Westside Type F Riparian Management Zone Exploratory Study, Final Report

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Washington State
Cooperative Monitoring, Evaluation, and Research Committee (CMER)
Report

Westside Type F Riparian Management Zone Exploratory Study Final Report

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Prepared for the
Riparian Scientific Advisory Group (RSAG)
Westside Type F Riparian Rules Effectiveness Monitoring Program.

Washington State Forest Practices Board
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Washington State Forest Practices Adaptive Management Program

The Washington Forest Practices Board (FPB) has adopted an adaptive management program in concurrence with the Forests and Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

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

To provide the science needed to support adaptive management, the FPB made the Cooperative Monitoring, Evaluation and Research Committee (CMER) a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with guidelines recommended in the FFR.

Report Type and Disclaimer

This exploratory report was prepared for the Cooperative Monitoring, Evaluation and Research Committee (CMER) and contains scientific information, which was intended to improve or focus the science underlying the Forest and Fish 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.

Proprietary Statement

Full Reference

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Abstract

This is the second of three planned studies by CMER to evaluate the effectiveness of the riparian management zone (RMZ) prescriptions in achieving conservation objectives of the Forest Practice Habitat Conservation Plan (FPHCP) for fish-bearing streams in Western Washington. In the first study, a random sample of Forest Practice Applications (FPAs) was selected from the Washington Department of Natural Resources Forest Practices Application Review System database for the purpose of assessing the relative frequencies that RMZ prescriptions were applied to the fish-bearing streams. The office-based study found that 11 of the 25 possible RMZ prescriptions accounted for 91% of the buffers applied.

This second, field-based exploratory study, examined post-harvest riparian stand conditions, riparian ecological functions, and the extent to which post-harvest riparian forest stands are on trajectory to reach desired future condition (DFC) targets in RMZs that had and did not have harvest in portions of the RMZ. Ten sites were randomly selected from RMZs in each of the 11 most-commonly implemented prescriptions identified in the first study. RMZ widths ranged from 90 to 200 feet. Data were collected 3 to 6 years after the harvest to allow early post-harvest windthrow to stabilize (per Schuett-Hames et al. 2012).

We found riparian buffer stands were generally young (median age = 46 years) and in the stem-exclusion phase of stand development. The weighted median residual site buffer stem density, basal area density, and quadratic mean diameters (QMDs) were 209 trees/acre, 209 ft^2/acre, and 13.8 inches. Canopy closures measured at the stream channel edge averaged 96.4% and 89% of RMZs met the shade targets specified in rule. There was no evidence to suggest that sites differed by riparian prescription or by Inner Zone harvest in meeting shade targets. The RMZs that did not meet their shade requirements were located either along very large streams or along small streams with high buffer mortality. The (weighted) median cumulative mortality in the early post-harvest period (3 to 6 years) was 8% of the live trees standing at each site immediately post-harvest, and the annual mortality rates ranged between 2.5% and 4.8%. The dominant mortality agent was windthrow (76% of all tree mortality), which was greatest in the Inner Zone along small streams, followed by stem exclusion/suppression (10% of the total mortality). Forty percent of early post-harvest treefall contributed large wood into and over the stream channel, and approximately eighty percent of that originated in the Core Zone. More wood fell and was recruited from buffers on small streams less than 10 feet wide than from buffers on channels larger than 10 feet. The weighted median for large wood recruitment per 100’ of stream length was 1.0 pieces/100’ and 2.8ft^3/100’, cumulatively for the 3 to 6 year period after harvest. The mean in/over-channel diameter of the recruited wood was 6.8 inches and the mean length of the portion in or over the channel was 8.7 feet. There was no evidence at any of the sites that either the harvest operations or windthrow caused any bank destabilization or sediment delivery from within the riparian zone. We used the WA DNR’s DFC model to project stand growth and assess whether the stands are expected to meet the DFC target of 325 ft^2/acre by age 140. We found that 67% of the sites that had no Inner Zone harvest and 92% of the sites that had Inner Zone (DFC) harvests were projected to meet the DFC targets by that stand age.

Collectively, these findings suggest that the riparian prescriptions evaluated were sufficient to maintain the riparian functions of shade, large wood recruitment, and sediment/erosion reduction as outlined in the FPHCP. However, because the RMZs consist of relatively young forests, restoring riparian functions to high levels in these stands will follow a developmental trajectory of decades to a century. The findings of this second study are intended to guide and focus the development of the third study, an experimental Before-After, Control-Impact (BACI) study, which was initially proposed to evaluate the effectiveness of the Western Washington Type F/S riparian prescriptions in maintaining in-stream habitat for aquatic biota, as defined by the FPHCP.

Executive Summary

Introduction

Timber harvesting rules for private and those state-owned timberlands subject to the FPHCP rules in western Washington State require that riparian buffers be left along all fish-bearing waters. The buffers (Riparian Management Zones, or “RMZs”) required by rules have various widths, which depend on the local tree-growing potential of the site (site class) and the width of each stream. There are 25 possible configurations of RMZ buffers prescribed for fish-bearing streams with buffer widths ranging from 90 to 200 feet. The RMZ consists of three Zones, two of which allow some level of timber harvesting under certain circumstances. All stream Type F/S RMZs have a 50-foot no-harvest Core Zone, a variable width Inner Zone that ranges from 10 to 100 feet, and an Outer Zone, which makes up the balance of the Type F RMZ. The RMZ rules allow for various configurations of tree thinning in outer (beyond 50 feet) portions of the buffers with the objective of accelerating the return of desired mature forest conditions with large trees capable of providing shade and the potential for large wood recruitment to adjacent stream channels.

This is the second of three planned studies by CMER to evaluate the effectiveness of the RMZ prescriptions in achieving conservation objectives of the Forest Practice Habitat Conservation Plan (FPHCP) for fish-bearing streams in Western Washington. In the first study, a random sample of Forest Practice Applications (FPAs) was selected from the Washington Department of Natural Resources Forest Practices Application Review System database, and the relative frequencies with which each of the allowed RMZ prescriptions were applied to the fish-bearing streams within those FPAs were determined for each FPA. That office-based study found that 11 of the 25 possible RMZ prescriptions accounted for 91% of the buffers applied. The prescriptions identified to be most commonly employed were for sites on Site Class (site potential) II and III land and most frequently do not include any harvest within the Inner Zone. Total RMZ widths for those site classes are 170 ft and 140 ft, respectively.

Methods

We examined 106 study sites that were randomly selected from the Forest Practices Activity Review System database; approximately 10 for each of the 11 most-commonly implemented prescriptions identified in the FPA analysis study. Data were collected 3 to 6 years after harvest to allow early post-harvest windthrow to stabilize (per Schuett-Hames et al. 2012). Crews collected data from 18,242 standing trees and 2672 pieces of down wood on the 106 valid study sites.

Results

We found riparian buffer stands were generally young (median age = 46 years; range 35 – 120 years) and in the stem-exclusion phase of stand development. The median (weighted by RMZ prescription occurrence in FPAs) residual site buffer stem density (TPA), basal area density (BAPA), and quadratic mean diameters (QMDs) were 209 trees/acre (range: 47-846), 209.3 ft^2/acre (range: 57-406), and 13.8 inches (range: 8.1-26.0). The weighted median relative density (RD) was 53 (range: 14-113). Canopy closures measured at the stream channel edge had a weighted median of 96.4% (range: 35% - 100%) and 89% of the RMZs met the shade targets (indicating their ability to provide stream shade) laid out in rule. There was no evidence to suggest that sites differed by riparian prescription or by Inner Zone harvest in meeting shade targets. The RMZs that did not meet their shade requirements were located either along very large streams or along small streams with high buffer mortality. The average cumulative site mortality in the early post-harvest period (3 to 6 years) was 8% (range: 0% to 75%) of the live trees standing at each site immediately post-harvest, and the median annual mortality rate was estimated to be between 2.5% and 4.8%. The dominant mortality agent was windthrow (76% of all tree mortality), which was greatest in the Inner Zone along small streams, followed by stem exclusion/suppression (9% of the total mortality). Forty percent of early post-harvest treefall contributed large wood into and over the stream channel, and approximately 80% of that originated in the Core Zone. More wood fell and was recruited from buffers on small streams less than 10 feet wide than from buffers on channels larger than 10 feet. Weighted median values of large wood recruitment per 100’ of stream length were 1.0 pieces/100’ (range: 0 to 25 pcs/100’) and 2.8 ft^3/100’ (range: 0 – 91.6 ft^3/100’). The mean in/over-channel diameter of the recruited wood was 6.8 inches (median = 6 in; range: 4 - 23 in.) and the mean length of the portion in or over the channel was 8.7 feet (median = 6.1 ft; range: 1 - 54 ft.). There was no evidence at any of the sites that either the harvest operations or windthrow caused any bank destabilization or sediment delivery from within the riparian zone. We used the WA DNR’s DFC model to project stand growth and assess whether the stands are expected to meet the DFC target of 325 ft^2/acre by age 140. We found that 67% of the sites that had no Inner Zone harvest and 92% of the sites that had Inner Zone (DFC) harvests were projected to meet the DFC targets by that stand age.

Conclusions

Collectively, these findings suggest that the riparian prescriptions evaluated were sufficient to maintain the riparian functions of shade, large wood recruitment, and sediment/erosion reduction as outlined in the FPHCP. However, because the RMZs consist of relatively young forests, restoring riparian functions to high levels in these stands will follow a developmental trajectory of decades to a century. The findings of this second study are intended to guide and focus the development of the third study, an experimental Before-After, Control-Impact (BACI) study, which was initially proposed to evaluate the effectiveness of the Western Washington Type F/S riparian prescriptions in maintaining in-stream habitat for aquatic biota.

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Definition of Terms and Acronyms Used in the Westside Type F Exploratory Study Report

BA – Basal Area (ft^2)

BAPA – Basal Area per Acre (ft^2/acre)

BFW - Bankfull stream channel width

Buffer - both a verb and a noun and is used when referring to the general concept of buffering streams from upland activity.

CMER- Cooperative Monitoring, Evaluation and Research Committee. The Cooperative Monitoring, Evaluation, and Research Committee is the committee responsible for the science within the Forest Practices Adaptive Management Program, a monitoring, evaluation, and research program established by the Forest Practices Board. Its purpose is to ensure effective implementation of the recommendations contained in the Forests & Fish Report and the Forest Practices Habitat Conservation Plan.

CMZ Channel migration zone. The area where the active channel of a stream is prone to move and this results in a potential near-term loss of riparian function and associated habitat adjacent to the stream, except as modified by a permanent levee or dike. For this purpose, near-term means the time scale required to grow a mature forest. (See board manual section 2 for descriptions and illustrations of CMZs and delineation guidelines.) (WAC 222-16-010)

CZ – Core Zone of the RMZ. The first 50' from the edge of the stream channel or CMZ edge.

dbh – Diameter at breast height (4' 6").

DFC- Desired Future Condition. Refers to the condition of a forest at 140 years, with respect to age of trees, canopy cover, downed logs, etc. The goal of the Forests & Fish riparian management strategy is to leave the riparian area in a condition today that is on a trajectory to replicate the conditions of natural stands of forest at age 140. The target basal area is 325 ft^2 at 140 years.

ESA - Endangered Species Act

FFR - Forests and Fish Report of 1999

FPA- Forest Practices Application. A permit required to conduct most forest practices activities, including timber harvest, on state or private forest land in Washington State.

FPARS – Washington State Dept. of Natural Resources Forest Practices Applications Review System geodatabase.

FPHCP- Forest Practices Habitat Conservation Plan. The purpose of the FPHCP is to provide programmatic "coverage" under the Washington Department of Natural Resources (WDNR) forest practices division regulating private forestlands, and eastern WA state lands. Landowners who conduct forest practices activities that are in compliance with the Forest Practices Act and rules will meet the requirements of the Federal

Endangered Species Act for "listed" species under the FPHCP (i.e., certain salmonid fish species and some stream associated amphibians). The FPHCP is meant to provide for the restoration of harvestable levels of salmon while maintaining an economically viable timber industry by providing for the protection and long-term conservation of aquatic designated species, meeting Clean Water Act requirements, and supporting the restoration and conservation of riparian habitat.

IPH – Immediately Post-Harvest. This is an inferred condition created by adding trees that were assumed to have fallen in the early post-harvest period to the sampled standing tree inventory.

IZ – Inner Zone of the RMZ. The secondary strip of streamside buffer; width varies.

LTCW- Leave Trees Closest to the Water (DFC Harvest Option 2). An Inner Zone harvest strategy that involves harvesting trees farthest from the water and leaving those closest to the water. The harvested portion is not a clearcut but retains twenty 12" dbh or larger trees per acre in the remainder of the Inner Zone.

LW – Large Wood. 4" minimum diameter by 3.3' minimum length (10 cm by 1 m)

LWD – Large Woody Debris. Formerly-used term for Large Wood

OZ – Outer Zone (of the RMZ). The strip of streamside buffer adjacent to the main timber harvest. Width and leave-tree configuration vary.

QMD – Quadratic Mean Diameter. Tree diameter (in inches) for a tree of average basal area in the stand; derived from the basal area per acre divided by the number of trees per acre (QMD = Sqrt(BAPA/TPA/.005454154).

RMA- Riparian Management Area. An area protected on each side of a Type F or S Water meant to buffer streams from upland activity. "RMA" is the regulatory streamside buffer under forest practices rules prior to the Forests and Fish Agreement.

RMZ- Riparian Management Zone. An area protected on each side of a Type F or S Water meant to buffer streams from upland activity. "RMZ" is the regulatory streamside buffer under the Forests and Fish forest practices rules.

Rx - Prescription [variant]

Stand - [Riparian] The tree/timber growing in the RMZ or one of its zones.

TFB - Thin From Below. DFC harvest Option 1. An Inner Zone harvest strategy of harvesting smaller diameter trees and leaving the larger trees.

TFW - Timber/Fish/Wildlife. A multiple-stakeholder group, process, and agreement set down in 1987 to work together to shape the management of forest-based natural resources in Washington State (Timber/Fish/Wildlife Agreement 1987).

Type F Water- Segments of natural waters that contain fish habitat (other than Type S Waters).

Type S Water- All waters inventoried as Shorelines of the State under the state Shorelines Management Act. Type S Waters also contain fish habitat and are treated the same as Type F Waters with regard to riparian buffers. There is a sub-category (Type S+) which has additional riparian requirements beyond the forest practices rules. Those waters are not included in this study.

WAC Washington Administrative Code. The administrative "rules" written to implement laws passed by the Washington State legislature. Available online at https://app.leg.wa.gov/wac

WA DNR – Washington Department of Natural Resources.

YR3-6 – Indicates data values at the time of sampling and reflects changes over the early post-harvest period. The single field survey was conducted between 3 and 6 years after harvest, depending on the site. Exact harvest dates were not available. The study was meant to have a consistent 3-year post-harvest sample date but not enough sites that met study criteria could be identified within that time-frame. The sample draw was therefore expanded to include sites that might have been harvested as many as 6 years prior to sampling.

Zone- Any of the three areas of the RMZ. Each Type F/S stream RMZ has a Core Zone, Inner Zone, and Outer Zone, each with differing leave tree requirements.

Chapter 1. Introduction

Early logging practices in the United States, prior to the 1970s, viewed streams and rivers as transport corridors for both felled logs and equipment and did not generally consider the need to buffer[1] streams from timber harvest in any way. The rise of environmental awareness in the United States, especially in response to widespread, severe degradation of air and water quality by the 1960s and 70s, led to national legislation on air and water quality, the establishment of the Washington State Department of Ecology and the US Environmental Protection Agency, and the beginnings of rules regarding forest practices at state levels. The Forest Practices Act of 1974 was the first legislation in Washington to require leaving riparian buffers along fish-bearing streams during logging. The initial buffer rules implemented under that legislation went into effect in 1976. Since that time, our understanding of the relationships between the riparian zone and riverine habitats, particularly with regard to salmonid fishes, has grown and led to the evolution of those initial rules as well as to the extension of the stream network to which they are applied. In the 1980s, Native American Indian tribes and landowners, along with state agencies and conservation groups, began collaborating to guide that evolution together. This collaboration was formalized in the landmark Timber/Fish/ Wildlife (TFW) Agreement of 1987 (TFW 1987). The TFW agreement not only laid out new versions of forest practices rules agreed upon by all the signatories, but also the various goals parties agreed to and the processes by which rules would be researched, modified, and monitored for effectiveness in a collaborative adaptive management process. The current forest practices rules (Washington Administrative Code, or WAC, 222-30-021) are the result of further negotiations by the TFW parties in the late 1990s, which culminated in the 1999 Forests and Fish Report (FFR) and agreement (FFR 1999) and subsequent 2001 version of the rules (commonly referred to as the “FFR rules”).

The riparian conservation strategy of the FFR identifies functional objectives and performance targets for key aquatic conditions and processes affected by forest practices (FFR 1999; WA DNR 2005, Appendix N – Schedule L-1) and prescribes measures to be taken in the course of forestry activities to reach those objectives. The FFR rules for timber harvest and related activities in riparian areas adjacent to Type F and S waters (those used by fish) are a main component of the conservation strategy. The rules for Westside Type F and S riparian zones “are designed to restore and maintain riparian processes that create aquatic habitat, with particular emphasis on LWD [large wood] recruitment and shade retention” (WA DNR, 2005). Habitat for fish (and stream-associated amphibians) is influenced by the functions, processes, and inputs provided by riparian (streamside) forests. These include litter fall, shade, long-term wood recruitment, stream bank protection, fine-sediment filtering, and coarse sediment supply and attenuation (e.g., large inputs from mass wasting). The forest practices rules are intended

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[1] The term "buffer" is used as both a verb and a noun and is used when referring to the general concept of buffering streams from upland activity. "RMZ" is used when referring to the entire regulatorily-designated buffer. "Zone" refers to one or more of the rule-designated RMZ zones described later in the introduction. "Stands" refers specifically to the tree/timber growing in the RMZ or one of its zones.

to maintain and restore ecological processes to achieve resource targets for shade/water temperature, large wood, organic inputs, and sediment filtering.

A key concept developed by participants in the FFR negotiations is that of "desired future condition" (DFC) of riparian buffers. The authors of the Forests and Fish Report, on which the riparian rules are based, agreed that a desired future condition they would design riparian rules to aim for was a "mature forest." They defined the mature forest target condition as those of a stand at age 140 years (midpoint between 80 and 200 years old). This Desired Future Condition state was understood to be a development reference point on the pathway to restoration of riparian functions (FFR 1999). Participants recognized that there is no single "140-year-old mature forest" and that there would be high variability within this definition. But they agreed that healthy forest stands of that age provide most of the functionality required to maintain aquatic habitat and that was therefore the agreed-upon target riparian stand age condition. A stand growth "DFC" model was developed by Forests and Fish collaborators in 2000 for the purpose of assessing the growth pathway and potential for riparian timber stands to achieve the DFC when they are 140 years old. The objective behind including such harvest options in the Forests and Fish rules was to encourage management of some buffers that would accelerate the attainment of desired mature forest conditions and recovery of in-stream habitat processes (FFR 1999; Fairweather 2001; WAC 222-30-021 (1)(b)(ii)(B)).

Another agreement point in the FFR plan was to obtain an incidental-take permit for the new forest practices rules and program from Federal agencies responsible for implementing the Endangered Species Act (ESA). The 2005 approval of the DNR Forest Practices Habitat Conservation Plan (FPHCP, or "HCP") for endangered aquatic species (WA DNR 2005) fulfilled this point from the FFR. The 2005 FPHCP is an agreement between the Washington State Department of Natural Resources (DNR) and Federal agencies that allows landowners to conduct forest practices (e.g., logging) that conform to the rules laid out in the HCP without having to conduct an environmental review on every harvest to ensure no damage to ("take" of) aquatic species listed under the ESA, including to their habitat. Its purpose is "to assure those conducting forest practice activities, covered by or subject to the Forest Practices program, that they will also be in compliance with the Endangered Species Act (ESA) for covered threatened and endangered species" (WA DNR 2005)[2]. The FPHCP is based on and incorporates the Forests and Fish Report and 2001 rule set.

A key component of the Washington State DNR Forest Practices Adaptive Management program (FP AMP) is assessing the effectiveness of the FFR rules in achieving the functional objectives and targets set out in Schedule L-1 of the Forests and Fish Report. This work is one of the mandates of the Cooperative Monitoring, Evaluation, and Research (CMER) committee, the collaborative science research branch of the FP AMP. CMER has planned a series of studies to assess the effectiveness of the Type F/S riparian rules in Western Washington (Westside

[2] Activities in violation of the forest practices rules are not covered for "take" under the HCP.

Type F Riparian Effectiveness Monitoring strategy) in meeting the functional objectives and targets of the FP HCP that are specified in Schedule L-1 (Appendix N of the FP HCP). This exploratory study is the second of three phases for assessing rule effectiveness. The study was undertaken to measure and examine post-harvest stand characteristics associated with commonly-implemented riparian prescriptions. The study focus is on assessing riparian functions of shade, large wood contributions to streams, and sediment generation/filtering, and the prognosis for riparian stands to reach the designated DFC condition. The findings from this study are intended to guide and focus the development of the upcoming phase three Type F riparian prescription effectiveness study.

1.1 Westside Type F and S Stream Riparian Prescriptions

The Type F/S riparian management zone (RMZ) rules established in 2001 and updated in 2013 for Westside Type F and S streams are specified in WAC 222-30-021 (1). They prescribe a total RMZ width that varies with site class. Site class is based on the tree-growing potential of the ground (soil and climate conditions) in a given location. The five site classes associated with the FFR riparian prescriptions are based on the “100-year Site Potential Tree Height.” Site classes are counterintuitively labeled with Roman numerals where higher numerals indicate lower site potential tree heights (i.e., “low site”; poorer growing conditions and smaller trees), and lower numerals indicate sites with better growing conditions and larger trees (“high site”). It helps to think of Site Class I as being “1st class.” As indicated in Table 1, the rules prescribe wider buffers for site classes capable of growing larger trees (greater site index; third column). The different rule widths are based on the assumption that larger trees can provide riparian functions (e.g., shade and wood recruitment) at greater distances from the stream channel than smaller trees at sites with lower site potential can, and that tree removal from the outer edges of the buffer in sites with higher potential tree heights are more likely to affect riparian functions. See Appendix F for more information about the Forest Practices Site Class designations.

Table 1. Description of site class categories, stream width categories and harvest options used in the Western Washington Type F and S riparian prescriptions.

Site Class Categories	50-year site index range for W. Wash. (WA DNR 2020) [tree height in feet]	Total RMZ width* equals ¾ of the 100-year site potential Douglas fir tree height indices for W. Wash.**
I	137+	200 ft
II	119–136	170 ft
III	97–118	140 ft
IV	76–96	110 ft
V	<75	90 ft
Stream width categories	**Description**	
Large stream	>10 feet bankfull width	

Small stream	≤10 feet bankfull width	
Inner Zone Harvest options	**Description**	**Notes**
Option 1	Thin from below (TFB)	Requires leaving the 57 largest Inner Zone conifers per acre
Option 2	Leave trees closest to water (LTCW)	Must leave at least 20 conifers >12" per acre in the harvested portion of the Inner Zone; No harvest within 50 ft of the Core Zone for large streams and 30 ft for small streams. Only available for Site Classes I, II, and III-S
No-Inner Zone-harvest	Leave all trees	

* Horizontal distance from channel or channel migration zone (CMZ) edge
** (WA DNR 2005, based on McArdle 1961)

The total RMZ width is divided into three zones oriented parallel to the edge of the bankfull channel (Figure 1). Closest to the stream is the Core Zone where no harvest is allowed. Beyond the Core Zone lies the Inner Zone, in which some harvest may be allowed. Beyond the Inner Zone lies an Outer Zone where landowners are required to leave 20 trees/acre (or in some instances fewer), which can be clumped or dispersed.

The Core Zone is 50 feet wide on all streams in all site classes. The proportions of the RMZ allocated to Inner and Outer Zones are dependent on the site class and the width of the stream channel. Inner Zones on streams less than 10 feet wide ("Small" streams) are narrower than those on streams greater than 10 feet wide ("Large") streams. The respective Outer Zones make up the remainder of the regulatory RMZ width.

Limited timber harvest is allowed in the Inner Zones when the trees in the combined Core and Inner Zones exceed those required for the stands projected to meet the "desired future condition" by the time they are 140 years old. Stand inventory data from the Core and Inner Zone are used to run the DNR DFC stand growth model to assess whether an RMZ is eligible for Inner Zone thinning. (See Chapter 5 for more information on the model.) If the model-projected basal area per acre and conifer proportion are sufficient to meet the DFC targets, the model identifies trees that may be harvested from the Inner Zone. In cases where Inner Zone harvest is allowed, landowners may use Harvest Option 1, thin from below (TFB), or in some cases use Option 2, leave trees closest to the water (LTCW). Where the DFC targets will not be met, Inner Zone harvest is not allowed. Landowners may also choose not to harvest in the Inner Zone even if the stand meets the DFC requirements. Reviews of forest practices applications (FPAs) conducted by McConnell (2007) and Schuett-Hames et al. (2017; Table 2; Appendix C) indicated that landowners use Option 2 (LTCW) more than 90% of the time when they have both options available to them and choose to do any harvesting in the Inner Zone. It is not known how frequently landowners choose the “no-harvest” option in RMZ stands that would meet the DFC requirements because modeling RMZ stands is not required when applying for a timber harvest permit. Only forest practices applications (FPAs) where a “DFC” harvest is planned must include the DFC model input and results, so there is no way to know how many RMZs could potentially have had an Inner Zone thinning prescription applied.

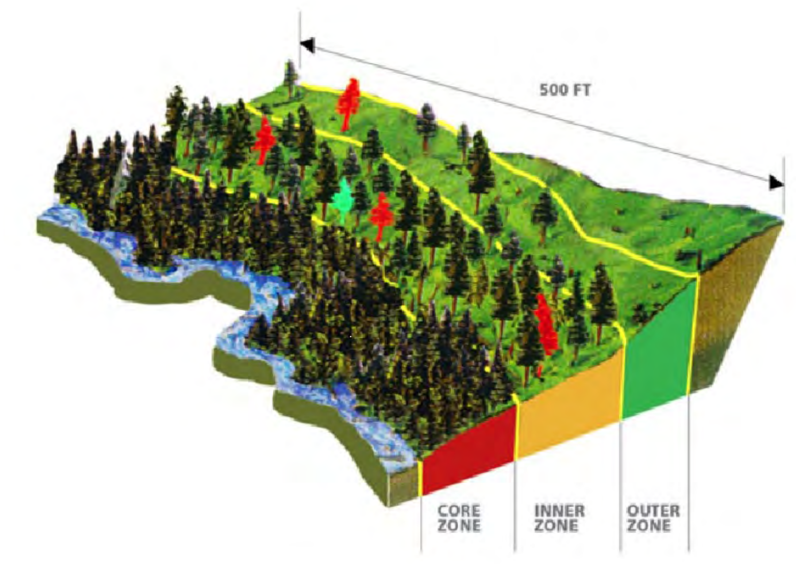


Figure 1. Diagram of the western Washington Type F Riparian Management Zone layout, showing the Core, Inner and Outer Zones.

The total prescribed width for Westside Type F and S RMZs varies according to five site class categories. Also, the relative widths of the Inner and Outer Zones vary by two stream width categories and three[3] Inner zone harvest options (Table 1). Given the possible combinations, there are 25 potential variations of the westside Type F standard rules, hereafter referred to as prescriptions (Rx) (Table 2).

[3] The Leave Trees Closest To Water (LTCW) option is only available for Site Classes I, II, and III-Small because to the no-cut “floor” requirements of 30’ on small channels and 50’ on large channels make that option irrelevant for other site classes.

Table 2: Westside Type F Riparian rules prescriptions (WAC 222-30-021) and results of the Phase 1 FPA Desktop Analysis.

Site Class	Prescription Variant		Total RMZ Width (ft)	Core Zone No Harvest Width (ft)	Inner Zone Width (ft)	Outer Zone Width (ft)	No-Cut Core+IZ "Floor" for LTCW (ft)***	Target Basal Area at age 140 yrs (ft^2/acre)	Desktop Analysis Stream Segment Count	% of Desktop Analysis Stream Segments
	Stream Width Category	Inner Zone Harvest Treatment**								
I	large*	No IZ harvest	200	50	100	50		NA	8	1.4%
I	large	Option 1- TFB		50				325	0	0.0%
I	large	Option 2- LTCW		50	84	66	100	325	11	1.9%
I	small*	No IZ harvest	200	50	83	67		NA	6	1.0%
I	small	Option 1- TFB		50				325	0	0.0%
I	small	Option 2- LTCW		50	84	66	80	325	7	1.2%
II	large	No IZ harvest	170	50	78	42		NA	52	9.0%
II	large	Option 1- TFB		50				325	0	0.0%
II	large	Option 2- LTCW		50	70	50	100	325	24	4.1%
II	small	No IZ harvest	170	50	63	57		NA	59	10.2%
II	small	Option 1- TFB		50				325	4	0.7%
II	small	Option 2- LTCW		50	64	56	80	325	13	2.2%
III	large	No IZ harvest	140	50	55	35		NA	86	14.8%
III	large	Option 1- TFB		50				325	31	5.3%
III	small	No IZ harvest	140	50	43	47		NA	107	18.4%
III	small	Option 1- TFB		50				325	8	1.4%
III	small	Option 2- LTCW		50	44	46	80	325	94	16.2%
IV	large	No IZ harvest	110	50	33	27		NA	15	2.6%
IV	large	Option 1- TFB		50				325	0	0.0%
IV	small	No IZ harvest	110	50	23	37		NA	6	1.0%
IV	small	Option 1- TFB		50				325	0	0.0%
V	large	No IZ harvest	90	50	18	22		NA	19	3.3%
V	large	Option 1- TFB[1]		50				325	0	0.0%
V	small	No IZ harvest	90	50	10	30		NA	30	5.2%
V	small	Option 1- TFB[1]		50				325	0	0.0%

*stream bankfull width >10 ft (large) or <10 ft (small)

** No Inner Zone harvest; TFB = Thin from below; LTCW = Leave trees closest to the water

*** The Leave Trees Closest To Water (LTCW) option is only available for Site Classes I, II, and III-Small because the no-cut "floor" requirements of 30' on small channels and 50' on large channels make that option irrelevant for other site classes.

1.2 Purpose and Objectives

The overall purpose of this exploratory study was to produce information needed to guide and focus the development of an experimental Before-After, Control-Impact (BACI) study of the effectiveness of the Type F/S Riparian prescriptions for Western Washington (Schuett-Hames et al. 2015). This exploratory study was not a designed experiment but, rather, an exercise in collecting data from riparian prescriptions that are already distributed across the landscape. It was intended to reduce uncertainties associated with the relative sensitivity of post-harvest riparian stand conditions, riparian functions, and soil disturbance associated with commonly implemented harvest prescriptions. Additionally, stand structure and soil disturbance data will be used to provide an estimate of the proportion of sites meeting FPHCP performance targets specified in the FP HCP Appendix N – Schedule L-1 and the proportion of the riparian stands that are on trajectory to meet the Desired Future Condition basal area target (Schuett-Hames et al. 2017).

Objectives

1. To evaluate post-harvest riparian stand conditions and riparian ecological functions across prescription variants with and without Inner Zone harvest.
    a. Riparian stand conditions associated with the prescriptions, including stand mortality, density, and basal area
    b. The frequency, magnitude, and distribution of windthrow and its effects on stand structure, buffer tree mortality rates and riparian functions
        i. The relative influence of differences in site conditions and geographic location on the above
    c. The level of riparian functions associated with the prescriptions, including data on post-harvest large wood recruitment, shade, and sediment delivery.
    d. Information on the magnitude of variability within and differences among prescription variants
2. To evaluate the extent (proportion of sites) to which post-harvest riparian forest stands are on trajectory to achieve DFC targets at sites with and without Inner Zone harvest.

We designed the exploratory study to learn more about:

- stand density,
- basal area,
- quadratic mean diameter,
- composition,
- stand mortality,
- the magnitude of variability within and differences among prescriptions.

Riparian buffers provide many functions, only some of which are specifically called out in the Schedule L-1 objectives and targets. The functions we assessed in this study were those related to provision of stream shade, large wood recruitment, and sediment filtering.

1.3 Study Approach

We used a retrospective, "after-impact" approach to compare and contrast post-harvest stand characteristics and associated functions among the eleven most-commonly applied Type F riparian prescription variants (Table 2). Data were collected from the study riparian buffers 3 to 6 years after the upland timber harvests were completed. Our analysis and findings are based on the assumption that the timber harvests and remaining buffers were compliant with the prescription rules. We recognize that flexibility in implementation might cause within-prescription variation; that is incorporated implicitly in our results, and we did not attempt to separate it from other sources.

The sampling schedule of 3 to 6 years post-harvest was designed to allow time for the newly established buffers to be exposed to typical wind disturbances (Ruel et al. 2001, Bahuguna et al. 2010, Schuett-Hames et al. 2012, Mitchell 2013) yet be soon enough after harvest to still allow crews to differentiate between pre-harvest and post-harvest tree mortality and recent wood recruitment (see "Fallen Trees and Large Wood Recruitment" below).

1.4 Population of Interest

The population of interest is riparian stands in the Core and Inner Zones of RMZs adjacent to Type F and S streams harvested according to the current Washington State Forest Practices standard riparian prescriptions for western Washington (lands shown colored in Figure 4). We excluded harvests that used alternative riparian prescriptions such as practices covered under hardwood conversion rules, 20-acre exempt parcel rules, alternate plans, and landowner-specific habitat conservation plans (HCPs). Riparian stands with channel migration zones (CMZs) or stream adjacent roads were excluded because they have specific regulations that would likely cause responses and measurement results to differ from those of stream-adjacent riparian buffers, thereby creating anomalies in the data we are trying to analyze and making our results less informative and useful. It would be impossible to determine whether those results represented true differences in the stands or were merely the result of the different rules in place for those sites. Similarly, the population of interest included only harvest plans approved under the current DFC target, which was revised in 2009 (WA DNR 2009, 2010).

A single FPA can have several Type F or S streams with multiple segments based on site class and stream width category, each with different prescriptions. The landowner can choose to break streams into separate segments with different harvest strategies based on stand characteristics and operational considerations. Therefore, the experimental unit was defined as one side of a Type F or S RMZ segment with a consistent DNR site class (I, II, III, IV or V), stream width category and harvest option.

1.5 Study Sample

We assumed that the riparian stands resulting from the prescriptions would vary in their capacity to provide key riparian functions post-harvest, because the prescriptions applied differed and were based on stream size and pre-harvest riparian characteristics (e.g., site class, percent conifer). We therefore used a stratified random sampling design with strata defined by riparian prescription variants, which differ in the buffer width and leave tree requirements shown in Table 1.

