55.00 (29.26)	27.50 (14.63)	15.00 (7.98)	2015	67.50 (35.90)	47.50 (25.27)	-	20.00 (10.64)
13	DF	2008	73.08 (33.99)	15.38 (7.15)	30.77 (14.31)	26.92 (12.52)	2015	46.15 (21.47)	34.62 (16.10)	-	11.54 (5.37)
	WH	2008	119.23 (54.44)	65.38 (29.85)	30.77 (14.05)	23.08 (10.54)	2015	100.00 (45.66)	61.54 (28.10)	11.54 (5.27)	26.92 (12.29)

Site	Species	Grow Year	All	Leader Above	Leader Within	Overtopped	Grow Year	All	Leader Above	Leader Within	Overtopped
14	DF	2008	155.00 (63.79)	40.00 (16.46)	62.50 (25.72)	52.50 (21.60)	2015	80.00 (32.92)	45.00 (18.52)	10.00 (4.12)	25.00 (10.29)
	WH	2008	75.00 (90.36)	52.50 (63.25)	15.00 (18.07)	7.50 (9.04)	2015	15.00 (18.07)	5.00 (6.02)	2.50 (3.01)	7.50 (9.04)
15	DF	2008	94.74 (59.96)	63.16 (39.97)	23.68 (14.99)	7.89 (4.99)	2015	71.05 (44.97)	68.42 (43.30)	-	2.63 (1.66)
	WH	2008	123.68 (84.14)	86.84 (59.07)	23.68 (16.11)	13.16 (8.95)	2015	28.95 (19.69)	23.68 (16.11)	-	5.26 (3.58)
23	DF	2008	73.91 (78.63)	45.65 (48.56)	15.22 (16.19)	13.04 (13.87)	2015	60.87 (64.76)	47.83 (50.88)	2.17 (2.31)	10.87 (11.56)
	GF	2008	15.22 (101.47)	13.04 (86.93)	-	2.17 (14.47)	2015	15.22 (101.47)	6.52 (43.47)	2.17 (14.47)	6.52 (43.47)
	RC	2008	50.00 (94.34)	-	10.87 (20.51)	39.13 (73.83)	2015	10.87 (20.51)	-	2.17 (4.09)	8.70 (16.42)
	SS	2008	97.83 (95.91)	21.74 (21.31)	23.91 (23.44)	52.17 (51.15)	2015	89.13 (87.38)	26.09 (25.58)	13.04 (12.78)	50.00 (49.02)