A Phase 1 in-office investigation of forest practices applications conducted during the design of this project (Appendix C; Schuett-Hames et al. 2017) found that of 580 riparian buffer prescriptions applied to the Type F and S Waters in 170 randomly-selected FPAs sampled, nearly 80% fell within 7 of the 25 possible Type F/S prescriptions (Table 2). Budget constraints were balanced with the need to learn about conditions in buffers left by those seven most widely applied prescriptions and about others that covered specific, potentially high-impact, conditions to select 11 prescriptions to explore in this study. The eleven prescriptions selected for investigation are shown in Table 3, which also shows the widths and areas of the Core and Inner zones that constituted the study plots. Prescriptions 1 through 8 represent the most-commonly applied riparian prescriptions on Type F and S streams. We hypothesized that impacts of windthrow had the potential to be especially detrimental to riparian functions provided by narrow buffers for Site Classes IV and V, and so also included three prescriptions in those site classes in this study (Rxs 9, 10, and 11) despite their low occurrence in the Phase 1 FPA sample analysis (and therefore presumably on the landscape) to study them. We excluded seven of the 25 possible variants that did not occur in that sample of 580 stream buffer implementations and another seven that each represented <2% of the total. The eleven prescriptions selected for inclusion encompass over 91% of the buffer prescriptions applied in the FPAs of the Phase 1 desktop investigation. The findings from this study are based on and should only be considered to represent conditions left by those eleven prescriptions.

The sample size was limited to 110 sites, which corresponded to 10 sites per prescription variant. A balanced sampling strategy had two clear benefits; 1) less common prescription variants were equally represented in the analysis across strata, and 2) fine-scale analysis at the strata-scale was possible. A power analysis conducted using data from the Westside Type N BCIF Study (Schuett-Hames et al. 2012) suggested that a sample size of N = 10 would be weak for "comparing any two prescription variants" for some variables (mortality in particular) but would provide reasonable estimates across treatments for other variables of interest such as basal area per acre and shade (Schuett-Hames et al. 2017 Appendix B). Therefore 10 samples were selected from each of the 11 prescriptions.

During the analysis phase, four sites were found to not meet the study requirements and were discarded, and one site was reclassified into a different variant, causing the sample to lose some balance. Detailed inspection of FPAs for DFC details revealed that one site in prescription variant 4 (small stream) had been misclassified and was actually on a large stream. It was re-assigned into the correct Rx 2. Two sites with Inner Zone harvest (6a, 8a) were discovered to have been laid out under the earlier DFC rule, not the post-2009 rule that was the subject of this study. Those sites are not included in any analyses. A site that was thought to have been a LTCW Type F RMZ (4e) was excluded from the study because it had been reclassified as a Type Np buffer on the FPA following a stream type change (Water Type Modification), though that information had not been input to the DNR database at the time. A fifth study plot (9h) was also excluded because we discovered the sample plot was laid out in the active channel or CMZ rather than in the actual RMZ left by the foresters. The sample sizes shown in Table 3 reflect these changes. Figure 2 shows how the final study sample allocation compares with the FPA evaluation sample results, as proportions of overall sample size.

Table 3: Harvest prescription variants (strata) included in Phase 2 Exploratory study, with sample allocation and final sample sizes.

Prescription (Rx)	Stream Width Class	Site Class	Inner Zone Harvest Treatment	Plot Length [ft]	Core Zone Width [ft]	Core Zone Area [acres]	Inner Zone Width [ft]	Inner Zone Area [acres]	Core + Inner Zone Width	RMZs Sampled N
1	**L**	**II**	**No harvest**	300	50	0.344	78	0.537	128	**10**
2	**L**	**II**	**LTCW[1]**	300	50	0.344	78	0.537	128	**11**
3	**S**	**II**	**No harvest**	300	50	0.344	63	0.434	113	**10**
4	**S**	**II**	**LTCW**	300	50	0.344	63	0.434	113	**8**
5	**L**	**III**	**No harvest**	300	50	0.344	55	0.379	105	**10**
6	**L**	**III**	**TFB[2]**	300	50	0.344	55	0.379	105	**9**
7	**S**	**III**	**No harvest**	300	50	0.344	43	0.296	93	**10**
8	**S**	**III**	**LTCW**	300	50	0.344	43	0.296	93	**9**
9	**L**	**IV**	**No harvest**	300	50	0.344	33	0.227	83	**9**
10	**L**	**V**	**No harvest**	300	50	0.344	18	0.124	68	**10**
11	**S**	**V**	**No harvest**	300	50	0.344	10	0.069	60	**10**
										106

[1] Leave trees closest to the water, [2] Thin from below

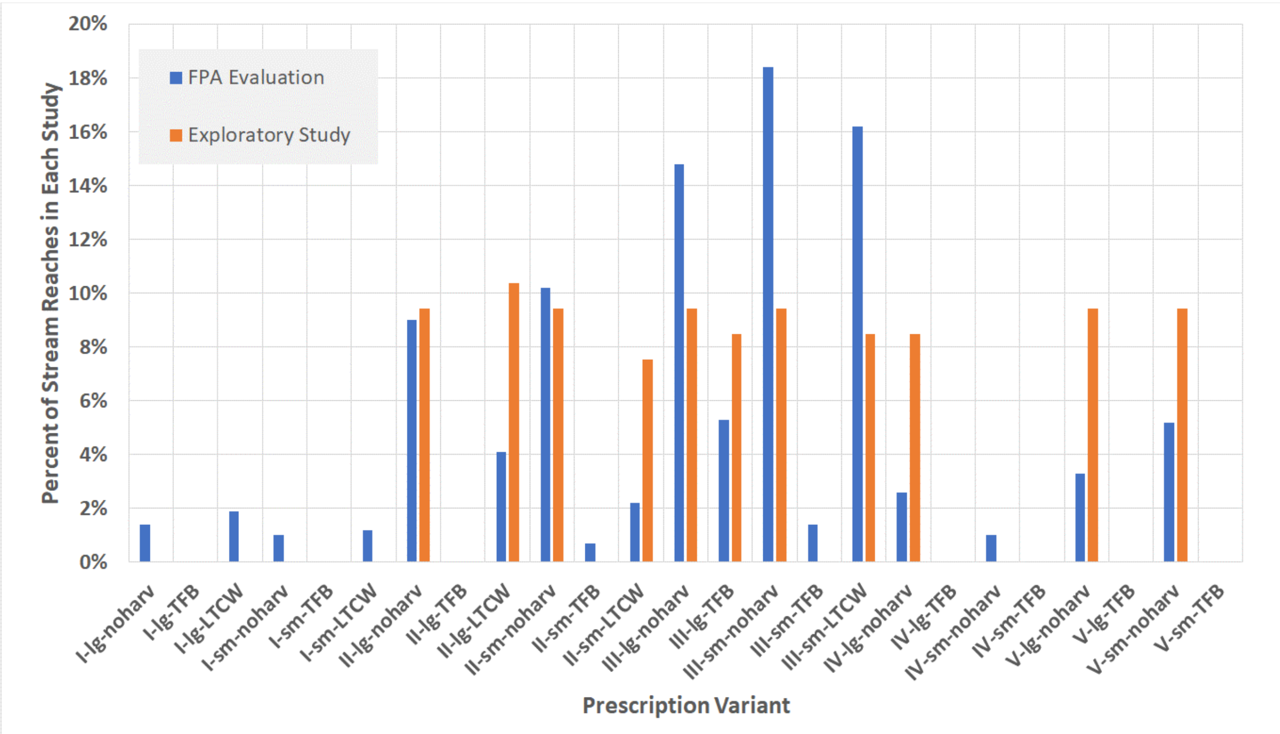


Figure 2. Comparison of percentage distribution of sample buffers in this study versus 580 buffers found in 170 randomly selected FPAs with effective dates from July, 2008 through June, 2013 (Schuett-Hames et al. 2017).

We typically report summary statistics such as averages and medians within each prescription. Where we report *overall* averages and medians, we report weighted medians and ranges because most metrics are skewed or otherwise non-normally distributed. We weighted the values to account for 1) differences in prescription sample sizes and 2) the relative proportions with which the various prescriptions are applied on the landscape. The first was accounted for by using the prescription variant size (n) as a fraction of the 106 sites and the second was accounted for by the percentage of sites using each prescription that was found during the FPA Desktop Analysis (Table 4). The percentage of the population for each prescription was divided by the percentage of each sample to develop a weighting factor for the values in each prescription and these were then normalized (divided) by 106, the total sample size (see Table A-2). Normalizing the sample weights facilitated calculation of weighted medians. The weights and resulting averages must be considered estimates with unknown accuracy, because we have no way of testing the assumption that the random selection of the FPA riparian prescription desktop analysis represents the actual landscape application of prescriptions over the period since the implementation of the new DFC harvest rule.

Table 4. Sample data weighting factors for each prescription (Rx).

Rx	Rx Name	Desktop Analysis Stream Segment Count	Sample Size n	Value Weight = [(Segment Count / 530) / (n/106)]/106	Weight * n
1	II-L-None	52	10	0.00981	0.0981
2	II-L-LTCW	24	11	0.00412	0.0453
3	II-S-None	59	10	0.01113	0.1113
4	II-S-LTCW	13	8	0.00307	0.0246
5	III-L-None	86	10	0.01623	0.1623
6	III-L-Thin	31	9	0.00650	0.0585
7	III-S-None	107	10	0.02019	0.2019
8	III-S-LTCW	94	9	0.01971	0.1774
9	IV-L-None	15	9	0.00314	0.0283
10	V-L-None	19	10	0.00358	0.0358
11	V-S-None	30	10	0.00566	0.0566
SUM		**530**	**106**		**1.0000**

Because the sampled strata and sample sizes were not balanced with respect to variables likely to influence stand structure and character, such as Site Class, we analyzed subsets of these data depending on the question we were trying to explore (Table 5). For instance, Site Class III is the only site class that has all three potential Inner Zone harvest options (TFB; LCTW; No-harvest), although they are on different stream sizes. In addition, the fact that the RMZ configurations differ based on site class and stream width means that comparisons among the harvest options can be done only using variables that do not depend on the zone widths (such as stem density, basal area per acre, and QMD, which are normalized for area) to be directly comparable in any kind of tests for association with an IZ harvest option. In contrast, comparing the absolute number of fallen trees between Prescription 11 (site Class V, Small streams, no IZ harvest) with the number from Prescription 2 (Site Class II, Large streams, LTCW IZ harvest) would be of limited meaning, because the two RMZs have very different widths and inherent growing capacity in the soils and therefore likely different numbers of trees no matter which IZ harvest option was applied.

Table 5: Number of sample sites by site class, stream width category and Inner Zone treatment type.

Site Class	Stream width category	IZ Treatment No harvest	IZ Treatment TFB	IZ Treatment LTCW
II	Large	10		11
	Small	10		8
III	Large	10	9	
	Small	10		9
IV	Large	9		
V	Large	10		
	Small	10		

1.6 Study Scope of Inference and Limitations

The scope of inference is limited to the eleven most commonly implemented harvest prescriptions as represented by the randomly selected study sites from each prescription in the sample frame. Given the elimination of confounding factors in the site selection, the approximate balance in sample sizes among prescriptions (strata), and the appropriate selection of prescriptions to use in each comparison, we can have high confidence in the comparative findings of riparian stand conditions and functions among the prescriptions sampled. However, extrapolation of the findings to the greater population of Type F and S streams with RMZs should be treated with caution because sample size was relatively small and not inclusive of the wide variability of channel/valley morphologies where Type F and S RMZs are implemented. We would have low confidence in making inferences about conditions in unsampled prescriptions, though we do know that the ones not sampled are rarely applied and therefore must represent a small portion of FFR stream buffers. However, we also do not know how the population of FPA prescriptions relates to stream length on the FP HCP landscape and at this point are unable to estimate that.

Importantly, we cannot attribute cause of any given results to a treatment effect based on the data from this study. Although we can say there were differences among the RMZs after applying some prescriptions, we do not have the sampling design and data to be able to state that any differences are due to the prescription applied. On the other hand, when harvest prescriptions leave functioning buffers that meet a given target of the FP HCP, then we *can* say the application of a prescription was not responsible for the level of function falling below that target.

1.7 Report Organization

This report is broken into chapters that address different objectives and riparian functions as separate sub-reports. This Introduction is followed by a description of the study site selection and sites in Chapter 2. In Chapter 3, we report on the riparian stand structure characterization and questions related to that. In Chapter 4 we present investigations into Mortality and Windthrow. Chapter 5 addresses questions related to assessing how many sites are on track to meet the Desired Future Conditions basal area target. In Chapters6, 7, and 8, we report on and develop estimates of the proportion of sites meeting FPHCP performance targets related to wood in streams/recruitment potential, shade, and sediment control. Many of the L-1 targets are vague and not measurable "targets." The vagueness can make it difficult to objectively evaluate whether the targets are being met. In each of those chapters, we identify the targets or objectives we are attempting to evaluate and the criteria we have called upon to test against. Chapter 6 addresses questions related to the riparian stands' current and future ability to provide large wood to the stream channels. Chapter 7 does the same for shade, using canopy closure as a surrogate for shade. Chapter 8 reports on the sediment filtering and delivery-related functions of the study buffers. In Chapter 9 we summarize the key findings and draw final conclusions.

Chapter 2. Study Sites

2.1 Site Selection, Screening, and Layout

We began the site selection and screening process with a query of the harvest unit layer in the Forest Practices Applications Review System (FPARS) database. Forest practice applications do not include the actual harvest date. Landowners have up to three years to harvest after FPA approval. Therefore, to capture units harvested three years prior to our sampling window of summer 2019, we queried FPARS for Western Washington harvest applications that had been approved or renewed between 2012 and 2015 using the following criteria:

- In western Washington
- For even-aged harvest of timber
- No Habitat Conservation Plan
- No alternate plans
- Includes RMZ
- Within 200' of Type F or S stream

The initial query returned ~7,000 harvest units from a starting total of 230,000 in FPARS. One thousand harvest units were chosen at random to screen for visual evidence of harvest using the National Agricultural Imagery Program (NAIP) aerial imagery from multiple years during the desired timeframe. The initial site selection effort required that harvest had been conducted within a very narrow window of time, confirmed by the landowner. This resulted in a rejection rate of over 99%. Therefore, we adjusted the selection process by eliminating the requirement for landowner confirmation on harvest date and expanded the harvest window to encompass units that possibly ranged from 3 – 6 years post-harvest. This expanded window was not anticipated to alter the results of the study because relatively recent post-harvest conditions would still be captured. Confirmation of harvest year was conducted by comparing with NAIP and Google Earth aerial imagery. The earliest study site harvest occurred in 2013, and all sites were confirmed to have been harvested by summer of 2016.

Each sample site (experimental unit) was 300 ft (91.4 m) long plus 75 ft of unsampled buffer on each end to avoid buffer edge effects, for a total of no less than 450 feet (137 m). We examined the FPA documents for information that was not present in the FPARS database to identify harvest units with stream segments at least 492 ft (150 m) long to allow for excess length on each experimental unit. There are often multiple stream reaches within a harvest unit and each one can have an RMZ on one or both sides of the stream reach (Figure 3). Stream segments with both one- and two- sided treatments were included in the study. In the case that a two-sided treatment was selected, one side was chosen at random by the crew for the data collection. A database of potentially viable stream segments was created that included the prescription variant and other covariates available from the FPA documentation.

We manually created linework that represented each potential qualifying segment based on the DNR stream layer in GIS and aerial photography. Sites were disqualified where stream-adjacent attributes were present that had potential to confound our ability to detect conditions related to timber harvest such as a road, channel migration zone, landslide, tributary stream with additional buffer, or large wetland. Factors that only affected a portion of an RMZ segment, such as wetland or mass wasting buffers, were not used to exclude entire segments but only to exclude the affected portions of the RMZ. In these cases, the affected portion of the RMZ segment was not surveyed, but the remaining unaffected portion was only included in the study if it met the minimum stream length criterion. Some sample reaches were discontinuous for these reasons. The presence of yarding corridors in the buffer was considered part of the prescription and did not exclude a segment from the study. The configuration of the Outer Zone leave trees was recorded but was not a factor used to screen sites as the OZ leave density of 20 trees per acre was deemed to be low enough to have little effect on the observed response variables of this study. Sample sites were randomly chosen from qualifying RMZ segments. To minimize the potential for spatial autocorrelation, final selections of candidate RMZ sites had to be spaced at least 2 km apart.

Despite extensive office screening of potential study reaches, we anticipated situations where on-the-ground conditions would not match up with the GIS layers, FPA maps, and landowner information we used for office screening. Up to three potential pre-screened RMZ segments at each site (termed the ‘primary’, ‘secondary’ and ‘tertiary’ segments, where secondary and tertiary were backups) were provided to field crews if available.

Field crews carried out further site screening. If a potential segment met study qualifications, the crew measured and marked out the 300-foot study reach channel edge delineation starting from a randomly-selected start point within the RMZ reach (Figure 3). Sites were laid out along the delineated study reach according to the landowner-declared FPA site class and RMZ treatment for that portion of the harvest. Crews delineated the Core and Inner Zone boundaries based on their (horizontal) measurements and the buffer requirements of the prescription; they did not try to recreate the forester’s original layout or second guess zones based on apparent harvest.

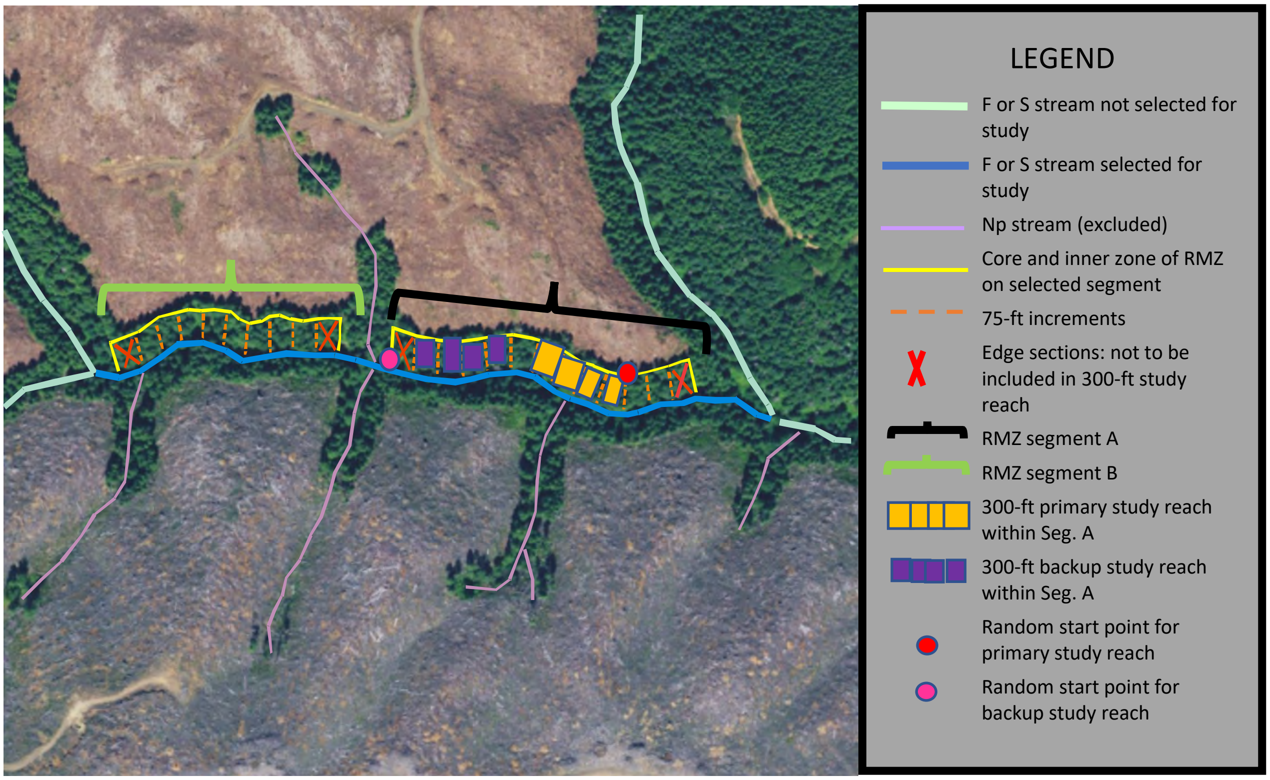


Figure 3. Aerial view of a harvest unit with two potential qualifying RMZ segments, a primary segment, and a backup segment.

2.2 Site Data Methods

Site classes were taken from the FPAs; no attempt was made to verify site class either from the site class map or in the field. Stream type data were pulled from the original FPAs for all sites. Site elevations were obtained by intersecting the sites with a digital elevation raster in ArcPro GIS. Valley orientations (Stream aspects) as 8-pt compass flow directions were determined by visual inspection of the GIS maps for each sampled buffer. RMZ cut-face exposure directions were calculated by adding two compass points (90 degrees) to the valley direction for RMZs on the right bank and subtracting two points for left bank RMZs.

Field data collection methods are described in their relevant report chapters.

2.2.1 Data Quality Assurance and Control

Field data quality was assured by creating a thorough field methods manual, instituting a rigorous crew training regimen (which included some refinements to the methods), and by the field principal investigator (PI) accompanying the field crews throughout the field work. Data quality was controlled in the office as data came in by the field PI and again after processing by the lead PI on the project. Histograms of raw data and calculated metrics were created, anomalous data were inspected for accuracy and reasonableness, and any necessary corrections were made to prepare the data for analysis.

2.3 Site Descriptions

Figure 4 displays the site locations and illustrates the spatial distribution of site classes on FFR/CMER lands. Sites are concentrated in the parts of Western Washington where most timber harvest occurs in recent years – dominantly the Willapa Hills and western Olympic Peninsula. Although it is not shown on the map, most of the study sites fall within the Sitka Spruce Zone, designated under the emergency forest practices rules of 2000 (https://geo.wa.gov/datasets/wadnr::sitka-spruce-zone-forest-practices-rule/about). Site classes II and III can be seen to dominate the Forests and Fish subject areas. Site Class III dominates the coastal area, which also has the highest concentration of study sites. There is a more diverse mixture of site classes in the western Cascades region.

Site characteristic data are provided for each of the 106 study sites in Tables A-3 and illustrated by prescription variant in Appendix B-1. Scatterplots of the abiotic site attribute data (Figures A-1 and A-2) demonstrate an even representation within each of the prescription variants 1 through 11 for these metrics, with the exception of elevation. Site class II and III prescription variants are clustered in lower elevations whereas site class IV and V prescription variants appear to have a bimodal distribution of sites sampled either under 500 ft or above 2,000 ft elevation (Figure 5).

Sites were in drainage basins facing all directions of the compass but were more prevalently in south and west-facing drainages (Appendix A, Figure A-3.1-A). There were few sites in east-facing valleys. There were no remarkable differences in the distributions among the prescriptions investigated (Appendix B-1). This reflects the locations of FFR lands in Western Washington, which are largely in west- or southwest-facing basins Figure 4. The north and east facing slopes of the Olympic Peninsula are dominated by Federal lands, while the east-facing slopes of the Willapa Hills are dominated by agricultural lands and the Interstate 5 corridor. Most of the east-facing slopes in the Cascade Mountains are in the eastern part of the state and not part of this study.

The newly-exposed edges (“cut face”) of study RMZs were more evenly-distributed around the compass points than the site valleys were, with a spike in the number with west-facing cut edges (Appendix A-3, Figure A-3.1-B). Each prescription stratum generally had some sites with RMZ cut edges facing all directions but tended to have more southerly to westerly-facing edges. Prescription 11 on small Site Class V streams had no RMZs with east-faces. Notably, the thin-from-below prescription sites (Rx 6) had mostly north- and east-facing cut edges Appendix B-1.

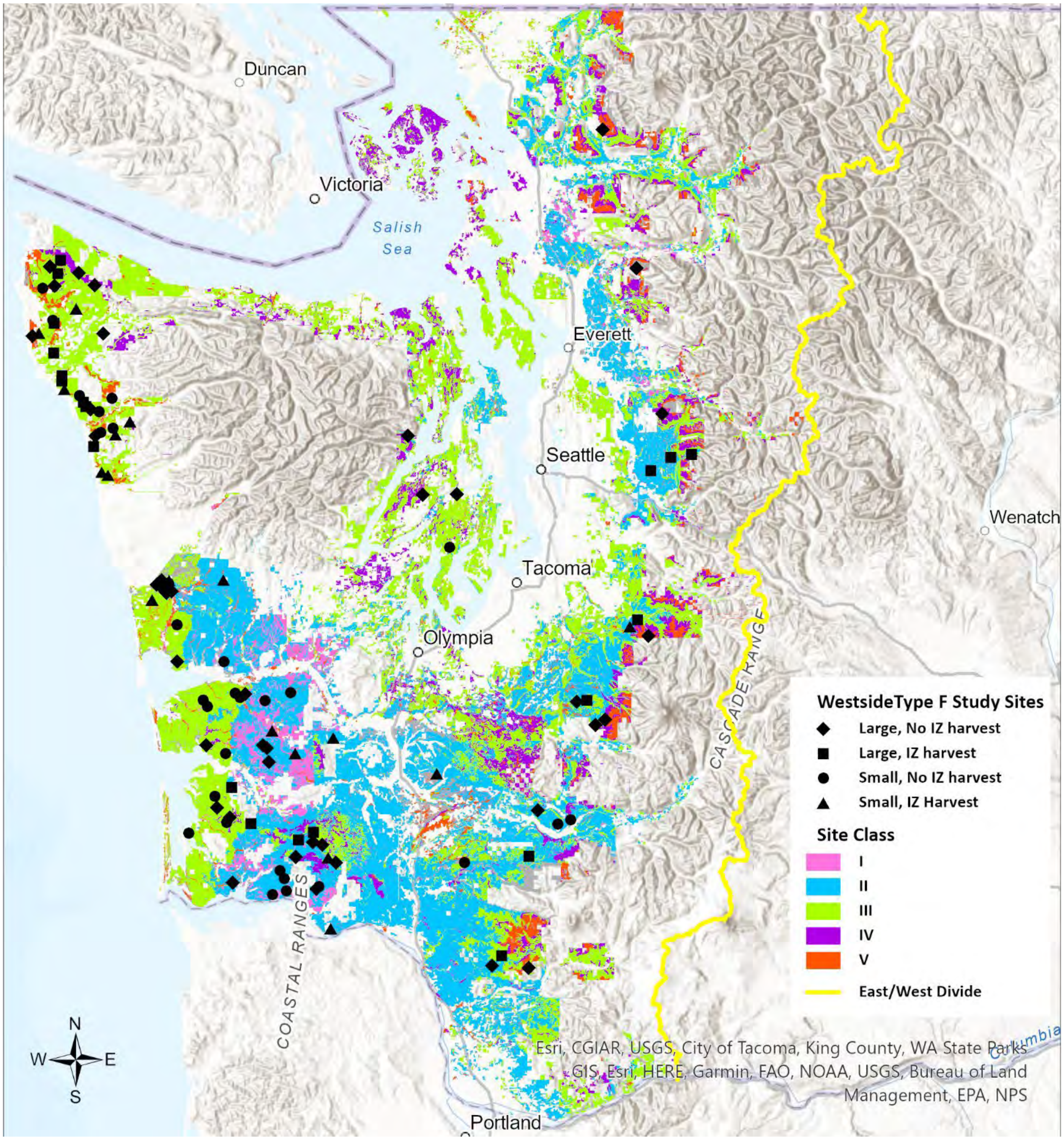
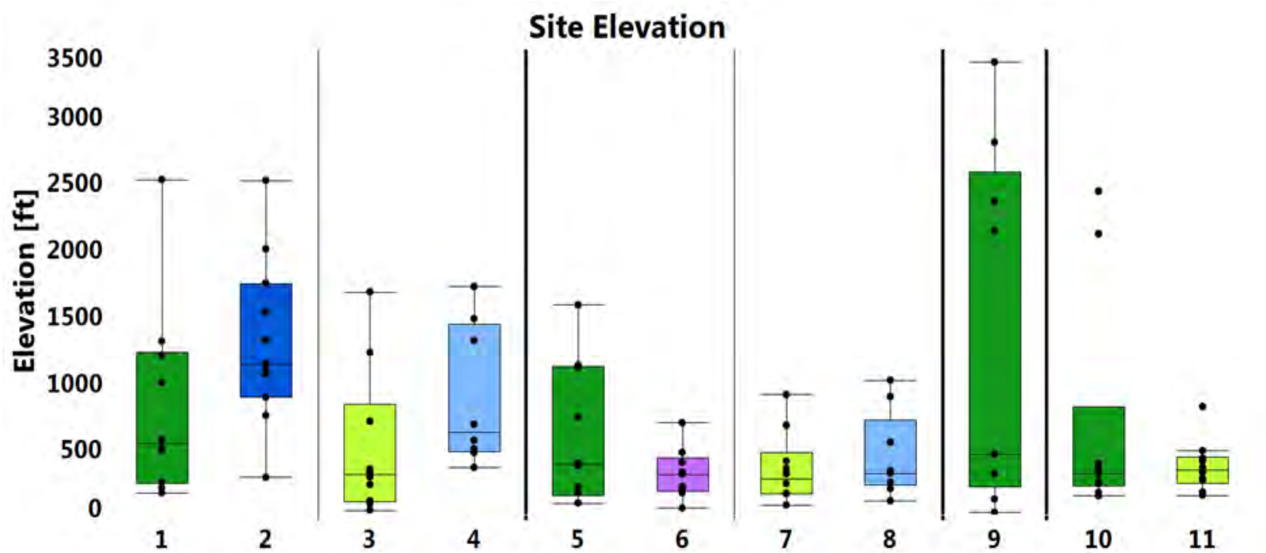


Figure 4. Westside Type F Study Site locations laid over Western Washington forestlands that are subject to the Forests & Fish forest practices rules ("FFR lands").



Site Class	II				III				IV	V	
Strm Size	L		S		L		S		L	L	S
IZ Harvest	None	LTCW	None	LTCW	None	TFB	None	LTCW	None	None	None
N	10	11	10	8	10	9	10	9	9	10	10

Figure 5. Site elevation by prescription variant.

Chapter 3. Stand Characteristics and Structure

The purpose of this chapter is to describe the range of stand conditions found in the RMZs remaining after timber harvest in support of study objective 1. We sought to better understand the variation within and among the tested prescriptions and to identify any prescriptions where the post-harvest riparian stand condition differs widely from the others, which might suggest they would be appropriate to carry forward as a focus of the Phase 3 study. The riparian stand structure and characteristics for study sites presented in this chapter also provide the foundation for understanding the findings presented in subsequent chapters of this report.

Our analyses are focused on answering the following questions:

- What stand conditions were associated with each of the prescriptions immediately after harvest and 3 to 6 years after harvest?
    - What were the variabilities in the stand conditions within each prescription?
    - Were there any prescriptions for which either the magnitude or variation within the stand metric stood out as differing from other prescriptions?
- Were there differences in either means or variances between sites that did and sites that did not have Inner Zone harvest?

3.1 Stand Characteristics and Structure Methods

3.1.1 Stand Characteristics and Structure Data Collection

Field data collection began after leaf-on in May 2019 and continued through early September 2019. Due to the expansion of the harvest period required during site selection, this ranged from three to six years after the units had been harvested. Data were collected digitally using a rugged field tablet in a series of digital Excel forms or within the ArcGIS Collector or Survey 1-2-3 app, depending on the type of data. For the specific procedures used for each type of data collected, please refer to the study field methods manual (Davis 2019). Site and riparian stand parameters measured and calculated are presented in Appendix A tables.

Surveyors inventoried all standing trees, live and dead, that were 4 inches or more in diameter at breast height (4.5 ft above ground) within the Core or Inner Zone of the RMZ. Trees on the edge of the RMZ boundary were considered within the RMZ when at least 50% of the diameter at breast height (dbh) of the tree was inside the study reach boundary. Live and dead trees under 4.5 ft tall were not counted, regardless of diameter; cut stumps were ignored entirely and were not included as dead trees[4], even if they were over 4.5 ft tall. For all qualifying

[4] Although counting of stumps was part of the study design, previous experience in CMER studies has shown that counting and assessing cut stumps within second- and third-growth stands is very difficult, expensive, and highly

standing trees, condition (live/dead), regulatory zone (Core/Inner), species, and dbh to the nearest tenth of an inch were recorded in accordance with the Washington DNR field procedures for forest resource inventory system manual (WA DNR 1996).

Stand age at harvest and buffer age at the time of sampling were employed as the input for the DNR DFC Model Worksheet, version 3.0 (https://fortress.wa.gov/dnr/protection/dfc/DfcRun.aspx) and as a factor relevant to understanding the role of stand characteristics in RMZ functions. The method for determining stand age was chosen based on available data and ability to make a field-based determination. For sites with Inner Zone harvest the stand age was determined from DFC model input data included in the FPA with the years between the DFC run and assumed harvest year added. Where no Inner Zone harvest occurred, field crews made the stand age determination based on ring counts taking from 3 – 5 stumps from the most recent harvest in the Outer Zone. The stumps selected for ring counts represented the most dominant species dispersed along the length of the 300 ft study reach (USDA Forest Service 2018). Ring counts were averaged to determine stand age at harvest and three years were added to estimate the age of the sampled buffer trees at the time of the study. Crews were instructed to avoid stumps from large remnant trees, since they were not representative of the main buffer stand for the purpose of DFC model calculations, but such stumps were occasionally included.

3.1.2 Stand Characteristics and Structure Data Preparation and Analysis

Data preparation consisted of loading field data into an Access database and then calculating stand-level variables from the site, individual tree, and wood piece data. "Yr3-6" stand metrics were calculated directly from the stand measurements collected by field crews in 2019, which was 3 to 6 years after harvest, depending on the site. We added trees that were determined to have died and/or fallen during the period since harvest (determined using established methods described in the field manual and in Chapter 4) to the Yr3-6 live tree total to estimate the stand conditions immediately post-harvest (IPH). Table A-1 details the metrics gathered for each prescription variant, and the methods and equations for calculating the metrics used in the analysis are detailed in Table A-2. The resulting stand metrics are provided for each of the 106 study sites in Table A-4 and summarized by prescription variant in Table B-7.

To characterize stand composition, we considered the dominant species by count and basal area, percentage of conifers by count and basal area, and species richness by count of species

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inaccurate. This is due to the way modern trees are harvested - very close to the ground and typically covered with leftover slash. Finding and digging out cut tree stumps to measure them was an effort beyond the project budget and when done in the past, has still resulted in little confidence in the completeness and accuracy of the data. Since this was a pilot study with a tight budget, and general stand information is present in the DFC run data as part of the FPAs for sites with Inner Zone harvest, the measurement of stumps component was not included in the study.

present. Species richness was determined using a simple count of the number of unique tree species recorded for each study site; this is a complement to the percent conifer metric. The standard deviation of the stem diameters within each stand (stddevDBH) was calculated to indicate the overall dispersion of tree sizes in the stand. We used species richness and stddevDBH as readily-accessible indicators of stand complexity (or uniformity), à la Spies and Franklin (1991) and Zenner (2000). Stand diversity metrics such as tree species richness are becoming a more commonly reported stand characteristic as the interest in managing forests expands to incorporate broader ecological functions than simply wood production (Spies and Franklin 1991; Zenner 2000). Although species richness is not a typical metric used to describe those upland forest stands being managed for timber production, which typically rely on tree planting using a single seed source to obtain uniform stands, it is an important descriptor for assessing riparian buffer stands and their potential to provide the multiple functions intended by the forest practices rules and FPHCP. Richness indicates species diversity and directly relates to the litterfall, nutrient cycling, and wood input functions of streamside stands identified with goals and targets in Schedule L-1 of the Forests and Fish Report (FFR1999). We only used these to describe the general character of the stands in the study and they were only calculated for the initial post-harvest state.

We limited the stand structural characteristics analyses to variables that were normalized by area because the prescriptions all had different Inner Zone and Total RMZ areas, rendering metrics with absolute numbers (e.g., number of trees and basal area) meaningless for comparison purposes across all the prescriptions. The stand characteristics we used were stand age, stand density (TPA), basal area per acre (BAPA), dominant species (first two letters of genus and species), percent conifer (by # of trees and by basal area), quadratic mean diameter (QMD), relative density (RDsum; Curtis 2010), and the standard deviation of the tree diameters in the stand (stddevDBH). We relied on non-parametric statistic descriptors and statistical tests, because nearly all the structural metrics were highly skewed, bi-modal, or otherwise deviated from normal (see Table 6), particularly within prescription strata.

We characterized the RMZ stands for the study overall by calculating weighted median values of these metrics for the entire sample set. Weighted medians were calculated by sorting the metric values and the corresponding sample site weighting factor (described previously in Section 1.5) in ascending order of the metric, accumulating the weights, and identifying the value at which the accumulated weight sum equaled 0.5. In cases where the weight sum did not equal exactly 0.5, the two metric values corresponding to the accumulated weight immediately preceding and just above 0.5 were averaged. We investigated the potential influence of abiotic site characteristics by inspecting crossplots of the stand condition metrics immediately after the harvest versus abiotic site characteristics (longitude, elevation, valley direction, site class, stream size, hillslope aspect) and stand age.

We then plotted stand structure and composition metrics by prescription and RMZ zone to investigate and compare the stand conditions immediately after harvest (IPH) and 3 to 6 years after harvest ("Yr3-6"). Graphical presentations of summary statistics for stand characteristic data are displayed by prescription variant in Appendix B. These boxplot diagrams are organized by prescription within site class and sub-divided into boxplots demonstrating the variation within the Core and Inner Zone of each prescription variant sampled. When viewing post-harvest descriptive results by prescription, it is important to recognize that prescriptions were implemented based on a) site class, b) stream width category, c) conifer basal area, and d) the landowner's choice of whether to harvest in the Inner Zone when the minimum conditions were met. Therefore, there are inherently high correlations between the post-harvest stand conditions for each prescription and the factors that determined which prescriptions could be applied (site class, conifer percentage/dominance, and basal area).

To identify prescriptions or cases that could help focus the Phase 3 study effort, we identified any prescriptions for which either the magnitude (mean/median) or dispersion (variance/interquartile range/total range) of stand composition or structural metrics stood out as differing significantly from those of other prescriptions. Average magnitudes of the stand conditions within each prescription were investigated by observations of boxplots showing datapoints by prescription and by calculating and inspecting means and medians. Dispersions were assessed again by inspection of boxplots and by comparing standard deviations, ranges, and 95% confidence intervals for stand metrics both collectively (Table 6) and by prescription (Table B-7). We tested metrics for differences in variances using Levene's and Brown-Forsythe tests of homogeneity to identify metrics for which the variabilities within some prescriptions differed significantly from those within others when the boxplots suggested substantial differences. The Brown-Forsythe test of variances is more robust to highly skewed distributions like the ones for stand data, so we typically report those results. We used ANOVA (rarely) or Kruskal-Wallis non-parametric tests to identify metrics for which apparent differences in means/medians were significant. We also used paired t-tests and Wilcoxon Signed Rank tests to compare stand structural metrics between Core and Inner Zones.

To answer questions about differences between sites with and without Inner Zone harvest, we made several comparisons of conditions in sites that did and did not have an Inner Zone (DFC) prescription applied for Site Classes II and III, which were the only site classes that had prescriptions of both types. Metrics for the four IZ harvest prescriptions were then compared with those for their comparable No-IZ-harvest prescriptions (e.g., Prescription 2 vs. Prescription 1) to understand whether differences between sites with and without harvest in the Inner Zone could be considered significant. We compared those prescription pairs individually because we knew that the underlying site class and stream size factors on which the prescriptions are based differed and that differences in the stand characteristics could differ by those factors and not necessarily by the just the prescription applied. Non-parametric Mann-Whitney tests were used to compare magnitude (central tendency) and Levene's and Brown-Forsythe tests for homogeneity of variances were used to compare the variances for each pair.

3.2 Stand Characteristics and Structure Results

3.2.1 Riparian Stand Composition

Overall, the sites in this study were dominated by conifer trees. Four fifths of the study site stands had conifer fractions over 50%. Half of the buffers were composed of over 90% conifer trees and nearly one fifth consisted of 98% or more conifer trees (Figure 6-A and B). The conifer fraction of the trees had a weighted median value of 83% and ranged from 0% to 100%. The conifer tree basal area fraction had a weighted median of 87% and also ranged from 0 to 100%. Sites typically had between three and seven different tree species among trees that measured more than four inches in diameter (Figure 6-C). 86% of the buffers had at least four different tree species within the overstory. The sites that were most dominated by conifers tended to have lower species richness. The standard deviation of the tree stem diameters within a site, indicating the amount of dispersion or stand uniformity, was most frequently between 3 and 6 inches (Figure 6-D). The weighted median stddevDBH was 4.8 inches. One buffer stand had a standard deviation of 17 inches. The average diameter and standard deviation for that site were driven by the presence of an enormous relic Sitka spruce tree in the buffer.

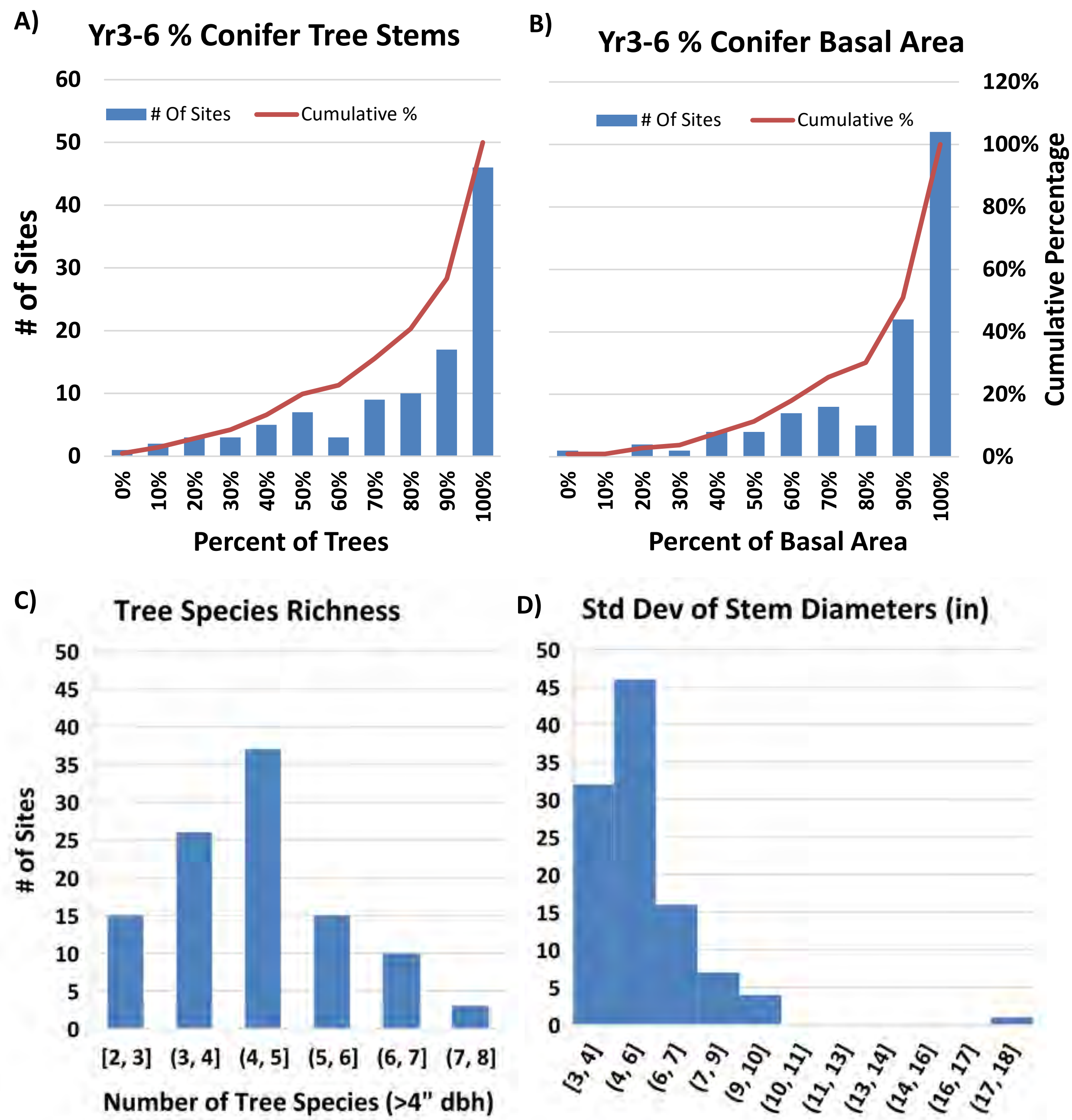


Figure 6. Percentage of conifer (A and B), tree species richness (C), and the standard deviation of the stem diameters (D) in each study buffer.

The riparian stands immediately after harvest were most frequently dominated (in terms of tree counts) by western hemlock followed by Douglas-fir and red alder (Figure 7-A). Western redcedar was the dominant species at three sites. Bigleaf maple and cascara each dominated at one site. Douglas-fir dominated sites were more prevalent in Site Class II than in other site classes and red alder dominated nearly as many sites as Douglas-fir did in both no-IZ harvest prescriptions of Site Class II (Rxs 1 and 3). Western hemlock was the most prevalent throughout the other site class prescriptions. There was little change in species dominance between the time of harvest and the time of sampling three to six years later (Figure 7-B) due to mortality. One site that had been dominated by western hemlock at harvest time came to be dominated by Sitka spruce trees, while two conifer-dominated sites converted to alder-dominated. A few sites changed between western hemlock-dominated and Douglas-fir-dominated. Stands in Site Class II seemed to be especially prone to a change in the dominant species.

The site class map in Figure 4 and the elevation plots in Figure 5 show those Site Class II lands to be at low elevations, in the Puget Sound basin and following large river valleys. There were two stream Type S sites in Prescription 1, one of which was in a floodplain or low terrace area with a hardwood-dominated buffer. Prescriptions 7 and 9 each had three hardwood-dominated sites. Half of the Prescription 9 sites in Site Class IV were located at very low elevations. One of those was on a large Type S stream on a low terrace at a confluence, near sea level. There were only a few hemlock and alder trees and one enormous relic Sitka spruce tree in the RMZ.

Comparison of sites with and without IZ harvest

Prescription variants that had IZ harvest had lower species diversity and higher percentages of conifer than their comparable no-IZ harvest prescriptions (i.e., contrasting Prescriptions 1 and 2; 3 and 4; 5 and 6; 7 and 8) (Figure 8). Prescriptions 1 and 3 (both no-IZ harvest) in Site Class II are notable for low median conifer composition and high variability among the sites within each prescription. Grouping IPH stand composition data by site class and IZ harvest category (Figure 9) shows that prescriptions with no IZ harvest had the greatest broadleaf composition, especially for Site Class II.

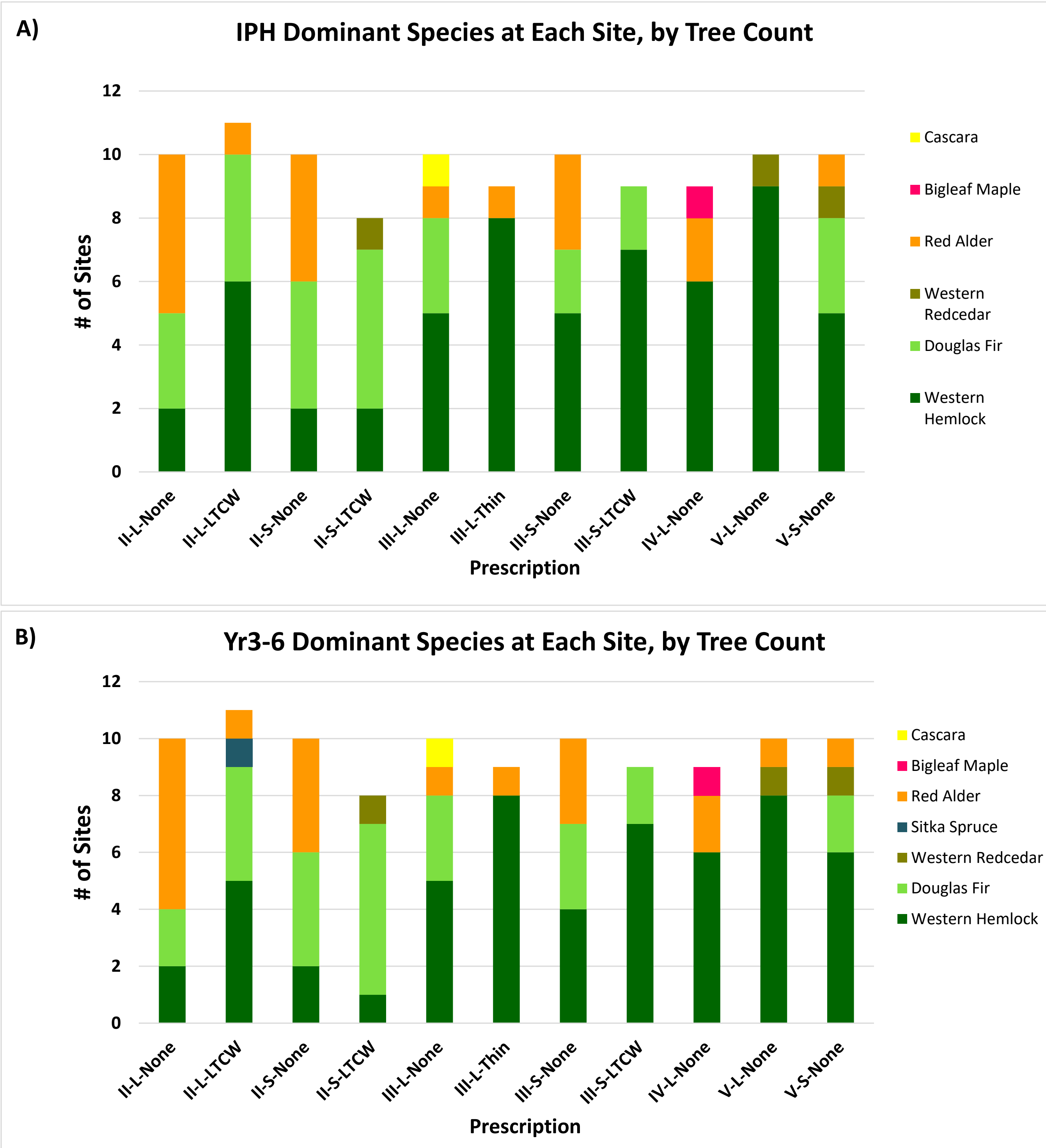
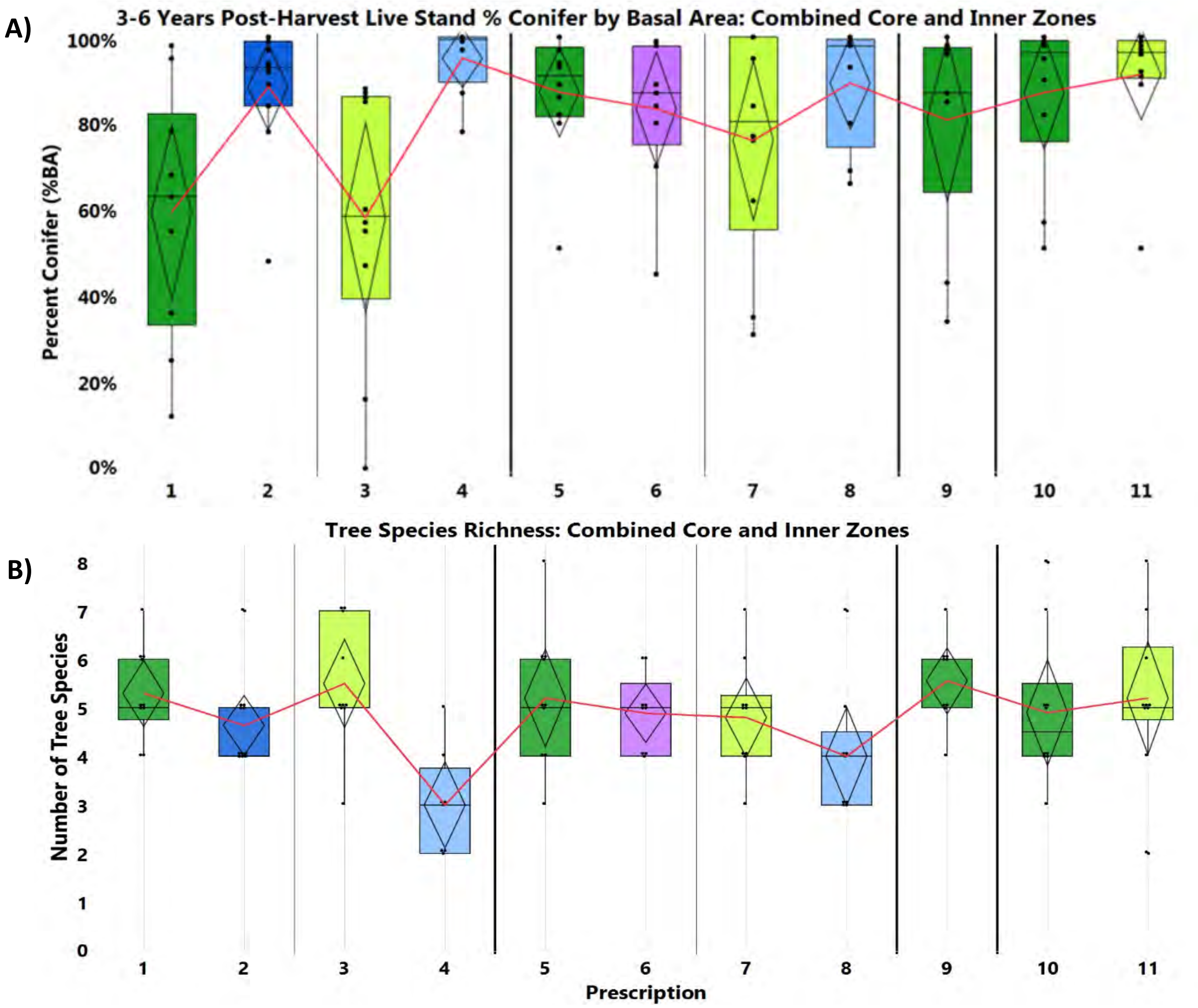


Figure 7: Dominant species by tree count by site within each prescription immediately after the harvest (A) and at sampling 3 to 6 years later (B).



Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
N	10	11	10	8	10	9	10	9	9	10	10

Figure 8. Percentage of conifer basal area in study buffers (A) and tree species richness (# of species) (B) by variant.

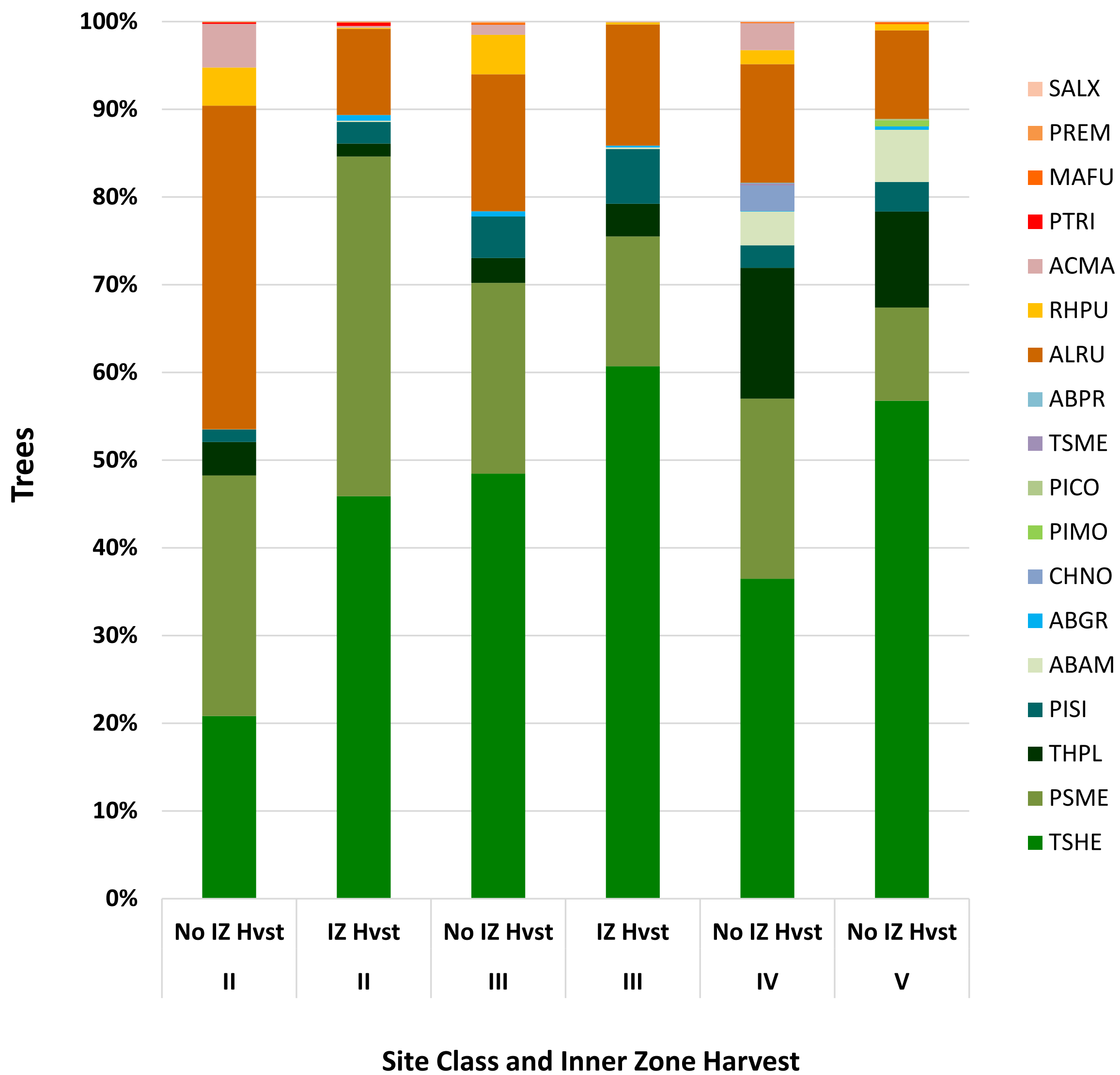
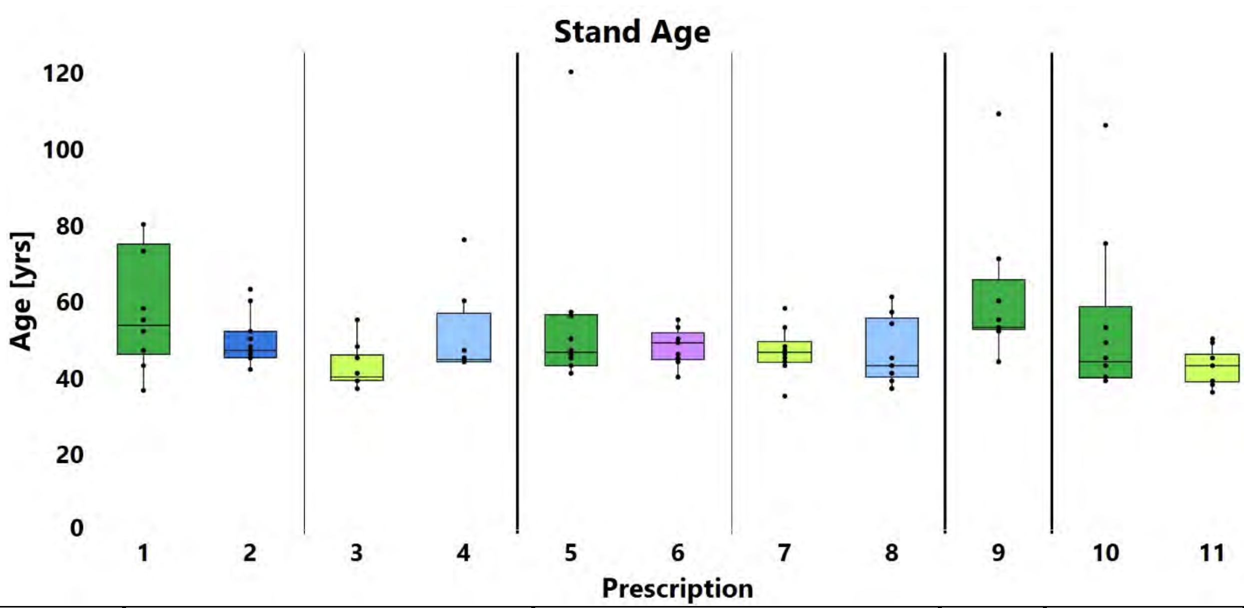


Figure 9. Stand composition immediately after harvest, displayed by site class and whether or not there was an Inner Zone harvest prescription applied.

3.2.2 Riparian Stand Age

The median stand age at harvest was 42 years and the average was 46 years (Figure 10, Table 6). Ages ranged from 30 to 116 years, and 80% were between 35 and 55 years (Table A-3). No strong differences in ages were observed among the prescriptions. There was a slight tendency for the median stand age to be older in prescription variants with Inner Zone harvest, though it was well within the variation of the No-IZ-harvest stand ages. The apparent age differences might reflect a difference in the methods of stand age derivation for IZ harvest/no-IZ-harvest sites since all ages for sites with Inner Zone harvest were derived from landowner data provided in the associated FPA rather than being acquired from tree ring counts on-site. Buffers in Site Class V on small streams were closely centered around 40 years old while the other variants had more variation among sites. Three sites in three different prescriptions (all no-IZ-harvest) were recorded to be over 100 years old at harvest. Inspection of the data showed that the eldest stand (Site 5b) contained ten 3- to 4-foot diameter Douglas-fir trees but was mostly composed of 15-27-inch alder and bigleaf maples and some smaller trees. The next eldest stand was composed dominantly of very large bigleaf maples with large western hemlock in portions. The stem densities in both stands were low, but the basal areas were near that of the overall study median and the QMDs were large. The third very old riparian stand was composed almost exclusively of many small (QMD = 10.7”) cedar and hemlock trees.



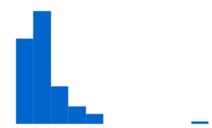
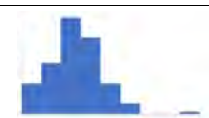
Site Class	II				III				IV	V	
Strm Size	L		S		L		S		L	L	S
IZ Harvest	None	LTCW	None	LTCW	None	TFB	None	LTCW	None	None	None
N	10	11	10	8	10	9	10	9	9	10	10

Figure 10. Stand Age by prescription variant.

3.2.3 Riparian Stand Structure

The stand structure metrics considered in this chapter, summarized across all study sites, are reported in Table 6. At the time of sampling, sites typically had a total of 130 standing live trees (range 30 to 396) and mortality of 25 trees since the time of harvest (range 0 to 189) in the combined Core and Inner Zone. The median stem density IPH, weighted by FPAs in each prescription stratum, was 240 trees/acre and ranged from 59 trees/acre to 931 trees/acre. Three to six years after harvest the weighted median density decreased to 209 trees/acre (range = 47 to 846 trees/acre). The weighted median basal area density (BAPA) IPH was 230 ft2/acre (range = 128 ft2/acre to 413 ft2/acre) and decreased to 209 ft2/acre (range = 57 ft2/acre to 406 ft2/acre) through the early post-harvest years. The weighted median quadratic mean diameter was 13.3” (range = 8” to 26”) IPH and increased to 13.8” while the range remained unchanged. The weighted median relative density decreased from 59 IPH (range = 35 to 121) to 53 at Yr3-6 (range = 14 to 113). Overall, the time since harvest resulted in metric distribution shifts for some metrics (e.g., density, BA) and little change in others (e.g., QMD, % conifer).

Table 6. Stand composition and structure metrics summarized across all study sites.

Metric	Weighted Median	Minimum	Maximum	Weighted Mean	Weighted Standard Deviation	Histogram
Stand Age at Harvest	42	30	116	45	14	
IPH Stem Density (TPA) [trees/acre]	240	59	931	262	252.8	
IPH Basal Area Density (BAPA) [ft2/acre]	230	129	413	239	124.3	
IPH Quadratic Mean Diameter (QMD) [in]	13.3	8.1	26.0	13.5	5.52	
Std Dev of IPH stem DBHs	4.8	3	17.1	5.2	3.52	
IPH Relative Density (inches, acres)	59	35	121	62	33.2	
IPH %Conifer by stems	85%	0%	100%	75%	62%	
IPH %Conifer by BA	90%	0%	100%	80%	53%	
Yr3-6 Stem Density (TPA) [trees/acre]	209	47	846	222	226.3	
Yr3-6 Basal Area Density (BAPA) [ft2/acre]	209	57	406	214	140.7	
Yr3-6 Quadratic Mean Diameter (QMD) [in]	13.8	8.1	26.0	13.9	5.56	
Yr3-6 Relative Density	53	14	113	54	36.2	
Yr3-6 %Conifer by stems	83%	0%	100%	74%	61%	

Yr3-6 %Conifer by BA	87%	0%	100%	79%	53%	

The only patterns that were readily apparent in the relationships between stand characteristics and site characteristics were those with site class (Figure A-4-1). A comparison of IPH data across prescriptions (Figure 11) shows that more productive site class lands have lower densities of larger trees and less productive sites have high densities of smaller trees (ANOVA; TPA: P<.0001, QMD: P=.0003; Appendix B sections B-2 and B-5). Basal areas and, hence relative densities, also tended to be higher on poorer site classes. The RMZ stands on poorer site classes also tended to consist of higher percentages of conifer trees (P = .0304) and conifer basal area (P = .0733). These relationships were true both for sites without IZ harvest and when looking at all sites together. Variances in the live stem density and basal area per acre differ among prescriptions (Figure 11). Site Classes IV and V not only have notably different median values for those metrics than the other prescription variants, they also have a wider range in values, resulting in higher variances.

Comparisons of IPH conditions between Core and Inner Zones of Figure 11 show the stem densities and basal areas differed for some prescriptions (mostly at more productive site class) with little to no differences at the less productive site class. Stem diameters (QMD) were similar between Core and Inner Zones and among all prescriptions. Paired t-test results for sites within each prescription revealed that QMDs did differ significantly between the core and Inner zones at sites in Prescriptions 2 (P = .0421) and 8 (P = .0169).

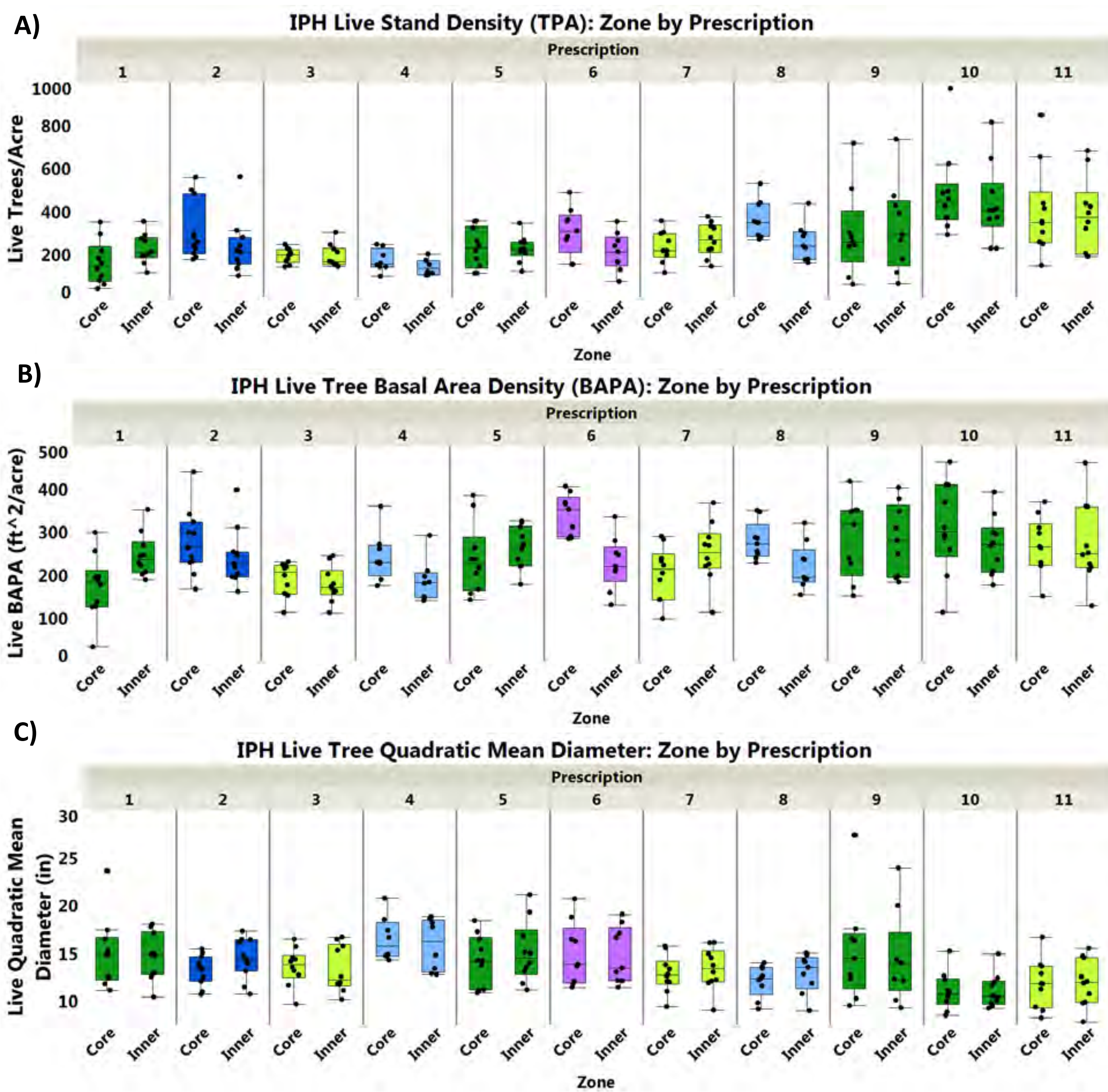
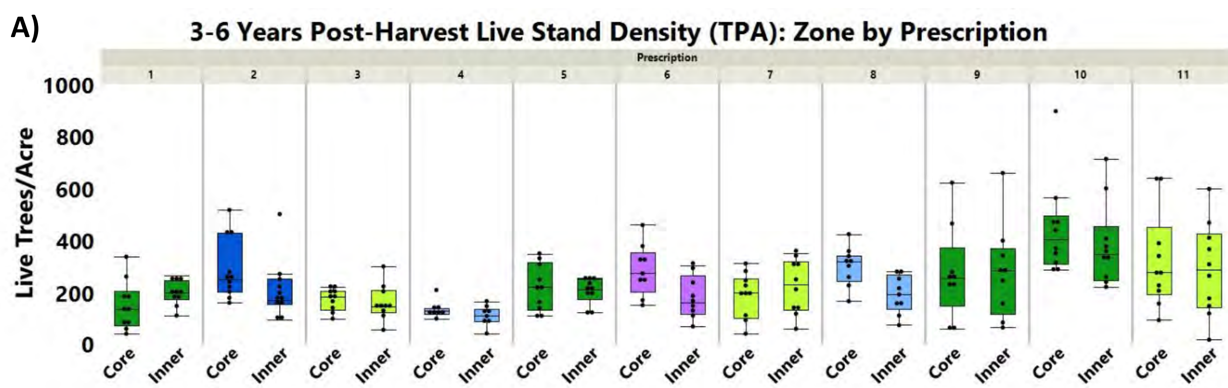
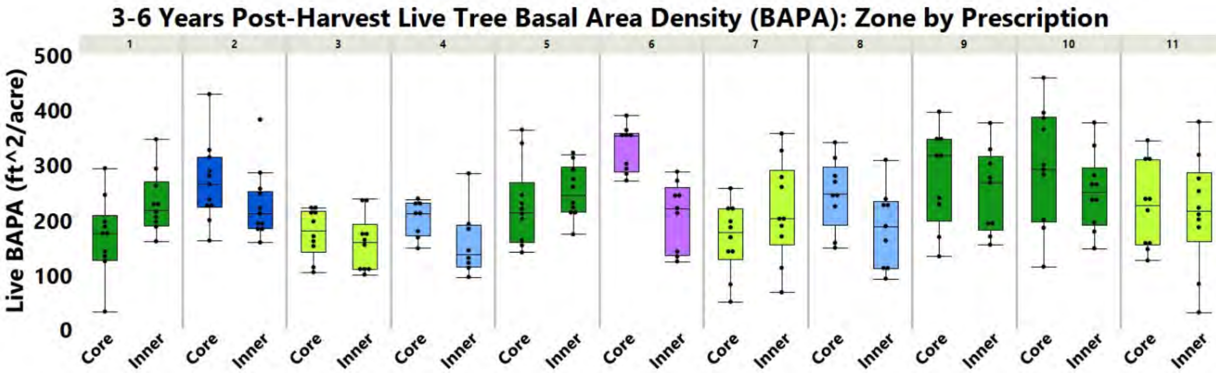


Figure 11. Initial Post Harvest stand characteristics by prescription variant and RMZ zone.



B)



C)

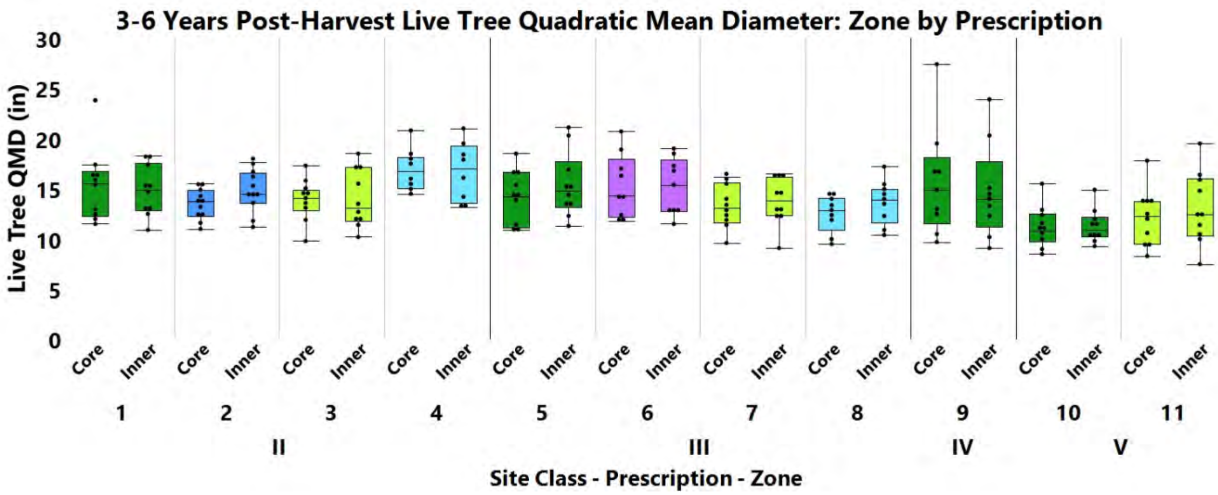


Figure 12. RMZ Stand characteristics by prescription variant and zone 3 to 6 years after harvest

Comparison of sites with and without IZ harvest

There was a slight tendency for stands with Inner Zone harvest prescriptions to be older than those with no IZ harvest (Figure 10). Post-harvest stem densities and basal areas tended to be slightly higher in the Inner Zone than the Core Zone for No-IZ-harvest prescriptions (P = .5189 and .2220; Table 7) whereas Inner Zone TPA and BAPA were lower than those in the Core Zone on sites that had IZ-harvest (P < .0001). This is entirely expected because removing trees is what the IZ harvests do (Figure 11). These relationships were true immediately after harvest and remained true 3 – 6 years later at the time of sampling. The QMD, however, did not differ between the Inner and Core Zones for either set of prescriptions immediately after harvest (Ps between .224 and .961) but did after a few years in the case of the IZ harvest sites (P = .0269).

Table 7. Students' paired t-test probabilities of Inner Zone TPA, BAPA, and QMD being higher/larger than those for the Core Zone.

Metric	No IZ Harvest Sites	Sites with IZ Harvest
Immediately Post-Harvest		
TPA	.5189	**<.0001**
BAPA	.2220	**<.0001**
QMD	.9612	.2240
3 – 6 Yrs Post-Harvest		
TPA	.6358	**<.0001**
BAPA	.6053	**<.0001**
QMD	.4966	**.0269**

The similarity between the stand metrics in the Core and Inner Zones for sites with no IZ harvest suggests that using Core Zone data as surrogates for pre-harvest conditions in the IZ harvest prescriptions might be reasonable. Comparing the IPH values of Core Zone stand metrics for IZ harvest sites and no-IZ harvest sites by Site Class, it would appear that the IZ harvest prescription stands started out with higher densities and basal areas than sites in their corresponding (by site class) no-harvest prescription stands. The higher basal areas at IZ harvest sites is expected because of the requirements for Inner Zone DFC harvest to be conducted, but that so many of the higher basal areas at IZ harvest sites were associated with high densities of smaller trees rather than lower densities of larger trees was not expected.

3.3 Stand Characteristics and Structure Discussion

Timber stands in the study RMZs (i.e., representing eleven commonly implemented prescriptions) consisted predominantly of young, dense, small diameter, coniferous stands. Stand structure was generally similar among the prescriptions as the age composition at most sites (80%) ranged from 35 to 55 (some sites had trees greater than 100 yrs old). The IPH stem density distribution was right-skewed (wt. median = 240, range = 59 to 931 TPA) and weighted median QMD was 13.3" (range = 8" to 26"). Species richness in the study RMZs had a median value of 5 tree species and 80% of the stands consisted of more than 90% conifer species. The median stddevDBH of 4.8 inches (13 cm) indicates high uniformity of trees within stands. There is a large overlap in the structure characteristics, indicating the similarity among all prescriptions.

The species richness weighted median value of 5 was consistent with richness values reported for young, mature, and old-growth upland conifer forests from coastal Oregon to the western Washington southern Cascades (Spies and Franklin 1991). Low standard deviations in the site-level stem diameters indicates that the RMZ stands were uniform in tree size as well as species mix. The median stddevDBH of 4.8 inches (13 cm) falls within the 95% confidence interval of 4 – 5.5 in. (10 -14 cm) Spies and Franklin (1991) calculated for young upland forest stands but differs notably from the 7.9 - 9.4 in. (20 – 24 cm) measured in mature conifer forests and 11.8 – 13.4 in. (30 - 34 cm) for old-growth forests. As harvest rotations continue to leave buffers, the distributions of stem diameters should grow wider and the stddevDBH increase. The frequency distribution of the buffer stem diameter standard distributions on the landscape and other new indices of stand structural complexity such as those developed by Zenner (2000) would be reasonable elements to include in a monitoring program to monitor for a shift toward the desired future condition of complex riparian forest stands capable of fulfilling multiple riparian functions.

The lower tree species diversity found in the LTCW buffers is not surprising under the prescription requirements for that treatment. In order to apply an Inner Zone harvest prescription, the stand must have a high proportion of conifer trees and basal area to begin with. Then the DFC harvest prescription itself further tends to reduce species richness by allowing removal of all broadleaf species as part of the harvest. Despite that and the generally high conifer percentages in the riparian buffers of this study, nearly all sites had some alder or other broadleaf species present to diversify the stands more than the cultivated upland forest stands were.

Trends or noticeable differences in stand structure among prescriptions and site class were limited and subtle. A comparison among prescriptions with no-IZ harvest (Figure 11) suggested an expected trend where some more productive site class lands (i.e., class II, Rx 1, 3)) had lower densities of larger trees compared to some less productive sites (i.e., class V, Rx 10, 11) which had very high densities of smaller trees. However, this association with site class is questionable because dominant species composition and BA are quite different between the referenced prescriptions. The proportion of broad leaf trees (mostly red alder) is larger, and the BA is lower at Prescriptions 1 and 3 (Site Class II) than at Prescriptions 10 and 11 (Site Class V). In comparison, Prescriptions 2 and 4 (Site Class II) are dominated by conifer and have higher BA indicating an inconsistency within the same site class. The reason for these differences in composition and BA are likely due to several RMZs in Prescription 1 and 3 being partially located within the floodplains of larger rivers. Consequently, the site class assigned to RMZs on a floodplain/low terrace may be a poor predictor of productivity given the heterogeneous topography and higher potential for river associated disturbance. Research shows that the frequency and location of riparian disturbances and subsequent patterns of development are strongly influenced by valley landform and height above the channel. Studies of riparian stands in western Washington show that floodplain landforms are dominated by deciduous stands as a result of frequent flood disturbances and less disturbed terraces/hillslopes are dominated by conifer and resemble upland forests (Villarin et al. 2009, Rot et al. 2000). The DNR Site Class mappers attempted to account for these differences, but Schuett-Hames et al. (2005) raised awareness that those maps are not always correct. Maps of this site potential were developed by the DNR based primarily on soil maps from the 1990s (see Appendix F). Close inspection of the map shows higher detail in some stream drainages than in others.

The harvest unit stand ages in this study ranged from 30 to 116 years old, concentrated between 35 and 50 (Table A-1 and Figure B-1). When counting tree rings to age trees for this study, field crews were directed to avoid non-representative stumps from the harvest, but it is possible that an especially old tree was used to determine age. Those could have been trees that were left in the previous round of harvesting as riparian, wildlife, or seed trees that then were harvested in this round, or they could have been suppressed trees that were released in a previous harvest round or other event. The trees selected for the age counts also could have been trees that were suppressed in the previous timber stand and then released to grow into the stand harvested in this study, which would result in a growth ring count that was not representative of the tree size or the general stand age. In the case of the two hardwood-dominated buffers, it may also be that the measured trees were saplings left in amongst unmerchantable hardwoods in the previous round of harvesting.

Riparian prescriptions under the Forest Practices Forests and Fish rules are based on the soil potential to grow trees of various sizes within 50 years. However, there are other intrinsic factors, such as hillslope and valley aspect, that are also known to be important to tree species compositions and growth rates and general forest development. Moreover, there is a wide range of establishment and management history among the stands. After the 1996 emergency stream typing rule (WA FPB 1996), many more streams were designated as fish-bearing than prior to the rule change. Therefore, many of the Small streams (<10 ft wide) and some of the Large streams in this study were clearcut to the stream edge prior to 1996. Thus, the buffer stands in this study were established at the same time as the upland timber stands. Those buffers would not only have been the same age as the harvest stands around them but would have been established with them and maintained to ensure conifer regrowth for their first few years. That stand initiation process (Oliver and Hinckley 1987) bypassed the natural early phases of establishment described by Franklin and Dyrness (1973; 1988), which includes phases dominated by herbaceous and shrub vegetation followed by pioneer deciduous (especially alder) trees before the conifer stand grows in. Lower-gradient and wider streams that experienced streamside disturbance still would have alder and other disturbance-tolerant vegetation growing in along the streams where the channel moved or flooded, but the smaller high-gradient channels would have been bordered by more upland conifer trees that were planted or seeded and the shrubs and deciduous vegetation suppressed chemically (Franklin and Dyrness 1988; Oliver and Hinkley 1987). One result of such a jump start to single-layer conifer dominance is a reduced number of species present in those buffer stands.

Oliver and Hinckley (1987) describe a number of phases in forest stand development, including the the “stand initiation.” They describe stand initiation, followed by a “stem exclusion” stage when the trees occupy all the living space and compete for resources. This stage commonly extends 80–100 years of age in western coniferous forests (Oliver, 1981; Franklin et al. 2002). As the overstory trees grow, an understory begins to take root in the shade of the larger overstory (“understory re-initiation”). Eventually overstory trees start to fall, creating canopy openings that allow the understory trees to grow and the development of old-growth multilevel structural characteristics. Franklin and Dyrness (1988) additionally note that re-establishment and invasion of the secondary (usually hemlock) understory beneath overstories of Douglas-fir in western Washington takes place as mortality begins to open the overstory stand at 100 to 150 years of age. This is a simplified progression that can be altered by disturbance or other means, and the time the forest spends in any of these stages can be prolonged or shortened by events, specific conditions, or deliberate management actions.

The mix of tree species, and more particularly of the broadleaf/conifer mix, that results from the stand development history is relevant to the future contribution of wood to streams and other riparian functions. Although many streamside buffers now on the Type F streams were established as described above, other Type F/S streamside buffers were left to natural succession after previous harvests. The natural succession of regenerating stands in western Washington, in the absence of concerted management, is for alder and other broadleaf species to pioneer regeneration in disturbed areas along streams. Broadleaf deciduous species contribute higher quality and more readily-available litterfall to streams than conifer species. This litterfall is a critical food source for stream invertebrates (summarized in Gregory et al. 1987). The presence of more tree species, including a mix of conifer and broadleaf species, may correspond with the presence of more and varied species of shrubs and herbs near the streams, which are an even more readily-available food source for benthic fauna.

Deciduous species also allow more light penetration to the stream and forest floor than dense conifer stands do, especially western hemlock. Therefore the presence of alder and other broadleaf species in the riparian stands can also increase primary production in the streams by allowing higher light levels than stands completely dominated and shaded by conifer trees, as many of the sites in this study are. Up to a light saturation level of around 10%, primary production in forest streams increases linearly with light increases (Gregory et al. 1987). However, in studying the productivity of non-fish streams in Western Washington in response to shade removal, McIntyre et al. (2018) found no significant increase in primary productivity in streams exposed to more direct solar radiation from shade reduction over streams in reference riparian buffers with no adjacent timber harvest. The growth of alder in riparian buffers also has the benefit of adding nitrogen to the disturbed and possibly depleted soils that were previously supporting conifer timber stands.

Many of the alder currently present in RMZs of this study are reaching the ends of their lifespans (40-80 years) and are or will soon be falling and allow conifer species the space and light to grow. When they fall, the fallen trees will contribute wood to the streams that can help to create fish habitat features and biotic feeding substrate in the short term. However, our local broadleaf trees (red alder, bigleaf maple, cascara, and occasional black cottonwood) deteriorate quickly and do not persist for long in streams (Gregory et al. 1987; Hyatt and Naiman 2001; Freschet et al. 2012). Ideally, the conifer trees would be large enough to begin to supply long-term functional wood to the channels as the broadleaf wood's functional capability diminishes; the proportion of conifer metric becomes important in this context.

The DFC model and forest practices rules prioritize conifer trees in the riparian stands (e.g., red alder conversion, conifer restoration, and DNR Alternate Plans; WAC 222-12-040). At the time of the FFR discussions, one problem present in riparian buffers was the widespread dominance of red alder and other deciduous vegetation that naturally seeded after the initial harvest of old growth forests on fish-bearing streams. Based on the presence and abundance of conifer stumps found in what have become alder dominated stands, there are riparian buffers lacking what were historically dominant conifers. Not only do conifers provide larger and more persistent wood in stream channels, they also grow taller than most of our broadleaf species and can provide shade at greater distances from the stream channel edge. Therefore, a high proportion of conifer is deemed desirable in the riparian stands. However, as this study shows, the history of water typing and forest practices riparian buffer rule changes has resulted in a situation where there is a large subset of stream buffers now on the landscape that instead of being overwhelmed with broadleaf trees, are overwhelmed with dense conifers. Such streams not only meet but *exceed* target shade and desired conifer fraction ranges.

Understanding the history of the RMZ stands we sampled is helpful to understand the stand characteristics and variability that exist today. The future development of forest structure in riparian stands will constantly change as trees grow, die, or are killed by natural disturbances and harvesting (Oliver and Hinkley 1987). The frequency and location of small riparian disturbances and subsequent patterns of development are strongly influenced by valley landform and height above the channel. Studies of riparian stands in western Washington show that floodplain landforms are dominated by deciduous stands as a result of frequent flood disturbances and less disturbed terraces/hillslopes are dominated by conifer and resemble upland forests (Villarin et al. 2009, Rot et al. 2000). Large-scale disturbances (e.g., fire, windstorm, disease, landslides) also play a major role in determining forest structure and species composition in riparian and upland areas. Following disturbances forests follow a general pattern of development (i.e., stand initiation, stem exclusion, understory reinitiation, and old growth) that may take hundreds of years and varies with location, species, and site productivity (Oliver 1980). Forest practices under current and future management schemes will influence riparian stand structure and composition over annual to decadal time scales. Under current RMZ rules, the outer edge of riparian stands adjacent to upland harvest units are exposed to harvest related disturbances (e.g., tree fall damage, slash burns) and increased risk of windthrow within the first few years after harvesting (McIntyre et al. 2018; Ehinger 2021; Beese et al. 2001). Further, riparian stands are vulnerable to repeated harvest-related disturbances with stand rotations occurring every 30 to 50 years.

3.4 Stand Characteristics and Structure Conclusions

3.4.1 What are the riparian stand conditions associated with each of the prescriptions in the early (3 to 6 year) post-harvest period?

- Riparian buffer stands were generally young, small, dense, and dominated by conifer in the stem exclusion phase of development.
- The weighted median (and range) for residual site buffer stem density, basal area density, and QMD 3 to 6 years after harvest were 209.2 trees/acre (range: 47-846), 209.3 ft^2/acre (range: 57-406), and 13.8 inches (range: 8.1-26.0). The weighted median relative density was 53 (range: 14-113) (Table 6).
- Most buffers had between three and seven different tree species among trees larger than 4” in diameter.
- The conifer fractions ranged from 0 to 100% by both number of trees (weighted median = 83%) and basal area (weighted median = 87%).
    - The dominant species were most frequently western hemlock and/or Douglas-fir.
- Seventy percent of the buffers were more than 80% conifer. Half of the sites were over 90% conifer and nearly 20% of sites were 98% conifer. The high-conifer sites tended to have low species richness.
- There was high variation in stand structure metrics other than conifer percentage within prescriptions, but large overlap among prescriptions.
- The site class assigned to RMZs on a floodplain/low terrace may be a poor predictor of stand productivity given the heterogeneous topography and high potential for river associated disturbances.

3.4.2 How do these vary between sampled variants with and without Inner Zone harvest?

- There were pre-harvest differences in species composition between sites that had and did not have Inner Zone harvest, and those differences persisted after harvest. Both of these differences are consistent with the requirements to qualify for an Inner Zone harvest prescription.

- Core Zones in sites that received Inner Zone harvest had higher basal area than those that did not receive Inner Zone harvest.
- Per the requirements for conducting an Inner Zone harvest, sites with Inner Zone harvest are associated with a high percentage of conifers whereas sites where no Inner Zone harvest tended to have higher percentages of broadleaf species.

3.4.3 Other conclusions

- Include species richness, the standard deviation of stem diameters, or other complexity indices in trend monitoring as metrics to track change in riparian buffer forest diversity and complexity.

Chapter 4. Mortality and Windthrow

4.1 Mortality and Windthrow Introduction

There is natural variability in mortality rates among riparian stands (Acker et al. 2003). Mortality and associated wood recruitment rates may be elevated due to competition mortality in stands in the stem exclusion stage of development or due to episodic disturbances due to disease, insect damage, wind, flooding or mass wasting (Liquori 2006). Harvest of adjacent timber exposes the outer edges of the buffer to wind, which can increase mortality and tree fall due to wind damage. Wind mortality typically is greatest during the first few years following harvest and the greatest damage often occurs on the outer edge of the buffers on the windward side, although it can extend throughout the entire buffer (Grizzel et al. 2000; Liquori 2006; Beese et al. 2019). There is extensive variability in windthrow mortality among sites due to differences in site conditions and exposure (Mitchell 2012) as well as regional and local differences in the frequency, wind direction and intensity and timing of windstorms, soil saturation, and flooding (Ruel et al. 2001; Acker 2003; Beese et al. 2019). Severe post-harvest windthrow typically is limited to a sub-set of sites where topography and site conditions are conducive to wind damage. High intensity storms may significantly affect both managed and unmanaged stands in sensitive topographic locations (Ruel et al. 2001; McIntyre et al. 2018).

4.1.1 Mortality and Windthrow Research Questions

- What are the frequency, magnitude and distribution of windthrow and its effects on stand structure and buffer tree mortality rates?
- What are the relative influences of differences in site conditions and geographic location on windthrow?
- Are mortality responses, especially from windthrow, markedly different in some prescriptions than in the others?
- Are there differences between sites that did and did not have harvest in the Inner Zone?

4.2 Mortality and Windthrow Methods

4.2.1 Mortality Field Data Collection

For standing dead trees, surveyors recorded pre- or post-harvest mortality status, determining whether the standing tree died before or after the most recent harvest using the decay criteria shown in Table 8 and an evaluation process laid out in the field methods manual (Davis 2019). Standing dead trees (both pre- and post-harvest mortality) were then assigned a mortality agent (cause of death) where one could be determined. If several agents appeared to have played a part, the primary agent was selected.

Table 8. Decay attributes and descriptors that can be used to define pre- vs. post-harvest mortality

Feature	Category
Leaves/needles	Green, Yellow, Red, Brown, Absent
Bark	Intact, Partial (sloughing), Trace, Absent
Twigs (<3cm)	Present (many; delicate structures of twigs intact); Present (many; twigs losing delicate structures); Few−absent
Branches	Secondary branches present, Primary branches only, No branches
Wood texture	Intact, Smooth, Abrasion (some holes and openings), Vesicular (many holes/openings)
Shape	Round, Oval, Irregular
Color	Original (bright); Intermediate (dark orange streaked with gray); Darkening, or if exposed to sun/wind, intensive silver/gray weathering; Dark; Red-powdery
Root pit	Fresh disturbance, no revegetation; Some light revegetation, early-seral; Medium to heavy revegetation, mid- to late-seral (possibly with conifer regeneration)

Surveyors also collected data, including mortality agent where possible, on all post-harvest fallen trees that were originally standing within the study site boundaries prior to being uprooted or breaking, even if they landed partially outside the study reach. Data were not collected on fallen trees that originated outside the study site boundary or on fallen trees for which the point of origin could not be determined, even if they landed within the study reach. If surveyors determined that the tree fell prior to the most recent harvest (e.g., was a pre-harvest fallen tree), no data were collected on the tree. Trees that had died previous to the most recent harvest but had subsequently (after the most recent harvest) recruited to the stream channel were tallied. The rationale for including these trees was that post-harvest windthrow could impact the number of old snags newly recruiting to the channel, which could have been an effect of the harvest treatment on riparian function that would otherwise not be measured. Surveyors identified these "pre-harvest-mort/post-harvest-recruit" trees in the channel to gain a general understanding of how common the phenomenon might be but did not collect additional information on volume, etc.

If a tree qualified as a post-harvest fallen tree, data were collected on that tree, and pieces of it if it broke. Large wood pieces were linked with the identification number of the parent tree to analyze attributes of the tree from whence it came and prevent counting one tree multiple times. When surveyors encountered a standing dead tree with the top broken off, the standing portion was treated as a standing tree and the broken portion was treated as a fallen top (if large enough to qualify). In these cases, standing tree data were collected for the remaining snag and fallen tree data were collected for the fallen top, except for dbh. For a broken top, if the parent snag was located in the Inner Zone, then the top was also considered to be in the Inner Zone, even if it fell into the Core Zone; the broken piece was labeled with the point of origin of its parent tree and marked so that cross-referencing to the parent snag was possible. This helped to avoid double-counting and ‘orphan’ fallen tree pieces.

4.2.2 Mortality and Windthrow Data Preparation and Metric Calculation

We calculated cumulative stand % mortality (total and by mortality agent) for the entire period between harvest and data collection. We then also calculated two annual mortality rates for each site using the formula:

$$1-\left(\frac{Yr3\ standing\ live\ count}{IPH\ standing\ live\ count}\right)^{1/y}$$

where y = 3 and y = 6 (years). As the actual time since harvest ranges from 3 to 6 years, the two values provide high and low estimates, respectively, of the range of mortality rates for the study.

The direction of wind exposure for the RMZ cut face was determined by converting the 8-point compass directions to azimuth degrees, adding or subtracting 90 degrees to the stream direction depending on whether the study RMZ was on the right or left stream bank, and then converting the cut face azimuth back to cardinal compass directions.

Past research has shown that windthrow in riparian buffers peaks 2 to 5 years after timber harvest and then becomes less prevalent (Johnston 2011; Schuett-Hames et al. 2019). Moreover, windthrow has been shown to be a stochastic mortality agent that tends to fell trees in clumps at specific points in time. Stem exclusion mortality, however, is a chronic mortality agent throughout the long stem exclusion phase of stand development and is likely to persist and dominate treefall beyond the early post-harvest period these data represent. We therefore calculated average values for annualized stem exclusion mortality rates in addition to the average annual total mortality rates.

4.2.3 Mortality and Windthrow Analysis Methods

We evaluated the extent of and causes of mortality among the various sites and prescription variants by developing tables displaying counts of trees killed by various mortality agents, categorized by buffer zone, and observing column graphs for each prescription of the percent of mortality of the stands immediately after harvest, averaged by site. We also calculated means, standard deviations, and 95% confidence intervals, and generated boxplots of mortality and annual mortality rates by prescription for overall mortality and that due to windthrow and stem exclusion specifically (Appendix B).

We addressed the question of geographic distribution and potential location effects on windthrow by mapping the degree of windthrow at sites by Inner Zone harvest type and inspecting the observed geographic patterns. We also explored whether there were patterns with factors such as elevation, stand age, and valley or RMZ cut face exposure direction by inspecting graphs of the frequency of high-windthrow sites versus those factors. We then further explored relationships between windthrow and fourteen potential factors through boosted regression tree modeling to see which appeared to have the most influence on the windthrow observed in this study. That investigation is presented in Appendix E and findings are also presented and discussed in this chapter.

4.3 Mortality and Windthrow Results

4.3.1 Mortality

Field crews counted 18,629 standing trees in the 106 valid sites. 1,447 of the 18,629 standing trees inventoried were determined to have been dead prior to harvest and so don't count toward our mortality estimates. 973 standing trees were determined to have died after the harvest. An additional 1,630 trees were determined to have fallen after the harvest. From these data, we estimate there were 18,812[5] live trees immediately after the harvest. Adding the standing post-harvest dead trees to the 1,630 additional fallen trees gave a cumulative mortality of 13.8%[6] in the 3 to 6 year period after harvest. Using this range of post-harvest period length, the annualized mortality rate over all the study sites was between 2.5% (assuming 6 years post-harvest) and 4.8% (assuming 3 years post-harvest). Wind caused 76% of the total tree mortality in the early post-harvest period, far more than any other agent (Table 9 and Figure 13). Suppression accounted for close to 10% of the total mortality, as did the "Unknown" category. Disease, erosion, harvest damage, and fire combined accounted for 5%.

[5] 18,629 – 1447 + 1630 = 18,812
[6] (973 + 1630) / 18,812

Table 9: Mortality by process and buffer zone

Mortality Agent	Core Trees	Inner Zone	Total Trees	Proportion of Mortality	Proportion of IPH Live Trees
Wind	967	1004	1971	76%	10.5%
Unknown	104	142	246	9%	1.3%
Stem Exclusion	134	111	245	9%	1.3%
Disease	39	36	75	3%	0.4%
Other	29		29	1%	0.2%
Erosion/flooding	16	9	25	1%	0.1%
Harvest/yarding	1	10	11	0%	0.1%
Fire	1		1	0%	0.0%
Total	**1291**	**1312**	**2603**	**100%**	**13.8%**

The weighted median mortality per site was 8.2%, and the site mortality ranged from 0% to 75%. The weighted median of the low estimate of annual site mortality was 1.4% trees/year and of the high estimate was 2.8%/year. Over half of the sites had less than 10% mortality. Thirty-two of the sites (30%) had fewer than ten trees die; one site lost no trees and three sites lost only one tree. High mortality, which we defined as 30% or more, occurred at 14 sites (13%). The seven sites with the greatest mortality were all on small streams less than 10’ wide (Figure 13, Table A-5). Stem exclusion caused mortality at a little over half of the sites and was always lower than 10% (Max = 6.6%). Disease was the dominant cause of mortality at one site and wind at the rest.

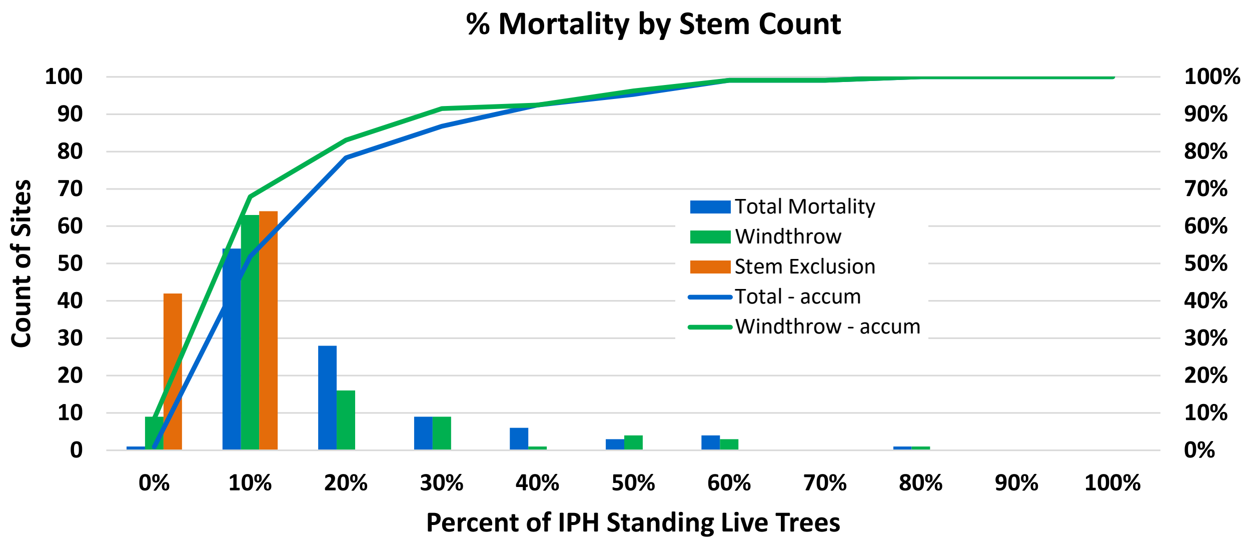


Figure 13. Mortality histogram displaying total, windthrow, and stem exclusion mortality.

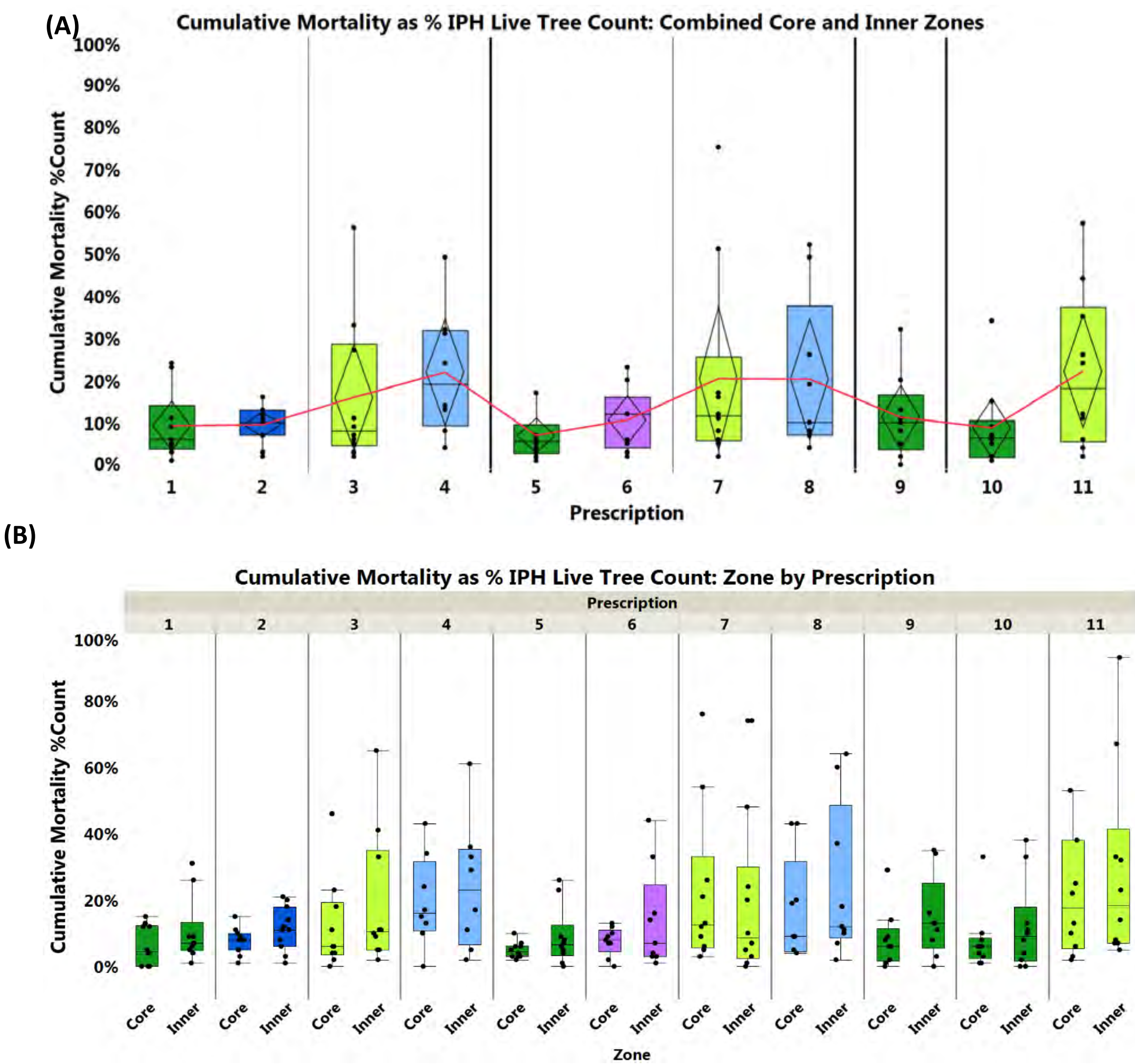


Figure 14. Boxplots of percent total mortality through the early post-harvest period (3 - 6 years) as a percentage of the standing live trees immediately after harvest, grouped by prescription (A) and also RMZ zone (B).

Small streams were associated with higher percentages of mortality than large streams (Kruskal-Wallis P < 0.001). Median mortality on both stand density and basal area bases in buffers on small streams was approximately double that in large stream buffers (11.6% vs 6.9%) (Figure 14-A; Table 10, Appendix B-3). For buffers on both large and small streams, mortality increased as Site Class became poorer (i.e., went to higher numerals). This trend was more pronounced on small streams. Mortalities of 30% or more ("High Mortality") nearly always occurred on small streams (12 of 14), including the site with the highest mortality. The Inner

Zone harvest sites with high mortality were all on small streams with the LTCW harvest strategy. No TFB sites (all on large streams) had high mortality (Figure 14-A; Table A-5).

Table 10. Statistical test results for Mortality

DIFFERENCES BETWEEN SMALL AND LARGE STREAMS				
	N	**Median (%Mort by stems)**	**Median(% Mort by BA)**	
Large	59	6.9%	4.0%	
Small	47	11.6%	8.5%	
Wilcoxon Test for Difference		**.0019****	**.0013****	
DIFFERENCES AMONG PRESCRIPTIONS				
	Test	**Total Mortality (% of stems)**	**Windthrow Mortality (% of stems)**	**Stem Exclusion Mortality (# of stems)**
Equality of Variances	***Brown-Forsythe***	.1153	.1912	.0591
	Levene's	*.0003*	*.0004*	*.0006*
Equality of medians	***Welch's***	.1478	.1263	.4642

Although there appear to be differences in the variances among prescriptions of any of the mortality types assessed, none were assessed to be significantly different than the others (Brown-Forsythe P > .05; Table 10). Some prescriptions had high variance in mortality even though we found no significant differences among prescriptions (Welch's P > .12). For example, mortality for Prescription 11 ranged from 2% to 57% and mortality for Prescription 7 (III-Small-No Harvest) ranged from 2% to 75% of the trees. Mortality tended to be slightly higher in Inner Zones than in Core Zones, except at the thinned sites (Figure 14-B).

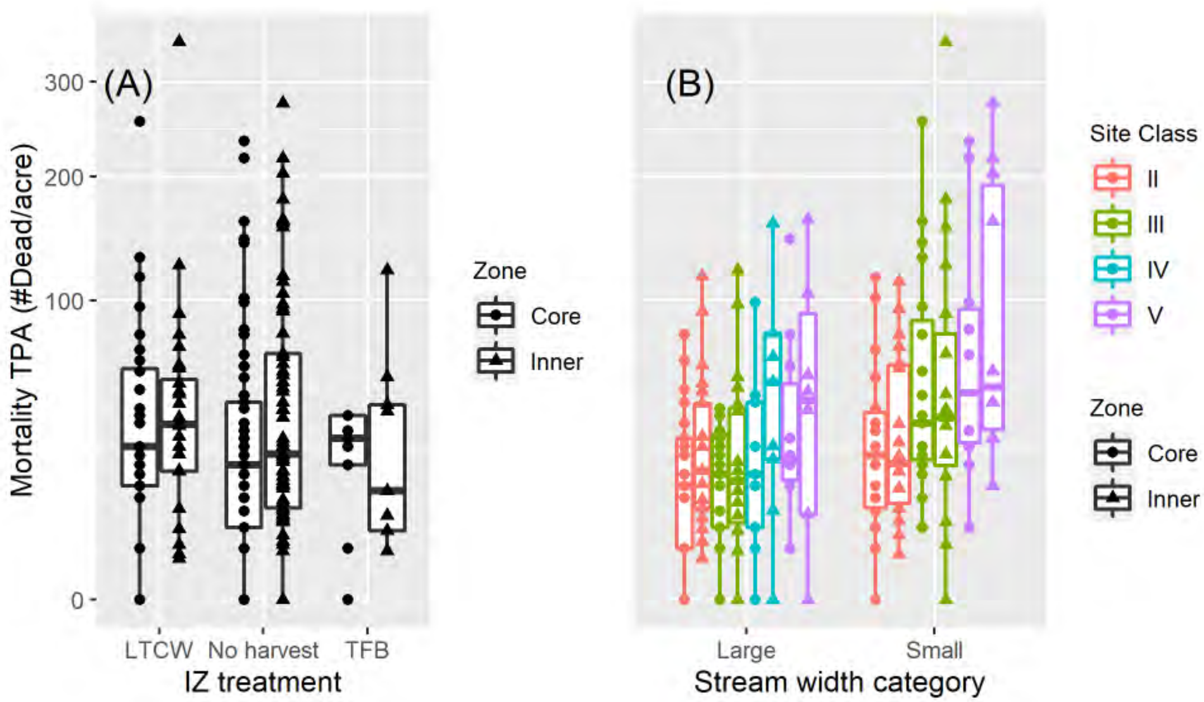


Figure 15. Early post-harvest mortality reported in trees per acre (TPA) by buffer zone, Inner Zone treatment, stream size and site class.

Mortality calculated in trees per acre (Figure 15-A) was lowest and least variable for the TFB Inner Zone buffers, which were only sampled on large streams. Mortality in the Core Zones for the TFB sites was comparable to that for the other two IZ harvest treatments (LTCW and No-harvest). The small sample size of 9 in the TFB variant compared with the large samples in the other two treatment variants means the TFB results should be read with caution. Mortality by TPA was similar between LTCW and No-harvest Inner Zones but the variability was much wider for No-harvest IZ prescriptions. Average mortality appears somewhat higher for Site Class V-Small RMZs. Mortality in the Inner Zones was higher and more variable than that in the Core Zones for all prescriptions (Figure 15-B).

4.3.2 Windthrow Mortality

As Table 9 showed, windthrow was by far the dominant mortality mechanism in the early post-harvest period. 10.5% of all the live buffer trees standing immediately after the harvests succumbed to wind in the first 3 to 6 years after harvest. One half of the trees lost to wind came from 14% (15) of the sites (Figure 16). The (weighted) median site windthrow was 5.9% and ranged from 0% to 73%. Nine sites had high windthrow, defined as more than 30% of the trees initially standing (Figure 19). The boxplots of windthrow by variant in Figure 17 corroborate the overall finding that windthrow was higher in small stream buffers. Ten percent (3 of 28) of the LTCW sites had high (>=30%) windthrow, all on small streams. In contrast, no TFB sites had high windthrow; the highest was 19% of the trees. The remaining 6 high-windthrow sites were in buffers that had no Inner Zone harvest. Nearly all sites had more windthrow loss in the Inner Zone than in the Core, but the high-windthrow sites tended to have equal amounts of loss through both zones. The QMD of windthrow was similar to, but slightly smaller than, the QMD of the initial stands (Figure 17-C vs. Figure 11-C).

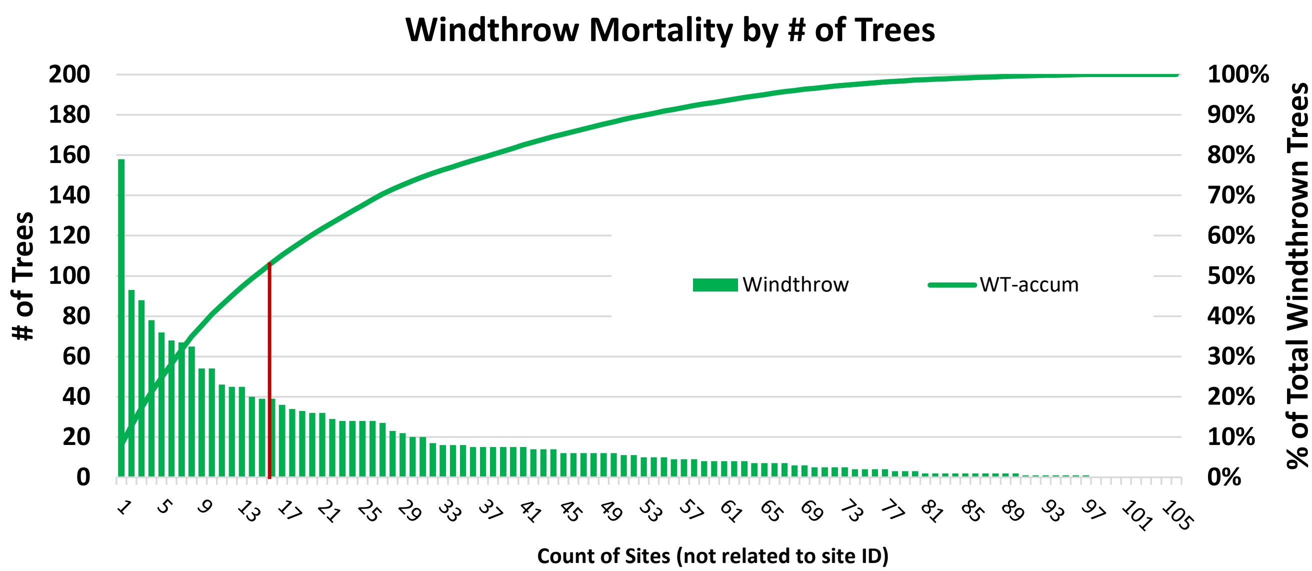
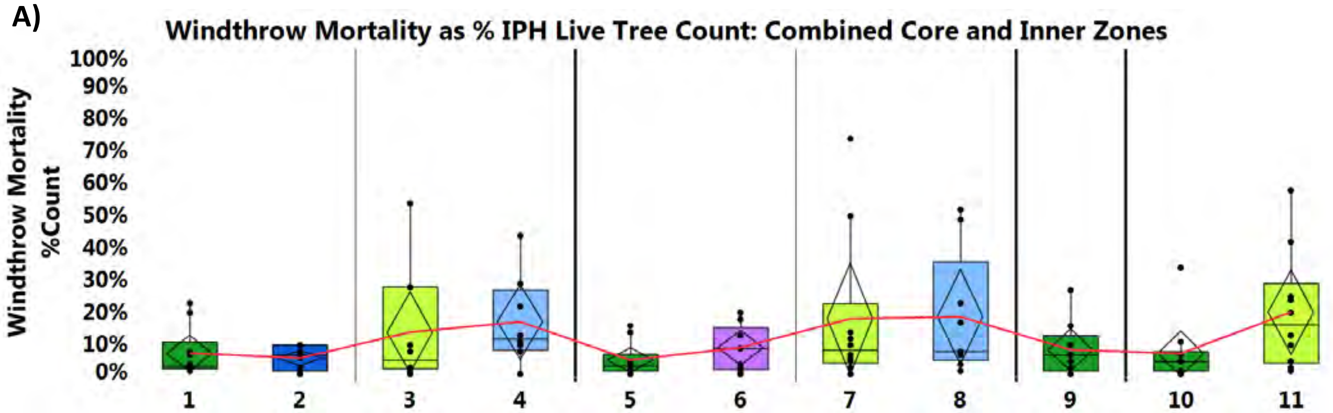
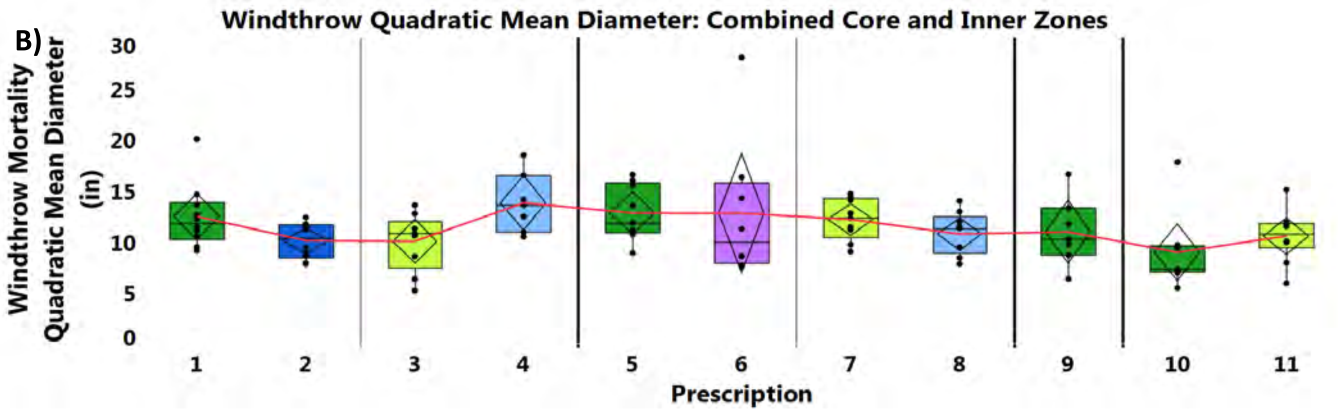


Figure 16. Windthrow histogram and cumulative mortality, by site count.

A)





Site Class	II				III				IV	V	
Strm Size	L		S		L		S		L	L	S
IZ Harvest	None	LTCW	None	LTCW	None	TFB	None	LTCW	None	None	None
N	10	11	10	8	10	9	10	9	9	10	10

Figure 17. Windthrow mortality in the early post-harvest period (3 to 6 years) by prescription, calculated as a percentage of trees initially standing (A). Size (quadratic mean diameter) of the blown down trees in (B).

The highest mortalities occurred along the western coast of the state at sites that are exposed to the southwest storms that dominate weather in western Washington (Figure 18). The sites with no IZ harvest tended to have greater windthrow mortality than sites with IZ harvest, except three LTCW sites. Buffers harvested with the TFB treatment experienced lower levels of windthrow, but the incidence rate (percent of sites experiencing windthrow) was the same as for the other IZ treatment types. Buffers that experienced high windthrow were generally young, unthinned stands on small streams at low elevations (Figure 19). One high windthrow site was on a large stream at about 2100’ elevation, but the remainder were on small streams below 400’.

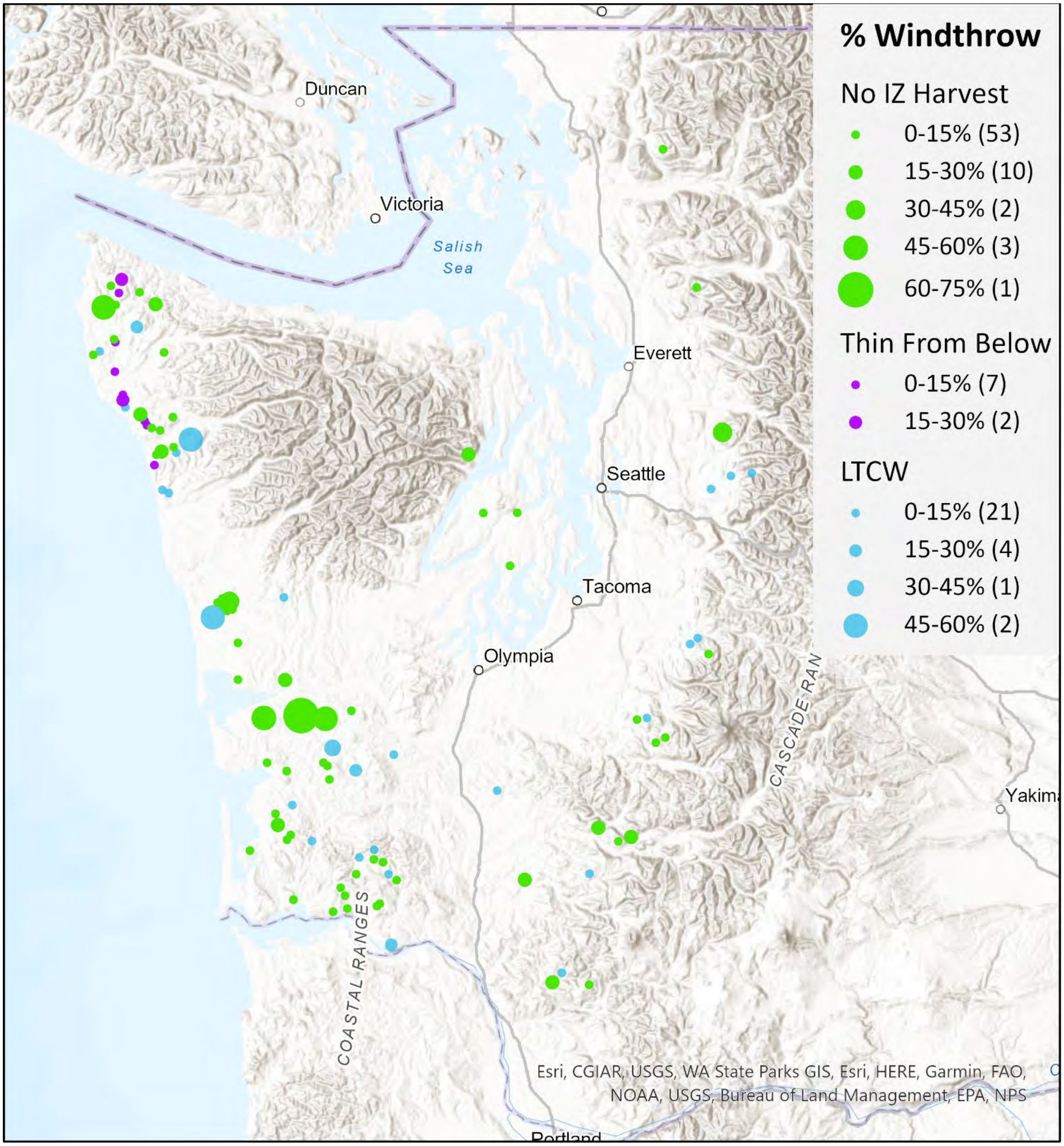
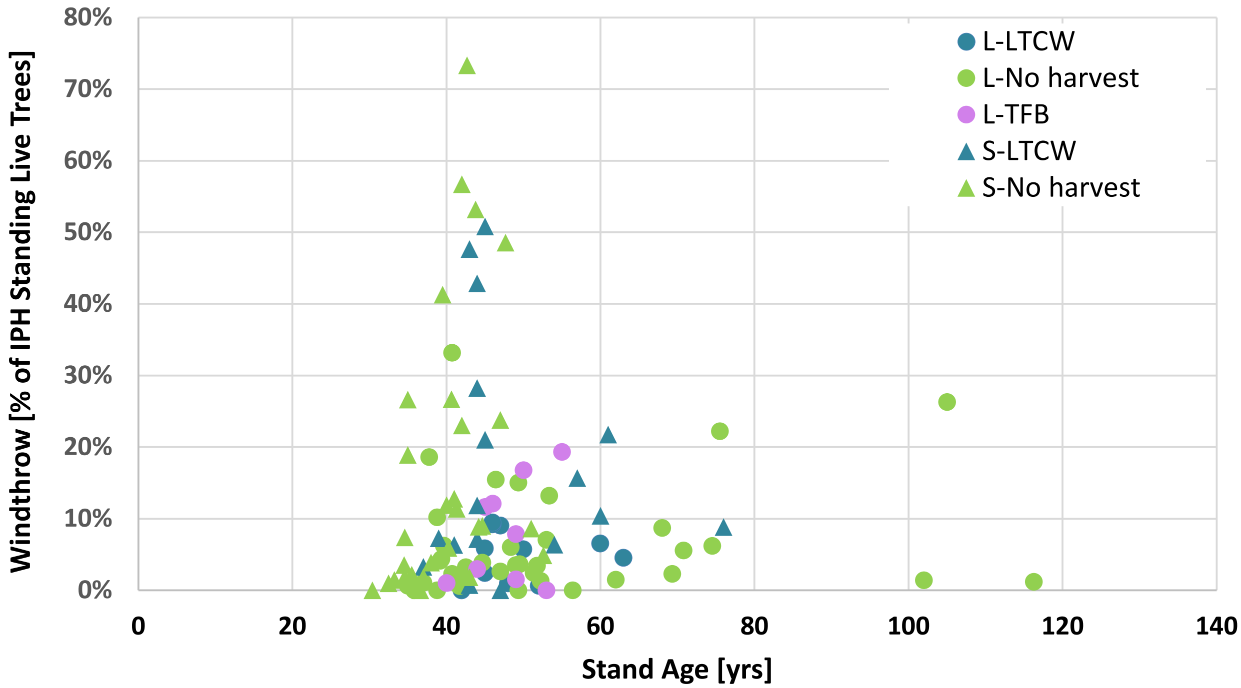


Figure 18. Map of sites displaying windthrow magnitude at each site as a percentage of the immediate post-harvest standing trees (marker size) and Inner Zone harvest type (color).

(A)



(B)

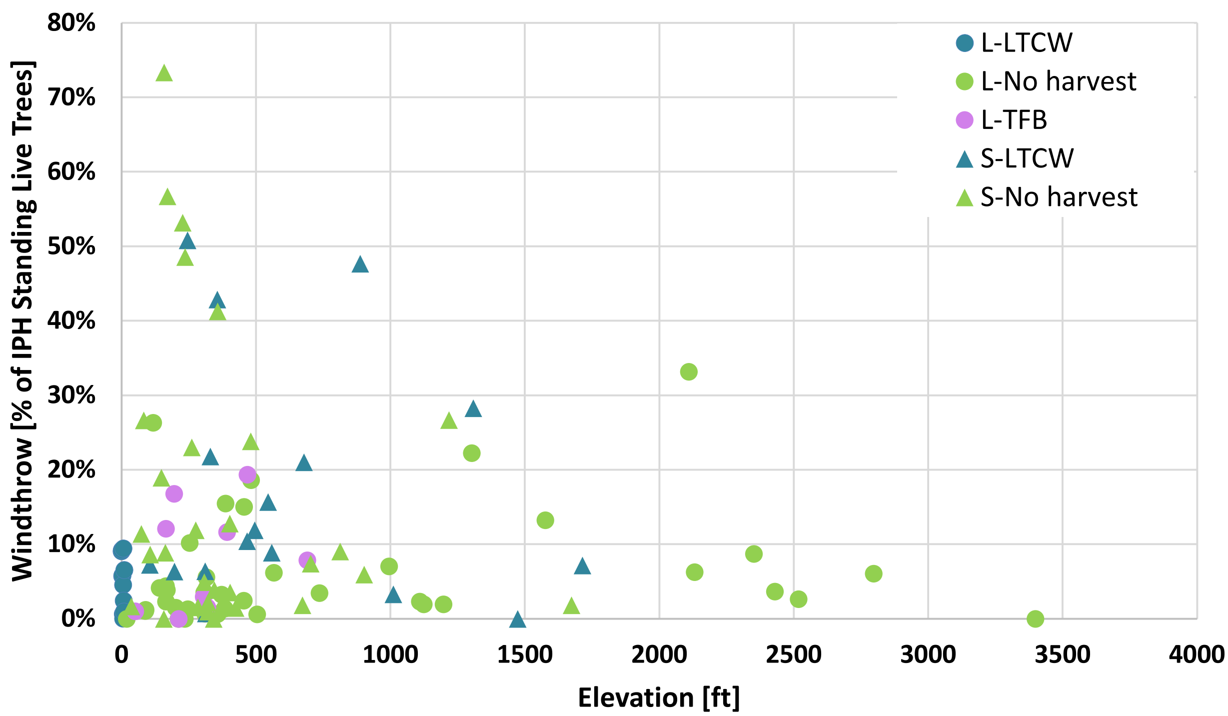


Figure 19. Windthrow as a percentage of IPH standing live trees, shown by stream size and Inner Zone harvest type as a function of (A) stand age and (B) site elevation.

Using boosted regression trees (Appendix E), we identified several factors that appeared to have the greatest influence on the amount of windthrow and whether a site was likely to experience high windthrow. The model factors that appeared to have the most relative influence were the exposure direction of the RMZ cutface (by far the most influential), stream direction, elevation, and channel width category (Table E-1). Stand age was very important in predicting the amount of windthrow, but not as important in predicting the occurrence of high windthrow. The BAPA and RD of the Inner Zone were more influential than those of the total RMZ, and the BAPA was more important than the RD. Site Class was relatively influential as a predictor of sites likely to experience high windthrow but not of the amount of windthrow. The dominant species of the Inner Zone was found to be relatively unimportant in all the analyses. The Inner Zone treatment and a factor derived by combining the Inner and Outer Zone treatments into categories presenting similar faces to an oncoming wind were not found to be significant predictors of either the amount of windthrow or whether a site would experience high windthrow.

4.3.3 Stem Exclusion Mortality

During the 3 to 6 year post-harvest period, stem exclusion accounted for only one tenth as much of the overall mortality as wind did (1.3% vs. 10.5%; Table 9). The weighted median site stem exclusion mortality for each site was 0.6% and ranged from 0% to 6.6%. The highest stem exclusion mortality was observed at a site in Prescription 2 (Large, Site Class II with a LTCW IZ harvest). 40% of the sites had no identified stem exclusion mortality. The average of the annual stem exclusion mortality low rate range was 0.2% of trees per year and the average of the high rate calculations was 0.4% per year. The highest annual rate calculated for any site was 2.25% per year.

The sites with Inner Zone harvest had greater stem exclusion mortality than sites with no-IZ-harvest (Appendix B-3). There was a tendency for some stands to self-thin at sites with higher relative densities (Figure 20). However, the trend was not consistent, and relative densities remained very high (orange points) at 33% of the sites at the end of the study period. The highest rates of stem exclusion mortality occurred in buffers that had relative densities over 60 several years after harvest (Figure 20).

The stem exclusion mortality calculated as a proportion of basal area (2.5%) was lower than that based on proportion of trees (7%) because most stem excluded trees were small (Figure 21-A and -B). The QMD of trees that died due to stem exclusion generally ranged between 4” and 12” Figure 21-B and were about half the QMD of the IPH stand (Figure 11-C).

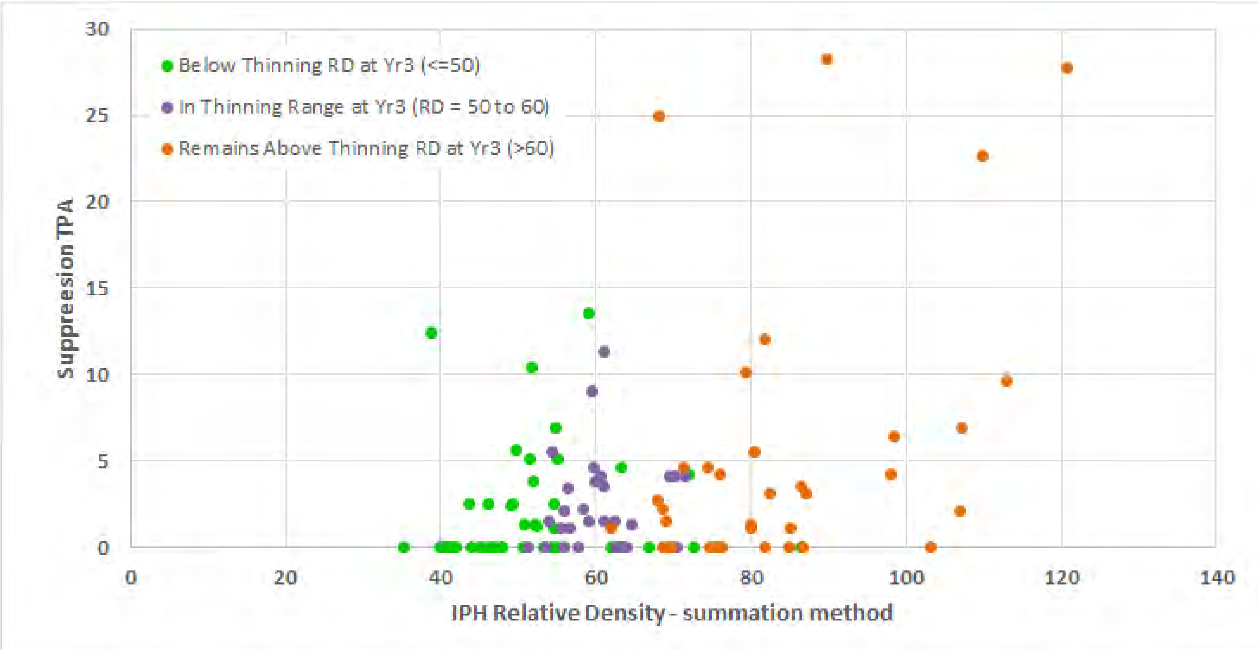
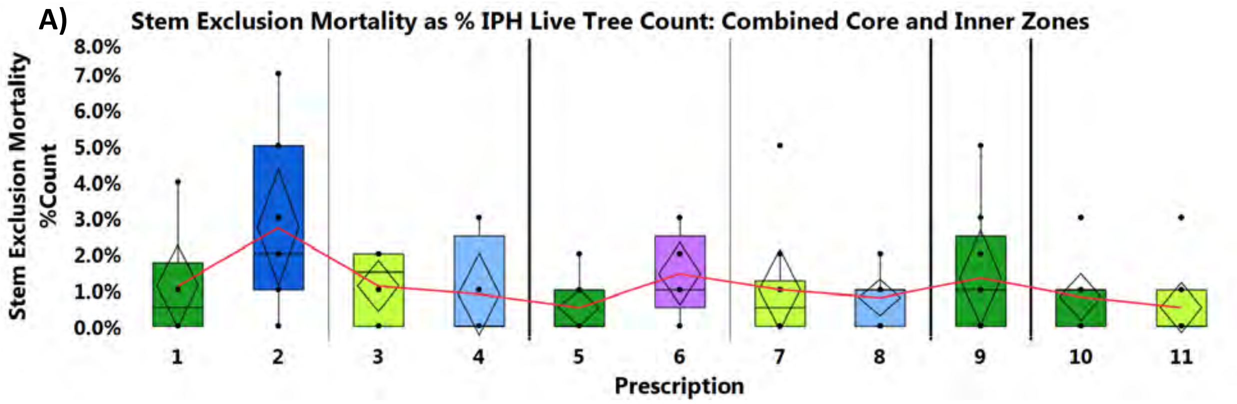


Figure 20. Stem exclusion mortality vs Curtis' (2010) stand relative density at IPH (X-axis) and at Yr3 (color).

A)



B)

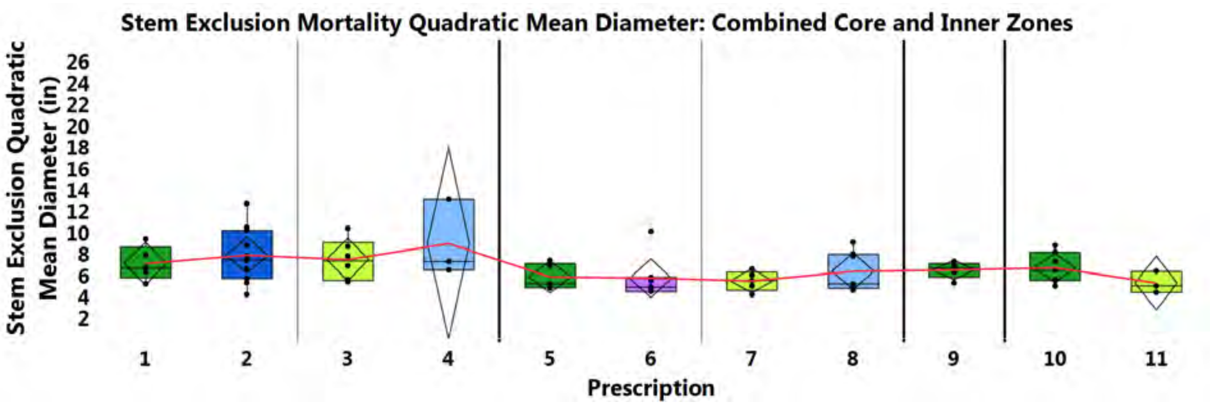


Figure 21. Stem exclusion mortality percentage in the early post-harvest period (3 to 6 years) by variant, calculated as a percentage of trees standing immediately after harvest (A) and quadratic mean diameter of the excluded trees in (B).

4.4 Mortality and Windthrow Discussion

Johnston et al. (2011) and Schuett-Hames and Stewart (2019) found that windthrow was the dominant mortality agent in riparian buffers after adjacent timber harvest and that the windthrow rate peaked between 2 and 5 years post-harvest. Schuett-Hames et al. (2012) observed that 75% of the mortality in the first 5 years after harvest was due to wind, similar to the findings of this study. After the early post-harvest period, windthrow diminished in importance and stem exclusion became the dominant mortality agent outside of major wind events (Johnston et al. 2011). Based on this experience, we anticipate that the windthrow experienced prior to our sampling was the highest rate these sites are likely to experience, outside of large wind events. Going forward, stem exclusion is likely to become the dominant mortality factor, and the annual stem exclusion rates are likely to be more representative of future mortality.

RMZs with Inner Zone harvest prescriptions tended to have larger trees than those with no IZ harvest. They therefore are likely to be farther into the stem exclusion phase of development than younger sites. Therefore, No-IZ-harvest sites are denser and have more trees being suppressed and either dying or susceptible to wind mortality.

The low levels of windthrow observed in TFB harvest RMZs in this study suggest a possible resistance to wind in the residual stands. The low number of sample sites (9) with that prescription and the absence of any sites with buffers facing the prevailing winds in this region constrains us from drawing firm conclusions. Thinning RMZ stands from below removes weaker, stressed, dying, and small trees that would be most susceptible to stem exclusion and wind mortality. Thinning also opens space and gaps between tree stems so that the buffer edge does not present a uniform, wind-resistant face to the wind. On the other hand, Beese et al. (2019) found that more open stands allowed wind to penetrate farther into buffer edges and cause blowdown farther into the stands.

The factors influencing mortality and windthrow that we observed in this study should be viewed with caution given that the study was not designed to assess factors underlying mortality. However, our findings from a large random sample show that windthrow is the dominant mortality agent for the RMZ and that high wind loss (>30%) occurred at a small percentage (8%) of sites. This study also contributes empirical mortality data that could be used in a future more extensive windthrow investigation. We view our findings from the mortality modeling as preliminary work to inform a future study specifically investigating factors influencing windthrow.

4.5 Mortality and Windthrow Conclusions

- Overall mortality was 13.8% of the live trees in the first 3 to 6 years after harvest, and windthrow was by far the dominant mortality agent.
    - Site mortality ranged from 0% to 75% with a weighted median of 8.2%.
    - The only site with no mortality was a sparsely-stocked Type S river buffer in Site Class IV with large trees.
- The (weighted) median annual mortality rate calculated from mortality during the early post-harvest (3 to 6 year) period was estimated to be somewhere between 1.4% and 2.8%, depending on the number of years since harvest. Site values ranged from 0% to 37% per year.
- The dominant mortality agent was windthrow (76% of all tree mortality), followed by stem exclusion/suppression (9% of all tree mortality) and "Unknown" (9%). (Table 9)
- Fourteen sites (13%) had high total mortalities (>= 30% or more of the tree stems).

4.5.1 What are the magnitude and distribution of windthrow?

- Windthrow mortality was 10.5% of the IPH live trees in the first 3 to 6 years after harvest.
- Windthrow mortality at individual sites ranged from 0 to 73% with a weighted median value of 5.9%.
- Nine sites (8.5%) had high windthrow values (>= 30%).
    - Eight of the high windthrow sites were young, unthinned stands on small streams at low elevations (Figure 19).
- Windthrow was higher on Small (<10 feet wide) streams than on Large streams (Figure 17).
- Windthrow mortality as a percentage of initial standing trees (and BA) was higher in Inner Zones than in Core Zones for most sites (Appendix B-3).
    - High windthrow sites lost trees equally from both zones.

4.5.2 How do these vary between the study sites with and without Inner Zone harvest?

- The highest windthrow occurred on three sites that had no Inner Zone harvest.
    - These were all sites with young stands on small streams.
- Buffers harvested with the Thin From Below treatment (DFC Option 1; N=9) experienced lower windthrow severity than other prescription variants
- The percentage of sites experiencing windthrow was similar for all the IZ harvest treatment categories (TFB, LTCW and No-IZ).

4.5.3 How does stand structure relate to the observed windthrow?

- High mortality (>=30%) predominantly occurred in small streams with RMZs composed of 35 to 50 year old stands (Figure 19).

4.5.4 What are the relative influences of differences in site conditions and geographic location on windthrow seen in this study?

- The highest mortalities occurred along the western coastal area of the state at sites that are exposed to the southwest storms that dominate weather in western Washington (Figure 18).
- The highest windthrow sites were at low elevations (Figure 19-B).
- As noted previously, windthrow occurred more frequently and more intensively on small streams.

Chapter 5. Desired Future Condition (DFC)

5.1 DFC Introduction

We introduced the background to the Desired Future Condition concept and philosophy behind the prescriptions in Chapter 1. In this chapter we used the Washington DNR Forest Practices Desired Future Condition model through the DNR web site to evaluate the extent to which post-harvest riparian forest stands are on trajectory to achieve DFC targets and specifically compared sites that did and did not have Inner Zone harvest prescriptions.

The DNR DFC model was developed by Forests and Fish collaborators in 2000 for the purpose of implementing the new forest practices rules of 2001. The model is an empirical stand growth model that relies on stand growth lookup tables derived from thousands of simulations using the University of Washington's Stand Management Cooperative version of ORGANON to predict stand basal area at age 140 years (Fairweather 2001). Landowners input the harvest unit location; stream length and acreage of each (core, inner) zone; initial stand density, basal area per acre, and conifer percentage; stand age; site class (from DNR Forest Practices site class maps); dominant tree species; and the numbers of conifers and deciduous trees in the stands by 2-inch diameter classes. The DFC program uses the input data to predict basal areas at a stand age of 140 years. The total projected stand basal area is calculated by weighting the projected basal area of the Core Zone and the projected basal area of the Inner Zone by land area in each zone. Note that the DFC model only uses data from trees 5 inches and larger; we did not use data from the smallest (4") trees we measured. As noted by McConnell (2010), the model does not account for ingrowth or growth of those smaller trees, nor does it account for effects of windthrow and other edge effects common to post-harvest riparian buffers.

5.1.1 DFC Research Questions

- What is the proportion of sites on trajectory to meet the DFC basal area target of 325 ft^2/acre when the stand is 140 years old?
- How does that vary between sites with and without Inner Zone harvest?

5.2 DFC Methods

5.2.1 DFC Data Preparation and Metric Calculation

The sampled stand data from each site were entered into the DFC calculator on the Department of Natural Resources "Desired Future Condition Worksheet, Version 3.0" interactive web page (WA DNR 2024), the same way a landowner would when preparing an FPA. Data entered were stand age, site location, site class, stream width category, riparian zone length (300 feet for our sample), the choice of whether the Douglas-fir or Western Hemlock growth model was most appropriate, and the number of conifer and broadleaf trees in each two-inch diameter class. The model uses those parameters to calculate the required zone widths and acreages of the Core and Inner Zones for calculating basal area densities. The age 140 basal area density projections provided by the model for each RMZ Core and Inner Zones, and the combined result were entered into the study site information database (see Appendix Table A-5). The percentage by which the RMZ was projected to exceed (or fall short of) the DFC target basal area of 325 ft2/acre was calculated by dividing the projected BAPA by the target BAPA and subtracting 1.

5.2.2 DFC Analysis Methods

Counts of sites projected to meet or exceed the basal area target were used to evaluate both the research questions. The overall count of sites expected to meet the target as a percentage of total site count for sites that did and did not have Inner Zone harvest and for each prescription category are presented in Table 11. Boxplots of projected basal area densities compared with the target Age 140-year basal area density were used to visually inspect relationships by prescription. To explore whether these results suggested an area or prescriptions to focus on in the Phase 3 study, we went on to explore reasons why the sites projected to be below target were so and whether there were signs pointing to relationships between projected basal areas and riparian functions. We particularly looked at mortality and percentage of hardwood.

5.3 DFC Results

The majority (75%) of RMZ stands in this study were projected to meet the Desired Future Condition conifer basal area target by age 140 years (Table 11). Many of the sites that were not on target were projected to be far off target, such as the sparsely-vegetated and hardwood-dominated river-side buffers (Figure 22). Labels in the figure note factors likely to be a cause of low projected conifer basal areas. Nearly all the sites that were projected to not meet the target were buffers that lost many trees to post-harvest windthrow or were dominated by hardwoods (including one site that had a 100% hardwood buffer). Three of the six sites on Type S streams (all Large) were not expected to meet the conifer basal area target.

Figure 22 illustrates clear differences in DFC trajectory distributions among the prescriptions (Brown-Forsythe P=.0014). Prescriptions 1 and 3 (Site Class II) had many sites with high hardwood compositions that were not projected to meet the 140-year DFC target. All but one of the Site Class V RMZs were projected to meet the target.

Table 11. Proportions of sites within each prescription variant that are projected to meet the DFC basal area target of 325 ft^2/acre at age 140.

	Total	IZ Hvst	No IZ Hvst	Prescription Variant										
				1	2	3	4	5	6	7	8	9	10	11
# of Sites	**106**	37	69	10	**11**	10	**8**	10	**9**	10	**9**	9	10	10
# of Sites Expected to Meet Target	**80**	34	46	4	**10**	5	**8**	8	**8**	4	**8**	6	10	9
Proportion Expected to Meet Target	**75%**	92%	67%	40%	**91%**	50%	**100%**	80%	**89%**	40%	**89%**	67%	100%	90%

The IZ harvest prescriptions were significantly different from the no-IZ-harvest prescriptions for Site Classes II and III (Wilcox/Mann-Whitney P = .0295). 92% (34) of the 37 valid sites with Inner Zone harvest were projected to meet or exceed the target basal area at age 140, whereas only 52% (21) of the 40 Site Class II and III sites that did not have Inner Zone harvest were expected to meet the DFC basal area target (Table 11). One of the three Inner Zone harvest sites that was not projected to meet the target (an LTCW harvest) experienced high windthrow. Two of the IZ-harvest sites that were projected to be below the target have high broadleaf (hardwood) compositions (Figure 22). Closer inspection of those FPAs and DFC data entry showed that tree inventories from the 300-foot reaches we sampled were not consistent with the tree inventory for the overall DFC reaches at those sites, both of which were over 1000 feet long. Photo inspections showed that the random selection process we used selected a singular hardwood patch that was not representative of the majority of the long, mixed conifer/hardwood buffers harvested under the DFC prescription.

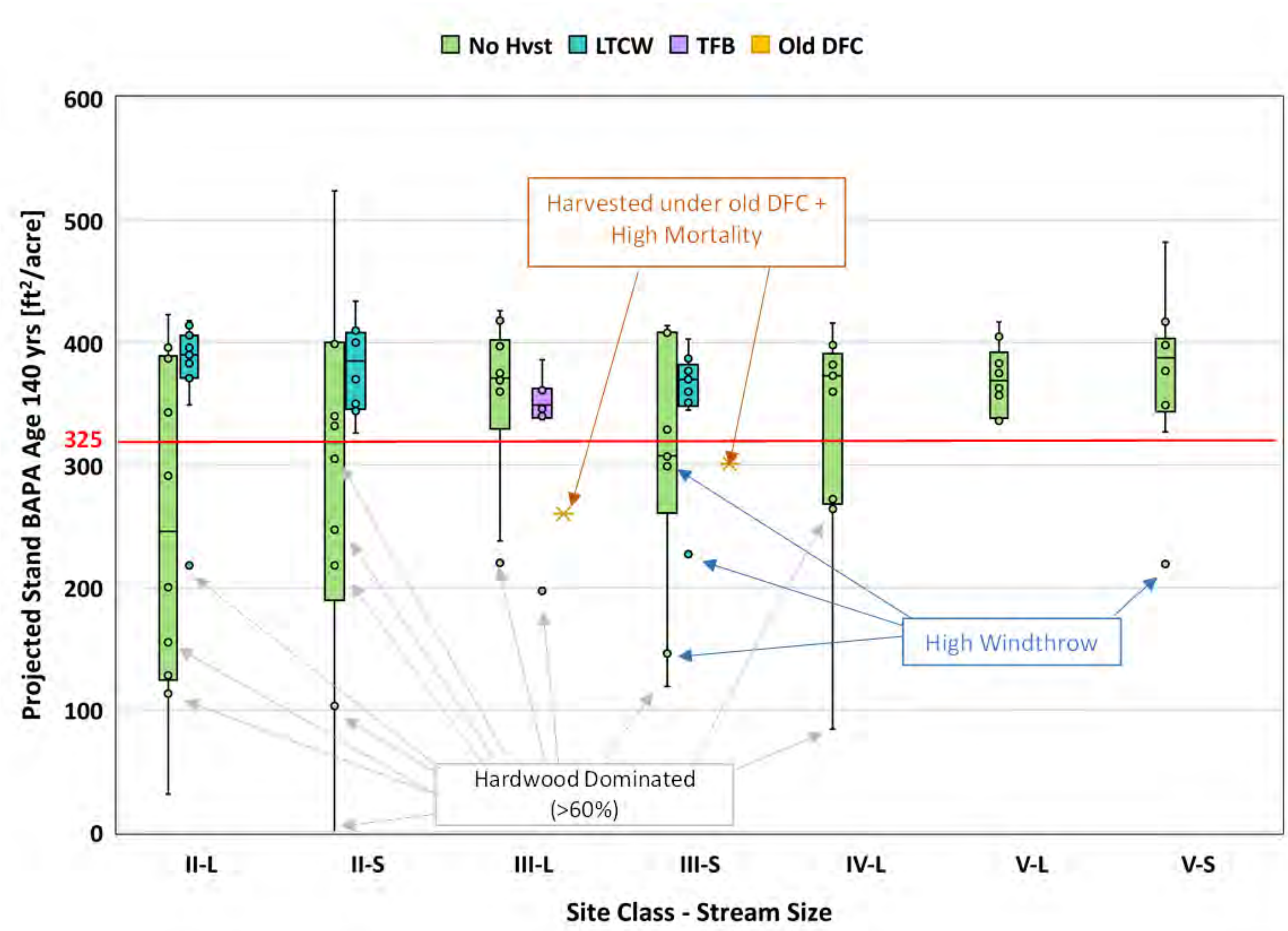


Figure 22. Projected basal area per acre of combined Inner and Core Zones at 140 years of age plotted relative to the desired future condition (DFC) target of 325 ft^2/acre (red line).

Mortality only appears to be an indication of future low basal area in the case of very high mortalities (>50% of the stems) (Figure 23). 9 of the 14 buffers (64%) that experienced greater than 30% stem mortality left residual stands that still were projected to meet the DFC target and also their shade requirements (Chapter 7). Of five IZ-harvest sites that experienced 30% or more mortality, four were still projected to exceed the DFC BAPA target. The fifth experienced nearly 50% mortality (by stems; 40% by basal area), which resulted in a Yr3 conifer percentage of only 66%.

Sites without IZ harvest that experienced high mortality were approximately evenly divided between meeting the DFC target and not. However, the ones that were not projected to meet the target were projected to be far below the target, whereas the ones that were projected to meet it were only projected to be slightly above target. Sites with 10% or lower post-harvest mortality were evenly divided between meeting and not meeting the DFC target by 140 years old.

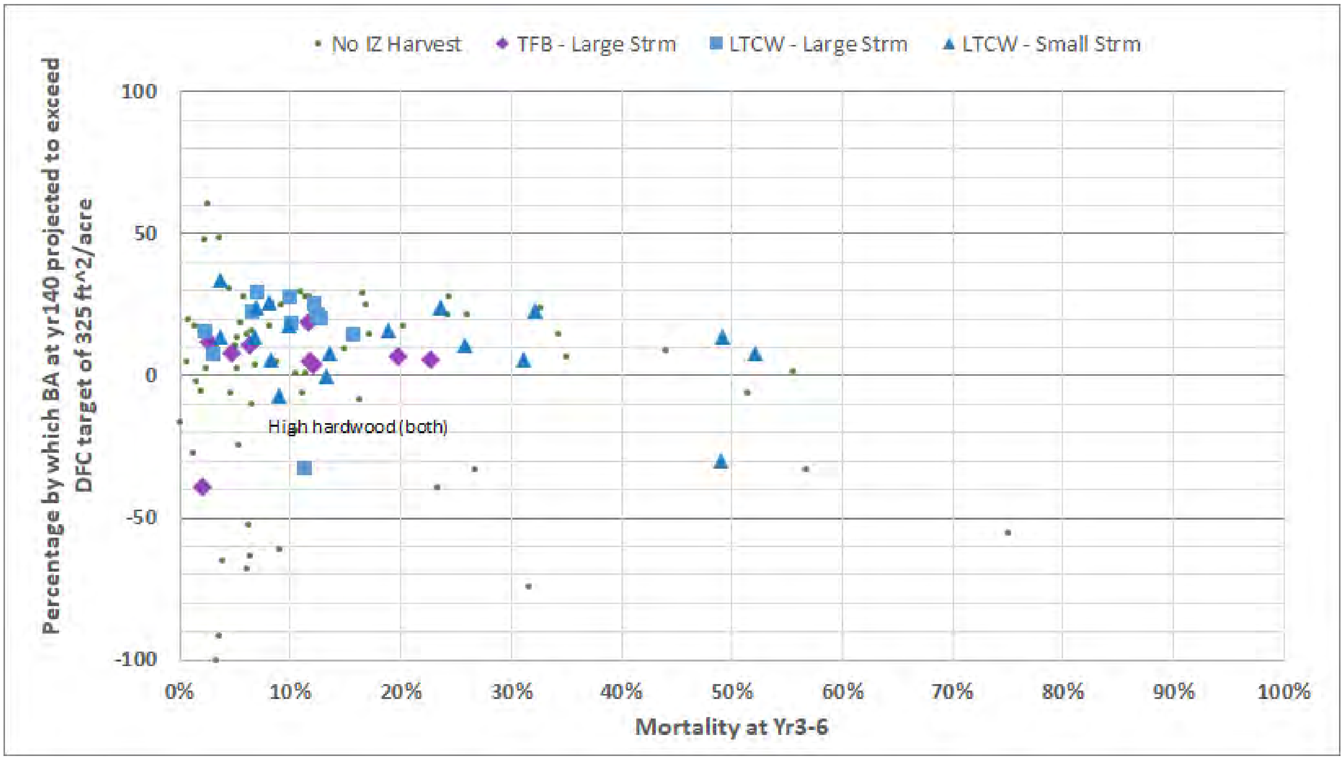


Figure 23. Sites with and without Inner Zone harvest - projected basal area/acre target exceedance at age 140 plotted versus stand mortality (mostly windthrow).

5.4 DFC Discussion

Two thirds of the No-harvest sites in Site Classes II and III were projected to meet the DFC target. Those sites might have qualified for a DFC harvest prescription at the time of harvest, but the landowner chose not to assess for or implement one. The Site Class II and III sites that are projected to exceed the DFC target basal area but were not harvested (52% of 40 sites) were nearly always young, whereas those that did receive DFC harvest prescriptions were somewhat older. This suggests that landowners are applying those prescriptions in buffers where the timber exceeding the DFC BAPA requirement has more volume and hence, economic value. We could discern no obvious geographic reason, such as proximity to log buyers, why landowners would choose not to harvest a buffer that qualified for a DFC harvest.

The finding in Chapter 3 that DFC Inner Zone harvests are implemented on stands with higher stem densities and smaller stem diameters than stands in the associated no-IZ-harvest prescription strata is consistent with the intent behind the DFC harvest rule – to allow more light into dense stands and accelerate tree and stand growth toward the desired future conditions of mature forest stands (Fairweather 2001). Even though most of the IZ harvests do not use the TFB prescription, the LTCW option also allows more light into the buffers and opens up growing room for leave trees and the growth of understory vegetation in the cut (heavily-thinned) portion of the IZ.

The large proportion of stream buffers on track to meet the DFC target basal area is encouraging for the prospect of the widespread restoration of relatively young riparian buffers that interact fully with in-stream habitat. Many stands in this study have basal areas projected to be well above the target by 140 years of age, which means that in the absence of catastrophic events, those stands would likely reach the target basal area sooner than 140 years old. But it will still require many more years for most of the current buffer stand trees to reach the size where the stands provide riparian functions at levels equivalent to their old growth predecessors on a sustained basis. The DFC model does not provide interim basal areas or other stand characteristics, but data collected from this study could be used in other stand growth models, such as the diverse-stand model developed by Liang et al. (2005), to estimate the proportion of buffers reaching the target over time. However, as results from this study indicate, just because riparian stands meet the basal area rule target does not necessarily mean they are providing riparian functions at desirable and sustainable levels. For instance, the high basal area stands of dense small trees might be providing high levels of shade, but they are only providing small wood to streams from trees that are growing slowly, not developing diverse multi-story forests, and may be potential fire and disease hazards.

5.5 DFC Conclusions

The DFC harvest options generally appear to be leaving stands that will meet the desired future conditions by the time the stands reach 140 years old. The DFC Inner Zone harvests did not diminish that trajectory in over 90% of the cases where they were conducted. Windthrow magnitude and incidence rate was similar in No-IZ harvest and LCTW sites and the magnitude was lower for TFB prescriptions (n = 9). At the IZ harvest sites that were not projected to meet the DFC target, the shade targets were still met in all but one instance.

5.5.1 What proportion of sites are on trajectory to meet DFC target of 325 ft^2/acre of basal area at a stand age of 140 years?

- Seventy-five percent of all buffers in this study were projected to meet the DFC target of 325ft^2/acre by a stand age of 140 years old (Table 11).

5.5.2 How does that vary between sites with and without Inner Zone harvest?

- Ninety-two percent of the buffers that had an Inner Zone prescription applied remained on track to meet the DFC target, despite experiencing heavy windthrow at several sites, whereas sixty-seven percent of the sites that had no Inner Zone harvest were on track to meet the DFC target (Table 11).
  - Comparing prescriptions in Site Classes II and III, which had both IZ harvest and no-IZ harvest prescriptions, fifty-two percent of the sites without IZ harvest were on track to meet DFC versus ninety-two percent of sites with IZ harvest.

Chapter 6. Large Wood Recruitment

6.1 Introduction

The condition of riparian stands (e.g. stand density, tree size and species composition) is an important factor controlling the availability of trees for recruitment to adjacent stream channels (Van Sickle and Gregory 1989). Timber harvest practices can affect both the magnitude and timing of wood recruitment as well as the condition of remaining riparian buffer stands. The wood recruitment potential from riparian buffers depends on factors such as the initial stand conditions, the number and location of leave trees, and the site conditions (Beechie et al. 2000). Denser stands with taller, larger trees have greater recruitment potential than stands consisting of shorter, smaller trees. Differences in riparian management prescriptions, e.g. buffer width and intensity of thinning within the buffers, affect the amount of wood potentially available for recruitment. In this chapter we report on large wood recruitment from the study RMZs to streams during the initial 3 – 6 years after timber harvest and the state of the RMZ stands after that period with regard to future recruitment potential.

6.1.1 Large Wood Recruitment Research Questions

- What are the magnitude and variability of wood recruitment to streams?
    - How does that vary among the different prescriptions?
    - Are there any prescriptions that are markedly different than the others?
- What proportion of mortality results in large wood recruitment to streams?
- Given the mortality and the residual RMZ stands, what remains for future wood recruitment potential?

6.2 Large Wood Recruitment Methods

6.2.1 Wood Recruitment Field Data Collection

For all fallen trees and broken pieces, surveyors recorded the regulatory zone of origin, dbh, species, mortality agent, fall type (uprooted, broken above breast-height, or broken below breast-height), and recruitment class (upland, floodplain, channel-spanning, suspended, bankfull). Recruitment class (Figure 24) describes the relationship of the fallen wood to the bankfull channel. The recruitment classes are ranked in a hierarchical order based on potential function, from the channel to the uplands (Robison and Beschta 1990). A single piece of wood often meets the criteria for multiple recruitment classes; however, only the “highest” class that applies to a piece was recorded. For example, if even a small portion of a piece intrudes into the bankfull channel, it was recorded as a bankfull recruitment class (Zone 1 or 2) even if other, larger portions of the same piece were spanning, suspended (Zone 3), floodplain (Zone 4) or upland (Zone 5).

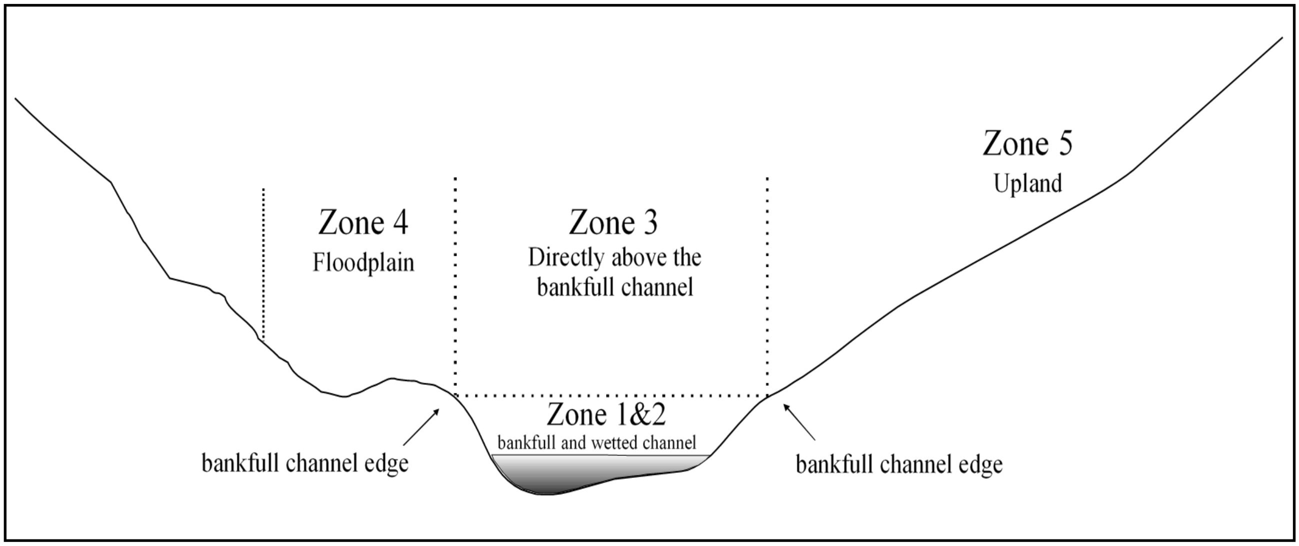


Figure 24. Channel zone recruitment class (adapted from Schuett-Hames et al., 1999).

If the post-harvest fallen tree, or any broken pieces, had recruited to the channel (e.g., if its recruitment class was ‘Channel-Spanning’, ‘Suspended’, or ‘Bankfull’), and if it met the size qualification for LW within the channel (at least 4 inches in diameter and 1 foot long), then it was considered recruited LW. In this case surveyors recorded the additional attributes of length and midpoint diameter of each portion of the piece within the bankfull channel width for each recruitment zone. If the tree or broken piece had a recruitment class of ‘Upland’ or ‘Floodplain,’ no additional data were recorded.

6.2.2 Wood Recruitment Data Preparation and Metric Development

We calculated the number of trees that fell in the RMZs and the proportion that reached the stream at each site.

We collected data on and calculated the number and volume of large wood pieces recruited into or over the bankfull channel using methods consistent with the Washington State TFW monitoring protocols that have been in use since at least 1990 (TFW 1990). This method counts and collects data on any piece in the riparian zone (especially on the floodplain) that exceeds the minimum “large wood” criteria used (4” midpoint diameter by at least 6’ long) as long as some portion of it lies within the channel width. The calculated recruited volume is the portion of those pieces that lie within the channel bankfull width. In this method, many pieces of wood are counted as large wood even though only a small portion of the piece may actually be within the channel width. The benefits of this method are that it captures information about wood available for future contributions to the channel in large flows or mass wasting events; provides information related to floodplain roughness; and might help elucidate key piece information. We called this the “floodplain” method and is one of the two methods commonly used to calculate recruited wood pieces and volume.

Other studies and reported volumes use a method that only counts pieces of wood for which the portion *within the bankfull channel width* meets the minimum size criteria, most commonly 4” diameter by 6’ long (0.1m x 2m). We refer to this as the “BFW” method. Requiring the piece within the channel width to be this minimum size results in fewer pieces reported as recruited than the “Floodplain” LW method. Studies that used the BFW method for counting large wood include work done in SE Alaska, northern California, and in Oregon (Grizzel et al 2000; Benda et al. 2002; Reeves et al. 2003; Martin and Grotefendt 2007). We calculated the BFW-LW as a second set of recruit metrics by screening for and using only wood pieces that met the size criteria at least 6 feet long by 4 inches in diameter *within* Zones 1-3. These metrics are reported in the appendix tables to enable comparisons with studies that use that method but are not used in this analysis.

The field crews used the floodplain method described here to collect wood data. That method is more comprehensive and allowed recruitment to be calculated using both methods. We summed the number of recruited wood pieces for each site and calculated the in-channel (channel zones 1, 2, and 3) volumes for each and added them to obtain a recruited volume for each site (“LW pieces/100 ft” and “LW vol/100’”). To obtain the BFW method measurement of recruited LW, the recruited wood data set was filtered for only those pieces that met minimum dimensions of 4” minimum diameter by 6’ long *within* channel zones 1, 2, and/or 3. The numbers and volumes of those pieces within the channel vertical plane were calculated and summed for each site (“BF-LW pieces/100 ft” and “BF-LW volume/100 ft”).

We also report counts of trees per 100 feet of stream length due to that metric’s relevance to enumerating trees available to be recruited to streams.

6.2.3 Wood Recruitment Analysis Methods

We evaluated the amount of wood that was recruited to the stream channels through the early post-harvest period and compared how that varied among the sites and prescriptions. We then explored the residual riparian stands and the potential for future wood recruitment to stream channels. Due to lack of accurate tree height data, we could only perform a rough estimation of stand heights and the ability for fallen trees to reach the channels. This was not intended to be an exhaustive analysis of recruitment potential, but we discuss the best-case potential for wood (from the tallest trees) to reach the channel, for the RMZ stand in its current condition.

We estimated heights for all trees of the five dominant species of trees in the study region (Douglas-fir, western hemlock, Sitka spruce, western redcedar, and red alder) based on published dbh-to-height regression equations (Table 12). Comparison of the calculated heights to unpublished timber cruise data (Appendix D) showed that the equations used resulted in reasonable height estimates for the study area. We then determined the dominant species at each study site and averaged the heights of all the trees of that species to establish the stand height. Only two sites were dominated by a (deciduous) species that has no meaningful height-diameter relationship (bigleaf maple and cascara). Because the conifer wood persists longer than the broadleaf species we have in Washington stream channels, we used the heights of the currently subdominant western hemlocks at those two sites for the purposes of this cursory analysis.

Table 12. Equations used to estimate tree height for the dominant stand species using Yang et al. (1978)'s equation with parameters developed for south coastal British Columbia (Staudhammer and LeMay 2000).

Height = 1.3 +El * [l – exp(E2 x ***dbh***^{E3}***)*]** **Where *dbh*** is in cm and ***Height*** is in meters

Tree Species	E1	E2	E3	
Western redcedar	39.0002	-0.02164	1.01568	
Red alder	26.5495	-0.03079	1.20438	
Douglas-fir	68.6382	-0.01296	0.98848	
Western hemlock	41.4831	4.01365	1.21692	

6.3 Large Wood and Recruitment Results

6.3.1 Tree Fall, Wood Recruitment to Streams, and Residual Stands

The median streamside live tree lineal density along streams in this study started at 55 live trees per hundred feet immediately after the harvest and decreased to 48 live trees per hundred feet of stream channel 3 to 6 years after the harvests (Tale A-5b). The range of lineal tree density at sites started at 11 to 145 trees/100 ft IPH and remained relatively unchanged at 10 to 132 (Table B-5b). Higher numbers of trees per hundred feet (lineal density) in the buffers were associated with smaller trees and not necessarily with wider buffers (Figure 25 A and B). There was not a large difference in the residual number of trees by stream width category, despite the higher mortality on small streams (Figure 25-B). The stand mean tree diameters most densely clustered around the overall study median value of 13.8 (Figure 25 A).

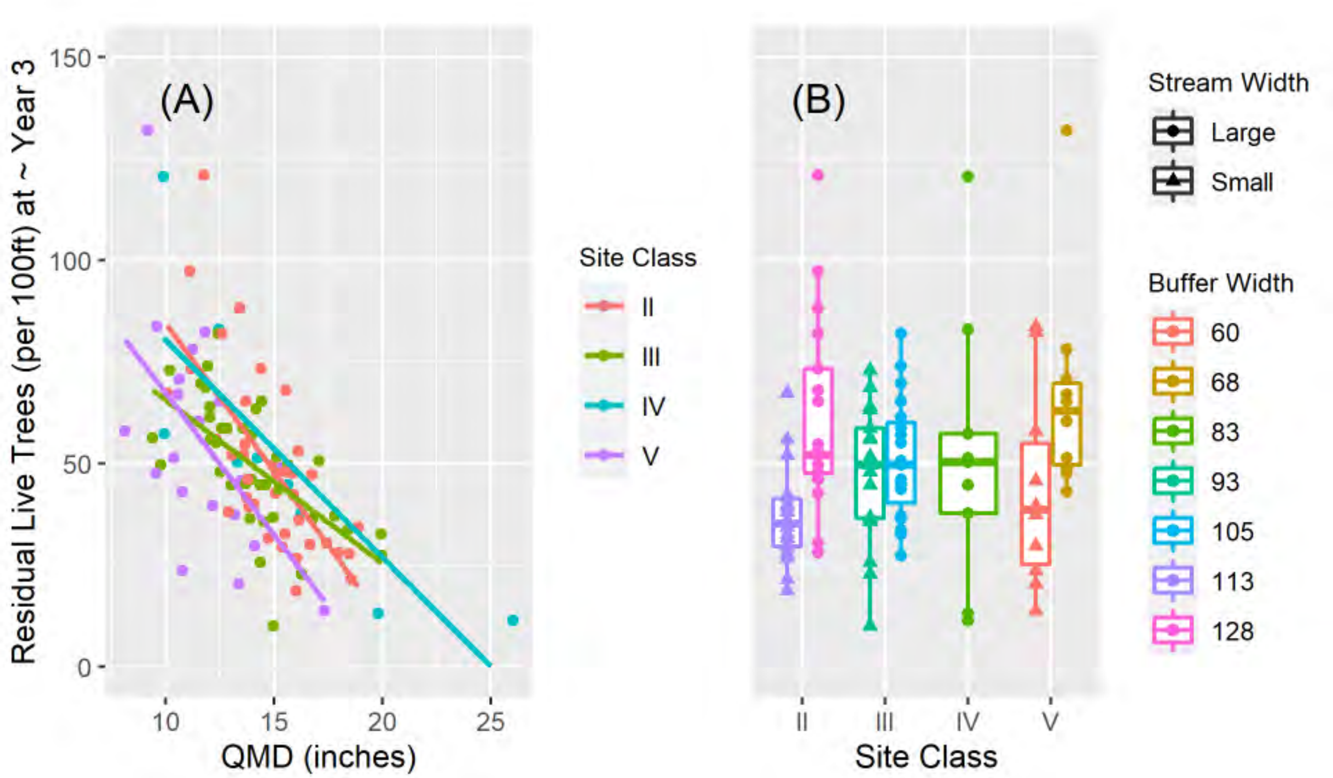


Figure 25: Early post-harvest residual trees per 100 ft of stream channel as a function of mean diameter (QMD) and site class.

Not all trees that died fell, and of those that fell, only 40% reached the stream channel (Figure 26, A – C and Figure 27). Ten and a half percent of the standing trees alive immediately post-harvest fell in the early post-harvest period (median = 6.3% per site). Boxplots in Figure 26-B show that fallen tree counts tended to follow the patterns of buffer width. Where the Inner Zone is wider, more trees tended to fall in that zone, whereas in Variants 9, 10, and 11 where the Inner Zone is narrow, more trees fell in the Core Zones. Inner Zone treatment was associated with more treefall on LTCW sites on small streams in Site Class III than in the corresponding no-harvest sites (Figure 26). More notably, for similar levels of fallen trees, the LTCW sites had substantially more trees reach the channel than at the no-harvest sites (Figure 26-C). Both treefall and recruited tree variances are extremely high for Rx 11 in Site Class V (Figure 26). Recruitment and other site characteristics for that prescription are driven by two sites with very high windthrow (44% and 57% of the trees).

24 sites had no LW recruitment to the channel. Five of those had no trees fall in the Inner or Core zone. Fifteen sites were on Large streams and nine were on small streams. Five sites with no recruitment were in Site Classes IV or V but only had between 0 and 5 fallen trees.

The overall average dbh of trees that provided LW to the channel was 12”. Trees from the Inner Zone that contributed large wood to or above the channel tended to be larger than those from the Core Zone (Figure 28). This result stands to reason as tree height is related to the size and quantity of recruited wood. Only the largest and nearest trees within the Inner Zone would be able to reach the channels as LW (Figure 29-A), whereas even smaller trees in the 50-foot wide Core Zone are tall and close enough to provide LW of minimal functional size to the stream (Figure 29-B).

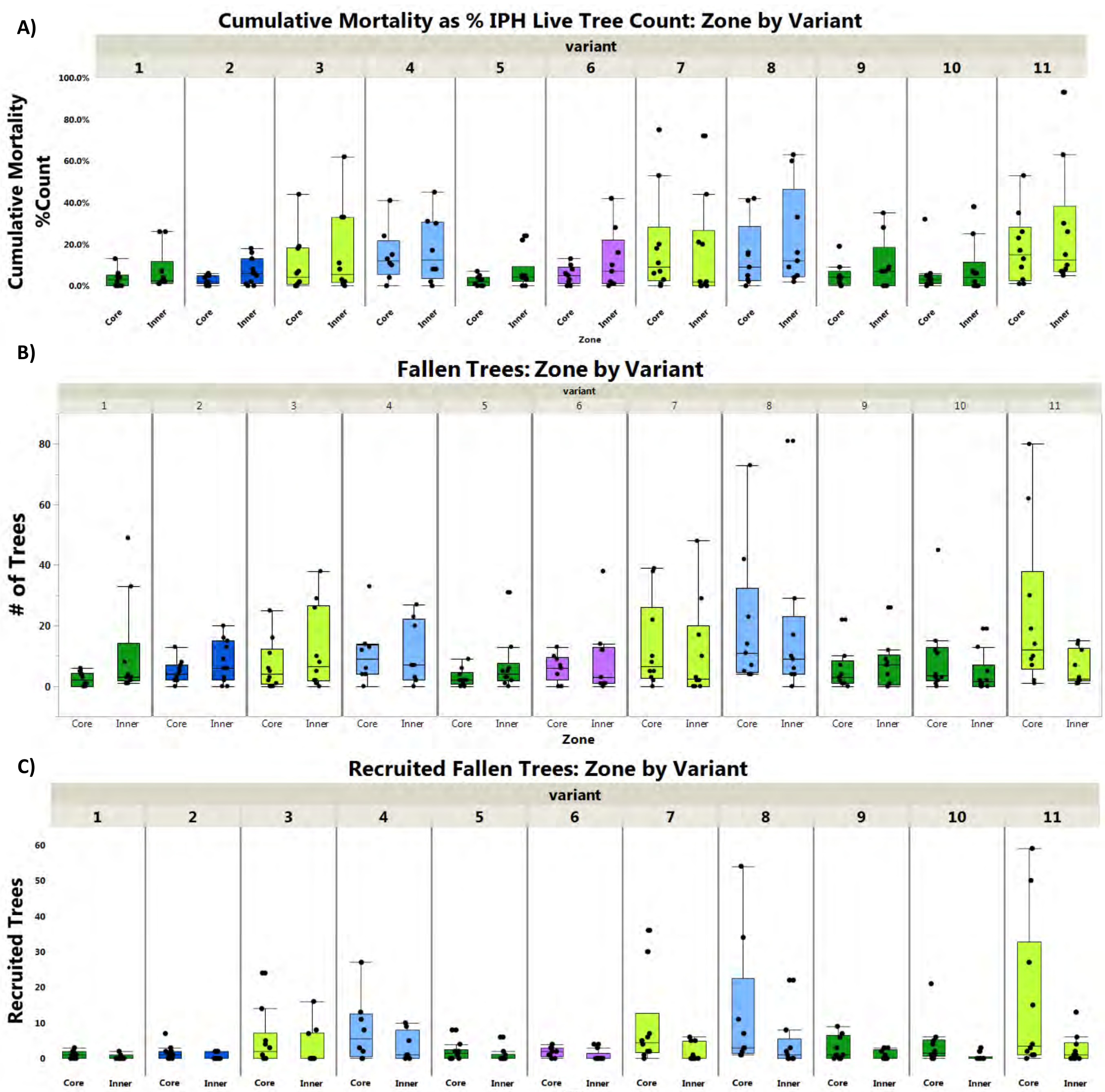


Figure 26. Mortality (A), Fallen Trees (B), and Recruited Trees (C) in the 3 – 6 year early post-harvest period, by prescription variant and RMZ zone.

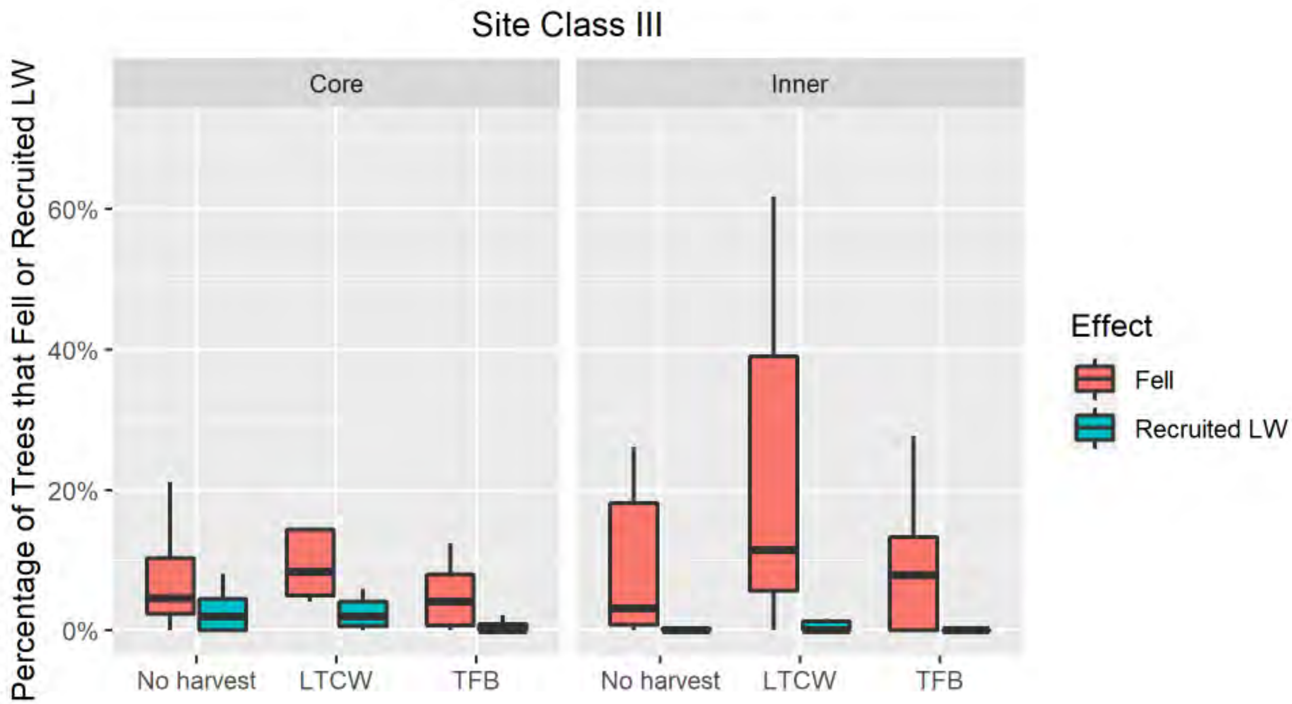


Figure 27. Site Class III, percentage of IPH standing live trees that fell in the 3 to 6-years post-harvest riparian buffers, shown by buffer zone and Inner Zone harvest treatment.

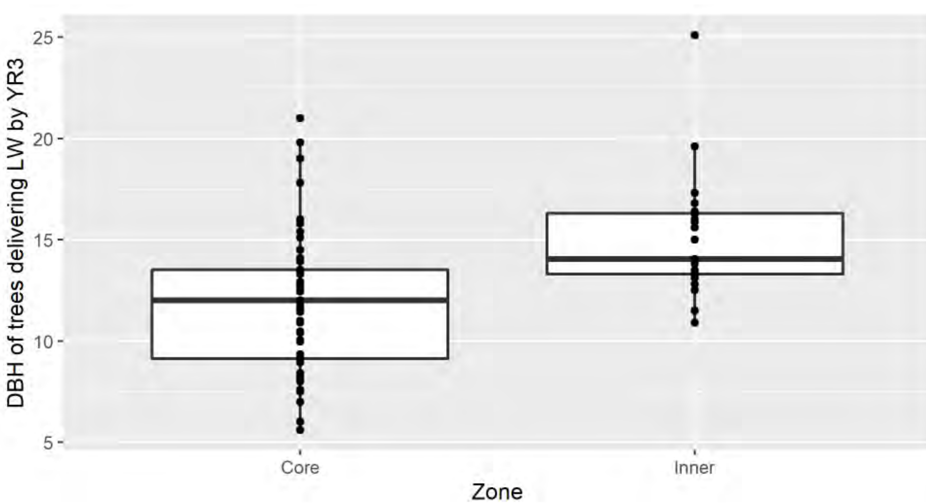


Figure 28: Diameter (dbh, in inches) of trees recruiting LW to the stream by zone.

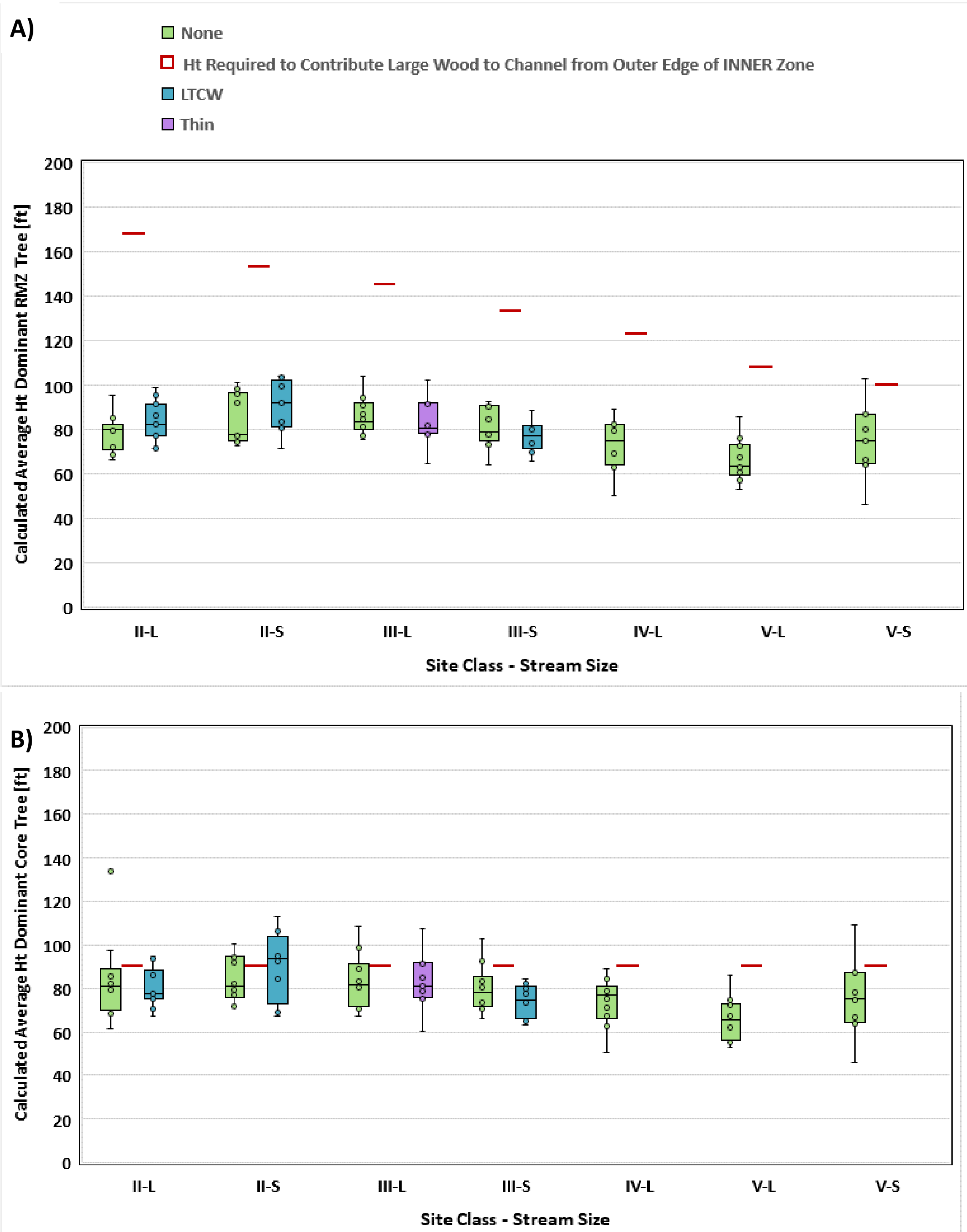


Figure 29. Average calculated heights of dominant trees (by # of trees) in each buffer shown for (A) Core + Inner Zones and (B) Core Zone only.

The weighted median wood loading from newly-recruited trees was 1 pc/100 ft of stream length (range: 0 to 25.3 pcs/100 ft) and 2.8 ft^3/100ft (range: 0 to 92). As we reported for mortality, the majority of the wood recruitment was from a limited number of sites. The number of recruited pieces was highly correlated with mortality calculated as percentage of tree stems (r^2=0.84) and total recruited wood volume was positively correlated with mortality calculated as percentage of basal area (r^2=0.65).

While the (quadratic) mean dbh of trees contributing LW was 12", the mean in/over-channel diameter of the recruited LW was 6.8 inches (median 6; max 23"). The mean length of recruited LW in or over the channel was 8.7 feet (median 6.1; max 54 ft).

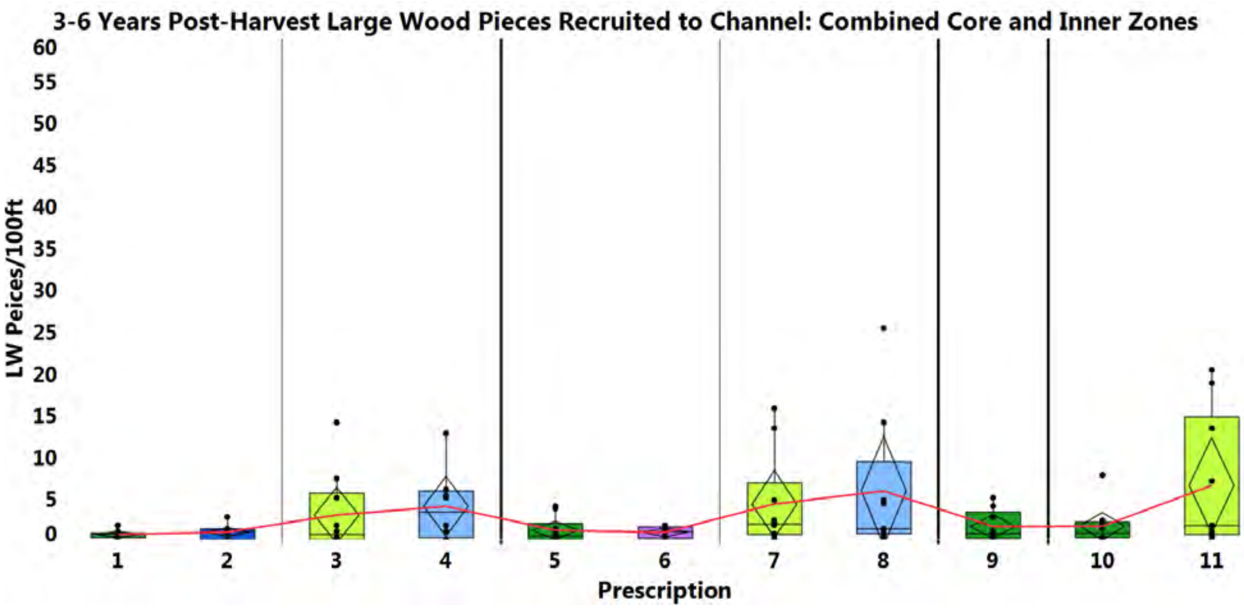


Figure 30. Large wood recruited to stream channels during the first 3 to 6 years after harvest.

6.4 Large Wood and Recruitment Discussion

The "lineal density" of buffer trees is the number of streamside trees per unit stream length and is an important measure of trees available for long term wood recruitment to streams. The median streamside live tree lineal density along streams in this study started at 55 live trees per hundred feet immediately after the harvest. As reported in Chapter 4, windthrow and other mortality mechanisms killed approximately 14% of the buffer trees over the first 3 to 6 years after harvest. The net result was that the median lineal density decreased to 48 live trees per hundred feet of stream channel 3 to 6 years after the harvests. There was not a large difference in the residual number of trees by stream width category, despite the higher mortality on small streams (Figure 25-B). That the lineal densities of trees among the eleven prescriptions have so much overlap is a remarkable result, because the largest of the RMZ Core + Inner widths on large streams in SC II are more than double that of the smallest on small streams in Site Class V. The early post-harvest loss of wood to blowdown can in many cases help replenish barren stream channels when it breaks down and enters the channel, but for now it is mostly spanning over the channels. Lineal densities are still quite high, and wood will continue to enter the channels as the stands develop and experience more stem exclusion mortality.

The question, however, becomes whether the buffer trees that fall will actually enter the stream. Only 40% of the trees that fell in this study fell into or over the channel. Grizzell et al. (2000) note that developers of several quantitative debris recruitment models (Robison and Beschta 1990, VanSickle and Gregory 1990) have assumed random tree fall directions which may have limited applicability in areas where windthrow is the dominant recruitment mechanism. These authors (Robison and Beschta 1990, VanSickle and Gregory 1990) are cited in the Draft FPHCP as part of their rationale underpinning the Riparian Conservation Strategy (Subsection 4d-1.1). Grizzell et al. (2000) reported that trees in their study did not follow this assumption and pointed out the non-random nature of wind-driven treefall. That could have an important influence on future recruitment to these streams.

Most of the trees that fell and reached the stream channel fell from the Core Zones and had a median dbh of 12 inches. Trees from the Inner Zone that reached the channel were larger, with a median diameter of 14 inches. The mean diameter of the wood pieces recruited to the channel was 6.3 inches. Wood pieces having a minimum diameter of 4” are considered large enough to be counted as LW and form habitat (pools, sediment storage, shade, substrate, etc.) in stream channels. Trees that fall into or over the channel from the riparian buffers such that the portion within the channel width is at least 4” diameter are considered “recruited” to the channel and count in assessment against the L-1 in-stream LWD target. The red line in the figure at 16” diameter illustrates the log diameter for wood to function as a key piece in channels 1-5m wide (Fox 1994 *in* WA DNR 2011). 16” is the minimum diameter for LWD placement in stream channels specified in the Board Manual (2013) guidance for wood placement in channels from 5 to 16 feet wide. Although it is not a target of the forest practices rules and has no regulatory bearing on RMZ rules, it is a useful reference point for thinking about riparian tree size in relation to fish habitat. Larger streams require even larger diameter wood to form stable habitat-forming features (Fox 1994; WA DNR 1997; Fox and Bolton 2007).

6.5 Large Wood and Recruitment Conclusions

6.5.1 What level of the following riparian functions is associated with the prescriptions 3 -6 years after harvest, and how do those functions vary between study sites with and without Inner Zone harvest?

Large wood recruitment (and recruitment potential)

- 10.5% of the initial post-harvest standing trees fell, and 40% of those contributed wood to the stream channel ("recruited").
- Despite treefall occurring nearly equally between the Inner Zones and Core Zones, Core Zone trees accounted for approximately 80% of the trees that recruited to the stream channel (in and over-channel).
- Windthrow was the dominant mortality agent and wood recruitment was highly correlated with windthrow.
- The weighted median instream wood recruitment at sites was 1.0 pcs/100' (2.8 ft^3/100') and ranged from 0 to 25 pcs/100 ft (0 to 91.6 ft^3/100'). Many sites received no wood inputs.
- The (quadratic) mean dbh of trees contributing LW was 12", and the mean in/over-channel diameter of the recruited LW was 6.8 inches (weighted median 6.9 in; max 23 in) (Table A-5). The mean length of recruited LW in or over the channel was 8.7 feet (median 6.1 ft; max 54 ft).
- The retention of a fixed-width Core + variable-width Inner Zone buffer that varied by site class and stream width category resulted in lineal stand densities that had a weighted median about 55 buffer trees (Core and Inner combined) per 100 feet of RMZ stream channel length in all variants/site classes immediately after harvest and 48 trees/100 ft 3 to 6 years later.
- Tree height estimates show how the current small size of riparian trees is limiting large wood recruitment. Only trees in the Core Zones and nearer portions of the Inner Zones are tall- and close enough to provide LW of minimal functional size to the stream.
- The combination of currently small sizes of the trees and the wide riparian buffer zones resulted in low input of wood that meets the minimum criteria for Large Wood.
    - The narrow (60 – 68 ft Core+Inner) Site Class V buffers are an exception, and the heights of trees from those buffers already exceed the Inner buffer width and have trees large enough to provide structural large wood on small streams from throughout the buffer.
    - Because the buffer in Variant 11 is narrow, a higher proportion of the fallen trees in those buffers recruited to the stream channel than from wider buffers.

Chapter 7. Shade

7.1 Stream Shade Introduction

Stream temperature is a function of multiple energy transfer processes, including direct solar radiation, longwave radiation, conduction, convection, and evaporation. Of these factors, direct solar radiation is the primary contributor to daily maximum summer stream temperature and has the most direct response to riparian canopy removal from forest harvest (Brown and Krygier 1970, Johnson 2004). Maintaining shade is an effective tool for minimizing stream temperature heat flux during the summer months when maximum stream temperatures are observed (Johnson 2004). Washington State enacted timber harvest regulations under the Washington Forest Practices Rules to maintain stream shade following timber harvest. Since removal of shade is strongly associated with stream temperature increases, forest practice rules in Washington have been established to minimize stream temperature increases following timber harvest near streams by application of minimum shade requirements.

The primary function of riparian vegetation in controlling water temperature is to block incoming solar radiation (direct and diffuse). Direct solar radiation on the water's surface is the dominant source of heat energy that may be absorbed by the water column and streambed. Absorption of solar energy is greatest when the solar angle is greater than 30° (i.e., 90 to 95 % of energy is absorbed as heat) and decreases as the solar angle declines due to the reflection of radiation off the water surface. Therefore, riparian vegetation that blocks direct solar radiation along the sun's pathway across the sky is most effective at reducing the amount of radiant energy available for stream heating (Moore et al. 2005). Research shows that the attenuation of direct beam radiation by riparian vegetation is a function of canopy height, vegetation density, and buffer width (Beschta et al. 1987; Sridhar et al. 2004; DeWalle 2010). Light attenuation increases with increasing canopy height and increasing buffer density as a result of the increased solar path occlusion and energy extinction, respectively. Buffer width has a variable influence on light attenuation depending on stream azimuth and width (e.g., effective shade cast from buffers for east-west streams may not require buffers as wide as those for N-S streams due to shifts in solar beam pathway from the sides to the tops of the buffers (DeWalle 2010). Riparian buffer width is important for a given stand type and age but is not always a good predictor of stream shading among different stands because of differences in stand height and density. For example, Beschta et al. (1987) showed that shade levels similar to those in old-growth forests in western Oregon could be obtained within a distance of 20 to 30 m depending on stand composition. Similarly, Sridhar et al. (2004) using an energy balance model with empirical data, demonstrated that stream temperature is most sensitive to a stand's leaf area index (i.e., an indicator of light attenuation by canopy density) followed by average canopy height (an indicator of direct beam light attenuation), and lastly buffer width. They found the most effective shading for temperature control in eastern and western Washington Cascade conifer stands was predicted for mature (high leaf-area-index) canopies close to the stream (i.e., within 10 m of the stream bank) and overall buffers of about 30 m.

Shade from riparian vegetation is not the only factor influencing stream temperature. Research shows that temperature response from timber harvest of riparian vegetation is variable and can be highly dependent on the volume of stream flow, substrate type, groundwater inflow, and surface/subsurface water exchange (i.e., hyporheic exchange) (Moore et al. 2005). In general, stream sensitivity to shade loss is a function of reach-scale physical characteristics and geomorphic setting. For example, streams at lower elevations (i.e., warmer air temperature), having no topographic shading, with shallow-wide channels (i.e., high width to depth ratio), or with bedrock substrate (i.e., hyporheic exchange limited) are more sensitive to heating from shade loss than are streams at higher elevations, with topographic shading, with deep-narrow channels, or with alluvial substrate.

Research in eastern Washington testing “all available shade rule” buffers under the Bull trout habitat overlay and standard rule buffers for Type F fishbearing streams showed a very small change (O.16 degrees C) in the average stream temperature in response to harvest for 75 to 80-foot buffers at 19 of 30 sites monitored pre to post-harvest (Cupp and Lofgren 2014). Recent studies of buffer effectiveness in western Washington on non-fish-bearing, perennially-flowing streams indicate stream temperature response varied widely and ranged from little change to as much as 4° to 6° C within two years post-harvest, with temperature increases persisting for up to nine years post-harvest in some streams (McIntyre et al. 2021, Ehinger et al. 2021). In most cases, post-harvest temperature changes varied in relation to the level of tree retention and buffer width. However, variability in the degree of temperature response to shade loss was observed, particularly in headwater streams, where temperatures both decreased and increased after harvest. Such variability was attributed to post-harvest increases in stream discharge (i.e., cool groundwater input) and variable inputs of slash that provided shade (Kibler et al. 2013; Jackson et al. 2001). Both McIntyre et al. (2021) and Ehinger et al. (2021) found that effective buffer shade was significantly reduced by post-harvest windthrow.

Because riparian buffer effectiveness for maintaining shade and stream temperature is not only a function of the riparian stand characteristics (height, density, width) initially after harvest, but also of spatially variable site-specific conditions, we expect the effectiveness of the Western Washington Type F-stream riparian rules directed at providing shade will vary in relation to stand characteristics, location, and time after harvest. RMZ prescription effectiveness to maintain pre-harvest stream temperatures will likely vary in relation to other key physical characteristics, such as those described above, that contribute to the stream sensitivities to thermal loading. However, in this exploratory phase study we limit our exploration to assessments of shade potentially provided by forest stands in RMZs left after timber harvests that used a variety of RMZ prescriptions. In this chapter we analyze canopy closure data obtained using spherical densiometers as an estimate of shading potential to provide information on the magnitude of shade variability within and differences among prescription variants.

7.1.1 Canopy Closure and Stream Shade Research Questions

- What is the magnitude of shade variability within and differences among prescription variants?
    - Are there any prescriptions for which either is markedly different than for the others?
- What level of shade is associated with the RMZs left by the various prescriptions 3 – 6 years after harvest?
- How does shade differ between sites with and without Inner Zone harvest?
- What are the effects of windthrow and residual stand structure on stream shading provided by the RMZs?

7.2 Shade Methods

7.2.1 Canopy Closure Data Collection

The purpose of canopy closure surveys was to provide estimates for canopy cover that provided shade to the stream channel. Although they are not directly equal, canopy closure is closely related to and was used as a surrogate for shade in this study. Canopy closure data were collected using spherical densiometers employing two methods: one based on Lemmon (1957) and described in the Forest Practices Board Manual (WA DNR 2000) that estimates average canopy closure produced by riparian vegetation on both sides of a stream ("Canopy Closure-midstream" or "Shade1"), and another based on Platts et al. (1987) that more specifically captured the shade conditions produced by the one-sided RMZ treatment being investigated ("Canopy Closure-into RMZ" or "Shade2"). The midstream canopy closure method by Lemmon requires the surveyor to read the densiometer four times in four different directions, counting number of obstructed within-square dots (96 total dots), and then average the readings. The Platts method for Canopy Closure-into RMZ takes one measurement looking into the buffer while standing in the channel, 5 feet from the channel edge. The surveyor counts the number of obstructed dots-at-intersections per 17 in the wedge-shaped subset. The Platts method isolates the canopy closure provided by the buffer under investigation by eliminating the confounding cover data that might be provided by the trees on the other side of the stream and makes it more comparable with closures provided by other buffers by taking measurements at a consistent distance from the RMZ, regardless of stream width.

Canopy closure data were collected at systematic intervals along the stream channel at five equally-spaced (60-foot intervals) stations within the study reach. A minimum of 30 feet was left from the upstream and downstream edges in the interest of avoiding the edges of blocks to avoid capturing shade effects from outside the study buffer. At each canopy station, surveyors collected data using both the FPB Manual/Lemmon method and the Platts method. GPS coordinates and photos were taken at each station using the Collector app.

7.2.2 Canopy Closure Data Preparation

We averaged the canopy closure station measurements for each site to calculate composite values for the sites. These are reported in Table A-5b. Medians, interquartile ranges, means, and standard errors compiled for each prescription are provided with the canopy cover boxplots in Appendix B-6.

7.2.3 Canopy Closure/Shade Analysis

The intent of this study was to assess the riparian functions provided by the study RMZs left using rule prescriptions. The analyses therefore only rely on data from the Platts method looking into the RMZ ("Canopy Closure into RMZ" or Shade2). The four-directional midstream canopy closure measurements (Lemmon method; "Shade1") data are included in Appendices A and B but are not included in this analysis, because they include information on the riparian conditions on the other side of the stream, which is not of interest for this study.

We used correlation analyses of canopy closure and several covariates to explore how site-specific covariates may influence shade provided by the RMZs in this study. We looked for patterns in the canopy closure data relative to prescription variant, Inner Zone harvest type, site characteristics, stand density, basal area, tree height, mortality, and stream width category. We used the stream width data from the FPA to classify the channel as "Small" (<10 ft wide) or "Large" (>10 ft wide), and we knew which sites were Type S, which are typically significantly greater than 10 feet wide. We used a combination of box plot and scatter plot observations, Spearman correlations, and Kruskal-Wallis non-parametric statistical tests to assess the significance of any perceived patterns. Levene's and Brown-Forsythe tests were used to assess whether observed differences in variance among the prescriptions were significant. Statistical tests were performed in JMP v.17.0.0.

We compared the measured canopy closures to two sets of forest practices rules targets to assess the level of shade functions. In the first assessment we compared canopy closures with the effective shade target range of 85%-90% specified in Schedule L-1 of the Forests and Fish

Report and FPHCP[7]. Effective shade is defined as the fraction of total possible potential solar radiation that is blocked by riparian vegetation and topographic features (Teti and Pike 2005, Allen and Dent 2001) and takes into account such factors as stream and buffer aspects relative to incident sun angles during the peak warming time of day and year. Complete effective shade calculations for each site were beyond the scope of this study and are not necessary for comparing the shading potential of timber stands in the various RMZ buffers.

Our canopy closure measures approximate effective shade by isolating the sky view blockage provided by the stands under investigation and excluding canopy openings over the channel. Also, by measuring shade at a fixed distance from the channel edge, the area of riparian canopy viewed is consistent for all sites regardless of channel width and stream aspect.

Allen and Dent (2001) and McIntyre et al. (2018) demonstrated high correlations between canopy closures measured using spherical densiometers by the midstream, four-point method and effective shade measured using precise hemispherical photographic techniques. Both studies showed that at high shade levels (greater than about 80%), canopy closures based on densiometer measurements overestimated effective shade by on average 11% but remained closely correlated (R^2 >.90). The method we used (looking into buffer) should correlate better with effective shade than the standard densiometer technique because we eliminated the confounding effects of channel cover. We used the canopy closure data to calculate the percentage of sites within each prescription that met or exceeded the lower limit of the L-1 target shade range (canopy closure >= 85%) but did not count or report the number of sites that exceeded the upper end of the range (canopy closure > 90%). We calculated the percentage of sites within each prescription that met or exceeded the lower limit of the L-1 target shade range (85%) but did not count or report sites that exceeded the upper range.

For the second assessment we compared measured canopy closure to the forest practices rule minimum shade requirements that apply to harvesting within 75 feet of the channel edge (WAC 222-30-040). The WAC directs that a shade analysis be performed according to the FP Board Manual, Section 1. The FP Board Manual Section 1 directs users to use either a shade model or, in the absence of that, to assess shade levels using elevation-based temperature/shade nomographs for western Washington provided in the Board Manual (Figs 1.2 on page M1.6 of the FPB Manual). The nomographs are graphs that specify a minimum level of canopy closure, measured using a spherical densiometer, for each site based on its elevation and maximum temperature limitation class (16^{o}C or 18^{o}C). The maximum temperature limitation is assigned by the Washington State Department of Ecology based on how the waters of each stream are used. To use the nomograph, the elevation of the site of interest is located on the x-axis of the

[7] Schedule L-1 (Appendix N of the FP HCP) specifies a shade target of between 85 and 90% of all effective shade (if shade model is not used) for Type F and S streams except Eastside bull trout habitat. We did not use a shade model in this study.

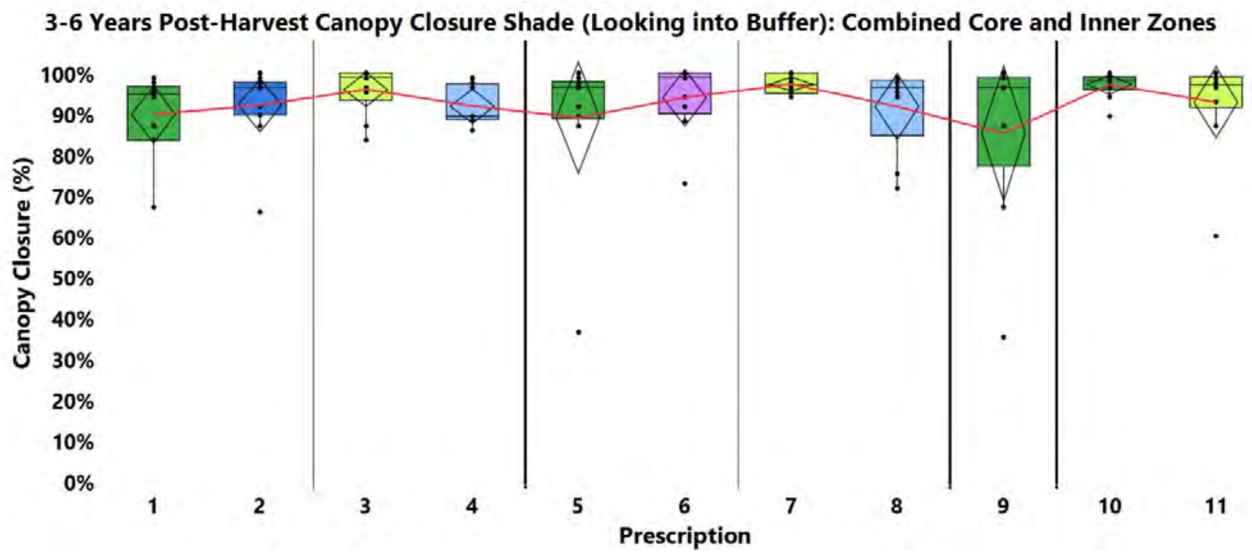
graph and the regression line then indicates on the y-axis the amount of canopy closure needed to keep peak stream temperatures below the regulatory limit. There are two of these for western Washington that correspond to the two designated peak temperature limits of 16^{o}C and 18^{o}C for streams on Washington forestlands. Although only three prescriptions in this study allowed harvesting of trees within 75 feet, we used the nomograph method for all sites as another way to objectively assess the ability of study buffers to provide desired shade functions. WAC 222-30-040 relates to Washington State Department of Ecology water quality standards for stream temperatures.

We identified the regulatory limit for shade that was applicable for each site and entered it into the site database. We entered the elevation-based equations for each nomograph target line into a formula and evaluated the measured canopy closure and values to the appropriate regression equation evaluated for the site elevation. The numbers and characteristics of sites that did not meet their target shade values were counted. To present the results of this analysis, the canopy closures looking into the buffers (Shade 2) for the study sites were plotted on the appropriate nomograph for that site. Locations graphed above and to the right of the target line are deemed to have adequate shade to maintain maximum stream temperature below the regulatory target designated for that stream. Points below and to the left of the red target line are deemed to have inadequate shade to maintain water temperatures below the regulatory maximum. Notable site features that could explain why sites did not meet the nomograph shade requirements were added to the graphs to aid interpretation of results.

7.3 Shade Results

7.3.1 Canopy closure by prescription

The weighted median of canopy closure for all sites was 96% and the range was 35 to 100% (Table A-5b). Median values for all prescriptions were over 89% and only those for Prescriptions 4 and 9 were below 95% (Figure 31). The boxplots in Figure 31 indicate that canopy closure is similar among all prescriptions and there are no apparent differences by site class (Kruskal-Wallis $P > 0.18$). RMZs in Prescription 9 (Site Class IV) had a wider interquartile range than the other prescriptions and Prescription 5 also had a very low outlier, but none of the variances was statistically significant (Brown-Forsythe $P = 0.58$). Canopy closure was below 80% at nine sites, including two outliers with canopy closures below 40%. Visual observations of aerial photographs showed that one of the two sites with very low canopy closure was on a low terrace of a large Type S stream (i.e., “Shoreline”) where geomorphic processes had either previously removed trees adjacent to the shoreline or site conditions (e.g. –saturated soils) were not good for growing trees. The other site with less than 40% canopy cover is a Type F stream in a tidally-influenced area. One site with shade below 80% had experienced high post-harvest stand mortality. The remaining sites with low canopy closure had no obvious explanation or pattern. Despite the low canopy covers, six of the nine sites with canopy closure below 80% are on trajectory to meet the DFC target basal area when the stands reach 140 years old (Table A-5).



Site Class	II				III				IV	V	
Stream Width	**L**		**S**		**L**		**S**		**L**	**L**	**S**
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ&IZ width (ft)	**128**	**100+**	**113**	**80+**	**105**	**105**	**93**	**80+**	**83**	**68**	**60**
N	**10**	**11**	**10**	**8**	**10**	**9**	**10**	**9**	**9**	**10**	**10**
Median (%)	94.7	96.4	98.8	89.4	96.4	98.8	97.0	96.4	96.4	98.2	97.0
IQ Range (%)	13.2	7.9	6.8	8.8	9.1	10.0	5.0	13.5	21.8	3.2	7.6
Mean (%)	89.8	92.1	96.0	91.9	89.0	93.9	97.3	91.7	85.2	97.1	92.8
StdErr (%)	3.1	2.9	1.9	1.7	6.0	3.0	0.7	3.5	7.1	1.0	3.9

Figure 31. Canopy closure measured facing the subject RMZ only (Shade 2), shown by prescription variant.

7.3.2 Canopy closure exploration with site and stand characteristics

Table 13 provides correlation coefficients and associated probabilities of significance for the canopy closure relationships with continuous site and stand variables. The correlation analysis results show that canopy closure was weakly and negatively correlated with stand age, QMD, tree height, and stddevDBH and positively correlated with stand tree density metrics (trees/acre and trees/100 ft of stream bank length) and relative density. There was no correlation with basal area metrics.

Although we are confident about the significant positive relationship between canopy closure and stem densities and the general shape of the trend line shown in Figure 32, we have little confidence in the precision and prediction capability of any shade trend line because nearly all the canopy closure values are higher than 80%. The nine sites with low canopy closures show no relationship with stand density, including the two with very low values noted previously. Because the two very low canopy sites were so distinctive, we also calculated correlation coefficients and significance probabilities for the site data excluding those two outliers. The correlation patterns remained unchanged (Table 13). There was no apparent difference in the canopy closure and stand metric relationships among the three Inner Zone harvest types.

Table 13. Correlations between site or RMZ stand characteristics and the canopy closure looking into the RMZ buffer.

	Yr3 Canopy Cover - Into RMZ			
Site and Stand Characteristics	**Spearman Correlation Coeff.**	**Probability**	**Correlation Without Outliers**	**Probability Without Outliers**
Longitude	-0.1559	0.1105	-0.1522	0.1231
Latitude	0.1565	0.1092	0.1503	0.1278
Elevation	-0.0647	0.5102	-0.1187	0.2301
Stand Age at Harvest	-0.2712	0.0049*	-0.2808	0.0039*
Stand Age at Sampling	-0.283	0.0033*	-0.2931	0.0025*
% Conifer Trees	-0.0908	0.3548	-0.1109	0.2623
% Conifer Basal Area	-0.1576	0.1065	-0.1615	0.1015
Tree Spp. Richness	-0.0863	0.3792	-0.0567	0.5676
Stand DBH std dev	-0.2673	0.0056*	-0.2251	0.0216*
Stand Density (trees/acre)	0.349	0.0002*	0.3405	0.0004*
Basal Area/Acre	0.0596	0.5438	0.0748	0.4503
Quad. Mean Diameter	-0.3409	0.0003*	-0.3261	0.0007*
Relative Density-summation	0.1854	0.0571	0.1727	0.0796
Avg Dom. Sp. Height	-0.2145	0.0273*	-0.213	0.0299*
Live Trees/100 ft	0.2769	0.0041*	0.2709	0.0054*
Live Basal Area/100 ft	-0.0641	0.5137	-0.0633	0.5236

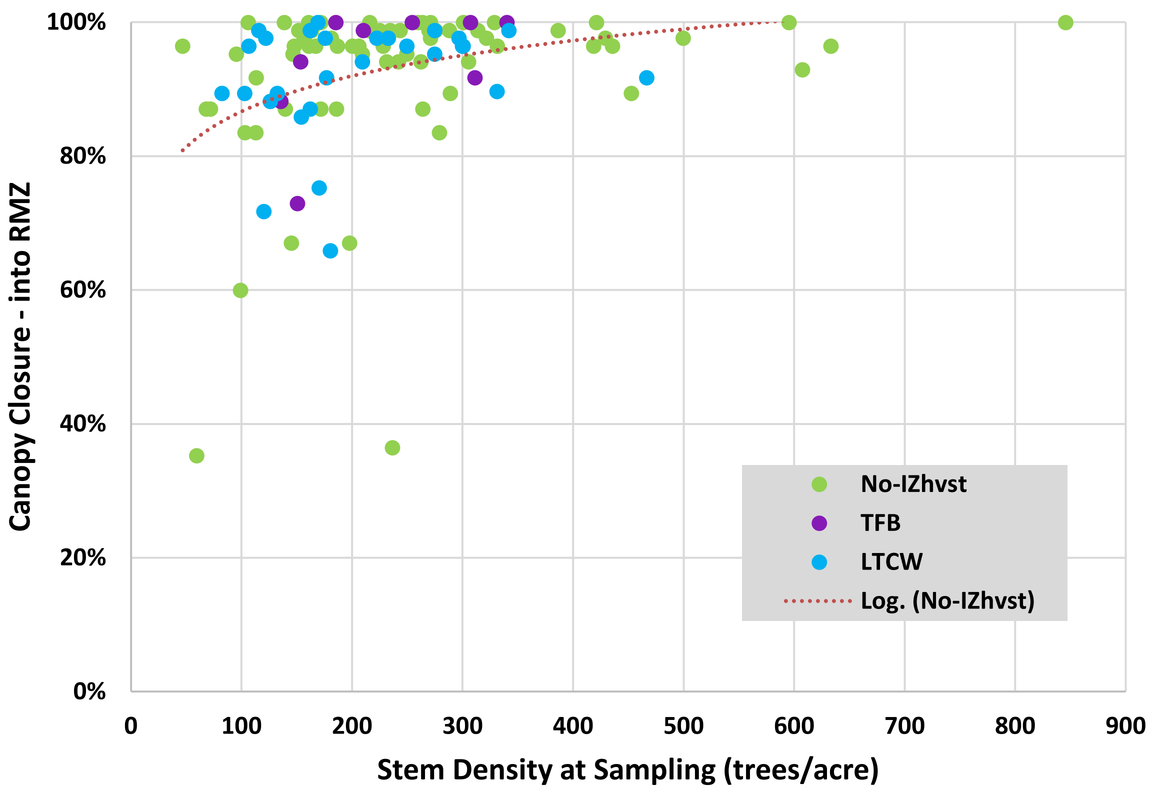


Figure 32. Canopy closure looking into the RMZ as a function of stand density (trees/acre), displayed by Inner Zone harvest type.

Canopy closures in the RMZ buffer stands of this study remain high regardless of post-harvest mortality (Figure 33-A). Closures are similarly high regardless of the whether or not the DFC model projects the stands will meet DFC basal area target when they are 140 years old (Figure 33-B). There are no apparent differences in the patterns of canopy closure vs. mortality or DFC basal area projection among the three Inner Zone harvest categories.

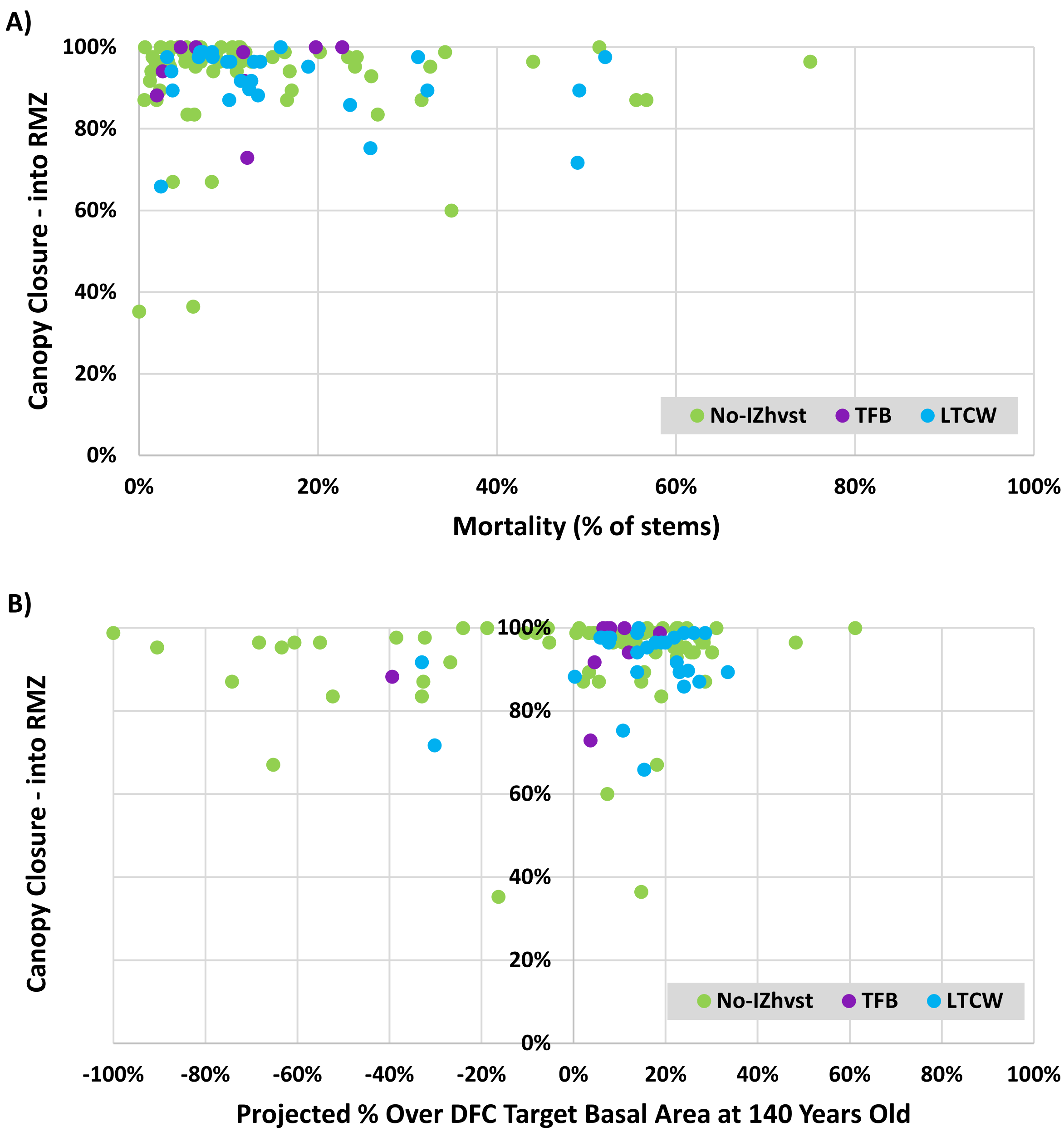


Figure 33. Canopy closure relationships with post-harvest mortality (A) and projected basal area at stand age 140 as a percentage of the DFC target basal area (B).

7.3.3 Comparison with Shade Targets

Ninety percent (95) of all sites and 89% of the sites with Inner Zone harvest met their respective canopy closure requirements (Table 14;Figure 34). Only one TFB site and three LTCW sites did not meet their respective shade targets. The remaining seven sites that did not meet their shade requirements had no harvest in the Inner Zone. Two of the eleven sites that did not have enough canopy closure at Yr3-6 (one LTCW and one with no-IZ-harvest) had greater than 30% windthrow loss. Of the fourteen sites with high mortalities, only four failed to meet the stream temperature shade nomograph target. This is probably because most of the high mortality sites (12 out of 14) were on small streams, whereas most of the buffers that did not meet their shade targets were on large streams (7 of 11). We cannot tell how wide those streams are because channel width data were not collected but, as noted previously, a few of the sites in this study were on very wide channels that were open as a result of mass wasting, river sinuosity, and newly-formed low terraces. Stand species composition at the larger-river sites was often different than at the rest of the study sites. Only one of the sites that did not meet its shade target was also not projected to meet the age 140 DFC basal area target.

Figure 34. Canopy Closure for each site plotted versus elevation and displaying the western Washington temperature nomograph targets

The evaluation of canopy covers relative to the minimum target for effective shade in Schedule L-1 of the FFR (Appendix N of the FP HCP) showed that 89% of the sites (94) met or exceeded the L-1 target minimum (lower section of Table 14). Also, 89% of the sites with Inner Zone harvest met that L-1 minimum. The sites with canopy closure below the target were evenly distributed across variants; only Variant 1 stood out (weakly) from the others (Table 14). The sites that did not meet the L-1 target minimum were not always the same ones that did not meet their nomograph target.

Table 14. Proportion of sites in each prescription variant that met their respective shade targets using FPB Manual Section 1 nomograph method and the proportion that met the minimum of the effective shade target range (85%) specified in Schedule L-1 of the FP HCP.

	Prescription Variant											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Site Class	**II**				**III**				**IV**	**V**		
Channel Sz	**L**		**S**		**L**		**S**		**L**	**L**	**S**	
IZ Trtmt	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No	
Total # of Sites	**10**	**11**	**10**	**8**	**10**	**9**	**10**	**9**	**9**	**10**	**10**	**106**
# of Sites Meeting Nomograph Target	9	10	10	8	9	8	10	7	6	10	8	**95**
Proportion Meeting or Exceeding Nomograph Target	**90%**	**91%**	**100%**	**100%**	**90%**	**89%**	**100%**	**78%**	**67%**	**100%**	**80%**	**90%**
# of Sites Meeting L-1 Target Minimum	7	10	9	8	9	8	10	7	7	10	9	**94**
# of Sites that did NOT meet L-1 Target Minimum	3	1	1	0	1	1	0	2	2	0	1	
Proportion Meeting L-1 85% Target Minimum	**70%**	**91%**	**90%**	**100%**	**90%**	**89%**	**100%**	**78%**	**78%**	**100%**	**90%**	**89%**

7.4 Shade Discussion

The current high levels of shade (average of 89% for all variants) in the study streams are consistent with the high shade levels observed in the stem-exclusion phase of early-to mid-successional even-aged riparian forests investigated in other Washington and Oregon studies. Warren et al. (2013) reported mean canopy covers over small fish-bearing streams ranging from 88% to 96% with standard deviations of ~4% from riparian buffers in 30 to 60 year old second-growth forests. These contrasted with values of 83% to 89% in adjacent old-growth forests. Allen and Dent (2001) reported shade (based on hemispherical photography) values between

83 and 95% over fish-bearing streams in nine unharvested forest stands 30 to 120 years old in coastal Oregon.

Many of the sites in this study on Type F streams have riparian stand structures and compositions that are comparable to those on non-fish (Type N streams), because many sites on the smaller streams were designated as Type N streams and harvested to the streambank under the previous forest practice rules. CMER studies by Schuett-Hames et al. (2012), McIntyre et al. (2021), and Ehinger et al. (2021) all reported mean canopy closures of around 90% (85% to 100%) on pre-harvest and unharvested reference riparian buffers on headwater non-fish-bearing streams. Immediately after timber harvest, Ehinger et al. (2021; Figure 4A-1) reported the canopy closure locations with >75 ft buffers, wider than the combined Core and Inner Zones of Site Class IV and V (Rxs 9, 10, and 11) buffers in this study, maintained mean shade values over 80%, like our sites on those prescriptions. McGreer et al. (2012) also found that 75 ft. buffers did not significantly alter the amount of solar radiation reaching the stream for eastern Washington Type F stream buffers.

The positive correlations observed between canopy closure and stand density were expected, as stand density is often cited as an important predictor of shade. However, those studies have only investigated stands with stem densities of up to about 150 trees/acre. Most of the stands in this study (77%) had stem densities that exceed that value. The small negative relationships between canopy closure and stand age, tree height, and mean diameters could reflect the maturation of those stands and the attendant formation of gaps and wider tree spacing in them as described by Oliver and Hinckley (1987). It also could reflect that more light (sky) can be seen in the densiometer through the trunks below the canopies of larger trees after the upland harvest, especially in dense stands where the canopies are small and high (Oliver and Larson 1990) so that more trunk is exposed. Allen and Dent (2001) also investigated variations in stream shade with stand characteristics. Their findings from the Oregon Coast Range also showed no relationship between shade and stand density or basal area for unharvested sites with higher densities that overlap the densities of this study's stands.

We are confident the shade values we report are reliable but recognize there is uncertainty about potentially overestimating when values exceed 80%, as indicated by Allen and Dent (2001) and McIntyre et al. (2021). Therefore, we compared our findings to the FP HCP target range minimum but did not attempt to report whether sites were above or below the 90% upper end of the effective shade target using our canopy closure data.

The validity of the State of Washington stream temperature nomograph method for determining necessary stream shade levels has often been questioned for relying so heavily on elevation and riparian canopy closure as predictor variables for stream temperature. However, stream temperature models developed and tested throughout this state and the Pacific Northwest identify elevation and canopy closure as two of the most important predictors of peak stream temperature. Isaak et al. (2017) developed NorWeST spatially-distributed stream network (SSN) models of mean August stream temperatures for 23 subregions of the Pacific Northwest, and in all but the California Coast model, elevation was the number one predictor. Riparian canopy cover was significant in 18 of the models, and the authors noted that, based on prior research, it likely would have been much more significant if higher-resolution and more temporally-specific riparian cover data were available at the scales needed for the NorWeST model. Siegel et al. (2023) developed a more ambitious model of daily stream temperatures across the Pacific Northwest using a Generalized Additive Model framework. They also found elevation and % canopy cover in the 100-m streamside buffers (based on the National Land Cover dataset) were two of the four most important non-temporal spatial model covariates.

A 2005 study tested the Washington nomograph method and original nomographs developed for eastern Washington against a robust data set for 305 sites (Glass 2005). That analysis found that the existing nomograph underestimated the amount of canopy closure required to meet the 16°C and 18°C temperature targets 10.5% and 9.2% of the time, respectively. Both the 16°C and 18°C nomographs overestimate the amount of shade needed more often than they underestimate shade.

7.5 Shade Conclusions

Canopy closures in RMZs on Type F and S streams in western Washington 3 to 6 years after harvest are very high. Medians and means for all prescriptions are over 89% and with interquartile ranges of 3 to 13% for most prescriptions and 21% for one (not statistically significant). None of the prescriptions was significantly different from the others and the Inner Zone harvest prescription made no apparent difference to shade retention. 89% of the sites exceeded the FP HCP target minimum of 85% shade and 90% of sites exceeded the target shades specified by the canopy closure shade-elevation nomograph. Sites that did not meet their shade targets tended to be either very large streams or small streams that experienced high buffer mortalities. The current high levels of shade (weighted median of 96.4% for all variants) in the study streams are consistent with the high shade levels observed in the stem-exclusion phase of early-to mid-successional even-aged riparian forests investigated in other Western Washington and Eastern Washington CMER studies (Cupp and Lofgren 2014; Schuett-Hames and Stewart 2019; Schuett-Hames and Stewart 2021).

Stem density, which ranged from 50 to 850 trees per acre, was the stand characteristic most highly correlated with canopy closure (r = .035; P < .01), but high variability at lower stem densities (i.e., < 300 TPA; Figure 32) confounded the ability to use it to predict canopy closure. Also, Post-harvest mortality was not a good predictor of shade levels; the latter is likely due to most mortality occurring in the Inner Zone (farther from stream) compared to the Core Zone. Despite high mortality on narrow Variant 11 buffers, canopy closure remained higher than 85%.

Chapter 8. Soil Disturbance and Sediment Delivery

8.1 Sediment Introduction

Sediment input to streams is an important management issue in the Pacific Northwest due to potential effects on water quality, fish and other aquatic life. Sediment input to streams in forested watersheds in the Pacific Northwest occurs from a suite of processes including soil creep, tree throw, landslides, surface erosion, and stream bank erosion (Roberts and Church 1986). The rates and processes of sediment production in forested watersheds vary greatly due to differences in tectonic history, geology, soils, and climate (Swanson et al. 1987). Mass wasting and surface erosion associated with forest roads and timber harvest practices can increase sediment input (Reid and Dunne 1984). Disturbance associated with timber harvest in or adjacent to riparian management zones can affect sediment supply due to increases in tree throw and root-pit formation, exposure of soils due to harvest or yarding activities, and bank erosion or mass wasting due to loss of root strength after timber harvest (Swanson et al. 1987).

The most likely source of increased sediment delivery associated with the westside Type F riparian prescriptions appears to be the potential for increased tree throw due to wind exposure in buffers after harvest of adjacent timber (Grizzel et al. 2000; Liquori 2006). Yarding corridors, narrow swathes cut through the buffer in order to transport logs suspended by cables to the other side of the stream, are another possible source of sediment delivery. However, since riparian vegetation and woody debris on the forest floor are effective in limiting the movement of soils exposed by windthrow, only root-pits in close proximity to the stream are likely to deliver sediment, and the research suggests that sediment input from tree throw is limited (Grizzel and Wolff 1998; Schuett-Hames et al. 2012). An increase in sediment delivery due to soil disturbance or mass wasting associated with timber harvest and yarding activities within the RMZ was believed unlikely due to the width of the no harvest zone (50ft). Additionally, the vegetation and wood on the forest floor helps limit the movement and delivery of sediment (Rashin et al. 2006; Lakel et al. 2010). The wide no-harvest zone also makes it unlikely that riparian management practices themselves result in an increase in bank erosion due to loss of root strength, however bank erosion rates can increase due to changes in stream flow or mass wasting events from upstream areas. Based on findings in previous CMER studies, we expected that sediment delivery would be low, and if present at all, would be most evident at locations experiencing windthrow where the thrown trees were near the stream channel.

8.2 Sediment Methods

Surface erosion within the core and inner zone, and potential sediment delivery to the stream, were assessed by examining the stream bank and RMZ using methods based on Litschert and MacDonald (2009). Surveyors looked for stream-bank disturbance or soil disturbance features caused by harvest or yarding activity that had a surface area ≥ 10 sq ft (1 m^2). Surveyors measured and recorded data only on the areas of a disturbance feature that fell within the Core and Inner Zones of the study reach and disregarded any part of the disturbance that fell beyond these boundaries. Data attributes included surface area of the disturbed zone, distance to bankfull edge, observed sediment delivery to stream, and specific harvest-based cause of the disturbance.

Evidence of soil disturbance, erosion, and sediment delivery was assessed qualitatively. Because no erosion or sediment delivery was observed (all values were zero for all sites), there were no analyses to perform related to this riparian function.

8.3 Sediment Results

No evidence was observed of harvest-based soil disturbances larger than 10 ft^2 (1 m^2) or any length of eroding streambank in any of the study reaches three to six years after harvest (Table 15). No prescriptions had results markedly different than the others.

Table 15. Soil disturbance and streambank erosion findings. No sites showed evidence of sediment erosion at the time of sampling (3 - 6 years post-harvest).

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	Large		Small		Large		Small		Large	Large	Small
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ+IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Variant	1	2	3	4	5	6	7	8	9	10	11
Soil Disturbance Area (ft^2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Streambank Erosion {ft}	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

8.4 Sediment Discussion

The expectation that we would find no or little surface or streambank erosion was met. Our evaluation of soil disturbance and sediment delivery was based on visual observations during the summer season when vegetation covered much of the ground and streambanks. Some erosion areas could have been hidden by this vegetation. It is also possible there was some amount of soil disturbance in the early post-harvest period, but by the time of data collection, no evidence was present in or near the streams. Sixteen Core Zone trees were identified as having died due to erosion or flooding (Table 9), which suggests there could have been some soil disturbance and sediment delivery. There also is reason to believe there could have been soil disturbance and consequent inputs immediately after the few high-windthrow events where the blowdown reached the trees adjacent to the channel.

Research on soil disturbance and input to streams under current forest practices rules in Washington has been largely conducted on headwater, non-fish-bearing streams (Rashin 2006, Jackson et al. 2007, Schuett-Hames et al. 2012), where small amounts of soil disturbance and evidence of sediment delivery were observed. Rashin et al. (2006) found that excluding timber harvest activities within at least 10 meters of streams and outside of steep inner gorge areas was the most effective way to prevent sediment delivery. They also observed some post-harvest sediment delivery from riparian leave trees that fell over was common during the first two years after harvest. Schuett-Hames et al. (2012) noted that the only evidence of sediment input tended to come from root pits associated with windthrown trees near the channel (average 8.6 ft) and was correlated with pit size. The formation of root pits was highest in 50-foot riparian buffers and during the first three years post-harvest. Other harvest-related soil disturbance was negligible in the 50-foot buffers but exceeded target levels in the 30-foot clearcut equipment limitation zones [portions of Type N stream length where all trees may be harvested but where harvest equipment is to remain farther than 30 feet from the stream channel]. The mean percentage of equipment limitation zone area showing soil disturbance was 6.2% in the clearcut patches versus 0.3% in the 50% buffer portions of the riparian zones.

The CMER Hard Rock study of Type N riparian buffer effectiveness in competent lithologies found little sediment delivery to streams despite high quantities of windthrown trees, both before and after timber harvest (McIntyre et al. 2018). 7 to 11 percent of the 4 to 7 overturned buffer trees (per hectare per year) delivered sediment to streams. Other surface erosion in riparian buffers was very low and did not differ from that in unharvested reference riparian zones. The Soft Rock study (Ehinger et al. 2021) of Type N riparian buffer effectiveness in incompetent lithologies found that although there was sediment input from overturned riparian trees, the quantities of sediment entering the stream from those sources was dwarfed by that contributed by a single mass wasting feature upstream.

Other studies investigating modern forest practices, though not Forests and Fish rules in Washington, have had mixed findings. For example, MacDonald et al. (2003b) did not find either channel instability or significant point sources of sediment along channels with 20-meter buffer strips. Reid and Hilton (1998) did find significant inputs (0.1 to 1 m^3 per kilometer of main-stem channel bank) due to windthrow root pits related to a large storm in northern California.

The low number of fallen trees attributed to bank erosion or stream-adjacent windthrow and the lack of evidence for sediment delivery to streams by six years after harvest in this study are consistent with those of the Type N studies and suggest that even initial post-harvest sediment generation and delivery were likely lower than that found in the Type N stream buffer areas. The lack of any evidence found in the 106 sites of this study suggests that neither soil disturbance nor chronic sediment delivery to the channels is a widespread problem associated with any of the Type F riparian prescriptions in this study. A narrower Core Zone, in conjunction with the other RMZ zones reducing windthrow of the Core Zone trees, might function as well as a 50' wide zone with regard to preventing erosion into the stream channel. If any future studies include narrower Core Zones, sediment delivery and erosion could be included as monitored variables.

8.5 Sediment Conclusions

No streambank erosion or sediment input to stream channels from overland, non-road related sources was evident, regardless of whether there was harvest in the Inner Zone. There was no evidence that any of the Type F riparian prescription variants had destabilized stream banks with sediment delivery in the first three years after harvest, although seven trees were recorded as having fallen due to erosion. The 50-foot no-cut Core Zones plus any of the Inner Zone widths, along with limitations on yarding corridors, in all the western Washington Type F/S prescriptions appeared to be adequately applied at all sites. Because our sites were evaluated 3 to 6 years after the timber harvest, we cannot know for certain that no sediment was contributed between the harvest and our data collection but any erosion that occurred did not persist. Although sediment delivery to fish-bearing streams resulting from timber harvest activities has been a problem in the past, the FFR riparian buffers on the fish-bearing streams in this study appear to have prevented chronic sources of sediment to those streams.

Chapter 9. Conclusions

The following section highlights specific findings related to each of the study questions.

9.1 Riparian stand conditions

9.1.1 What are the riparian stand conditions associated with each of the prescriptions in the early (3 to 6 year) post-harvest period?

- Riparian buffer stands were generally young, small, dense, and dominated by conifer in the stem exclusion phase of development.
- The weighted median (and range) for residual site buffer stem density, basal area density, and QMD 3 to 6 years after harvest were 209.2 trees/acre (range: 47-846), 209.3 ft^2/acre (range: 57-406), and 13.8 inches (range: 8.1-26.0). The weighted median relative density was 53 (range: 14-113) (Table 6).
- Most buffers had between three and seven different tree species among trees larger than 4" in diameter.
- The conifer fractions ranged from 0 to 100% by both number of trees (weighted median = 83%) and basal area (weighted median = 87%).
    - The dominating species were most frequently western hemlock and/or Douglas-fir.
- Seventy percent of the buffers were more than 80% conifer. Half of the sites were over 90% conifer and nearly 20% of sites were 98% conifer. The high-conifer sites tended to have low species richness.
- There was high variation in stand structure metrics other than conifer percentage within prescriptions, but large overlap among prescriptions.
- The site class assigned to RMZs on a floodplain/low terrace may be a poor predictor of stand productivity given the heterogeneous topography and high potential for river associated disturbances.

9.1.2 How do these vary between sampled variants with and without Inner Zone harvest?

- There were pre-harvest differences in species composition between sites that had and did not have Inner Zone harvest, and those differences persisted after harvest. Both of these differences are consistent with the requirements to qualify for an Inner Zone harvest prescription.
    - Core Zones in sites that received Inner Zone harvest had higher basal area than those that did not receive Inner Zone harvest.

- Per the requirements for conducting an Inner Zone harvest, sites with Inner Zone harvest are associated with a high percentage of conifers whereas sites where no Inner Zone harvest tended to have higher percentages of broadleaf species.

9.2 Mortality and Windthrow

- Overall mortality was 13.8% of the live trees in the first 3 to 6 years after harvest, and windthrow was by far the dominant mortality agent.
    - Site mortality ranged from 0% to 75% with a weighted median of 8%.
    - The only site with no mortality was a sparsely-stocked Type S river buffer in Site Class IV with large trees.
- The (weighted) median annual mortality rate calculated from mortality that occurred during the early post-harvest (3 - 6 year) period was estimated to be somewhere between 1.4% and 2.8%, depending on the number of years since harvest. Site values ranged from 0% to 37% per year.
- The dominant mortality agent was windthrow (76% of all tree mortality), followed by Stem exclusion/suppression (9% of all tree mortality) and "Unknown". (Table 9)
- Fourteen sites (13%) had high total mortalities (>= 30% or more of the tree stems).

9.2.1 What are the magnitude and distribution of windthrow?

- Windthrow mortality was 10.5% of the IPH live trees in the first 3 to 6 years after harvest.
- Windthrow mortality at individual sites ranged from 0 to 73% with a weighted median value of 5.9%.
- Nine sites (8.5%) had high windthrow values (>= 30%).
    - Eight of the high windthrow sites were young, unthinned stands on small streams at low elevations (Figure 19).
- Windthrow was higher on Small (<10 feet wide) streams than on Large streams (Figure 17).
- Windthrow mortality as a percentage of initial standing trees (and BA) was higher in Inner Zones than in Core Zones for most sites (Appendix B-3).
    - High windthrow sites (>=30% mortality) lost trees equally from both zones.

9.2.2 How do these vary between the study sites with and without Inner Zone harvest?

- The highest windthrow occurred on sites that had no Inner Zone harvest.
    - These were also sites with young stands on small streams.
- Buffers harvested with the Thin From Below treatment (DFC Option 1; N=9) experienced lower windthrow severity than other prescription variants

- The percentage of sites experiencing windthrow was similar for all the IZ harvest treatment categories (TFB, LTCW and No-IZ).

9.2.3 How does stand structure relate to the observed windthrow?

- High mortality (>=30%) predominantly occurred in small streams with RMZs composed of 35 to 50 year old stands (Figure 19).

9.2.4 What are the relative influences of differences in site conditions and geographic location on windthrow seen in this study?

- The highest mortalities occurred along the western coastal area of the state at sites that are exposed to the southwest storms that dominate weather in western Washington (Figure 18).
- The highest windthrow sites were at low elevations (Figure 19-B).
- As noted previously, windthrow occurred more frequently and more intensively on small streams.

9.3 DFC target

9.3.1 What proportion of sites are on trajectory to meet DFC target of 325 ft2/acre of basal area at a stand age of 140 years?

- Seventy-five percent of all buffers in this study were projected to meet the DFC target of 325ft^2/acre by a stand age of 140 years old (Table 11).

9.3.2 How does that vary between sites with and without Inner Zone harvest?

- Ninety-two percent of the buffers that had an Inner Zone prescription applied remained on track to meet the DFC target, despite experiencing heavy windthrow at several sites, whereas only sixty-seven percent of the sites that had no Inner Zone harvest were on track to meet the DFC target (Table 11).
    - Comparing prescriptions in Site Classes II and III, which had both IZ harvest and no-IZ harvest prescriptions, fifty-two percent of the sites without IZ harvest were on track to meet DFC versus ninety-two percent of sites with IZ harvest.

- The DFC harvest options generally appear to be leaving stands that will meet the desired future conditions by the time the stands reach 140 years old. The DFC Inner Zone harvests did not diminish that trajectory in over 90% of the cases where they were conducted. Windthrow magnitude and incidence rate was similar in No-IZ harvest and

LCTW sites and the magnitude was lower for TFB prescriptions (n = 9). At the IZ harvest sites that were not projected to meet the DFC target, the shade targets were still met in all but one instance.

9.4 Riparian functions

9.4.1 What level of the following riparian functions is associated with the prescriptions 3 -6 years after harvest, and how do those functions vary between study sites with and without Inner Zone harvest?

Large wood recruitment (and recruitment potential)

- 10.5% of the initial post-harvest standing trees fell and 40% of those contributed wood to the stream channel ("recruited").
- Despite treefall occurring nearly equally between the Inner Zones and Core Zones, Core Zone trees accounted for approximately 80% of the trees that recruited to the stream channel (in and over-channel).
- Windthrow was the dominant mortality agent and wood recruitment was highly correlated with windthrow.
- The weighted median instream wood recruitment at sites was 1.0 pcs/100' (2.8 ft^3/100') and ranged from 0 to 25 pcs/100 ft (0 to 91.6 ft^3/100'). Many sites received no wood inputs.
- The (quadratic) mean dbh of trees contributing LW was 12", and the mean in/over-channel diameter of the recruited LW was 6.8 inches (weighted median 6.9; max 23") (Table A-5). The mean length of recruited LW in or over the channel was 8.7 feet (median 6.1; max 54 ft).
- The retention of a fixed-width Core + variable-width Inner Zone buffer that varied by site class and stream width category resulted in lineal stand densities that had a weighted median about 55 buffer trees (Core and Inner combined) per 100 feet of RMZ stream channel length in all variants/site classes immediately after harvest and 48 trees/100 ft 3 to 6 years later.
- Tree height estimates show how the current small size of riparian trees is limiting large wood recruitment. Only trees in the Core Zones and nearer portions of the Inner Zones are tall- and close enough to provide LW of minimal functional size to the stream.
- The combination of small sizes of the trees and the wide riparian buffer zones resulted in low input of wood that meets the key piece minimum sizes for their respective stream sizes at most sites. Some trees can input wood that meets the minimum criteria for Large Wood.

- The narrow (60 – 68 ft Core + Inner) Site Class V buffers are an exception, and the heights of trees from those buffers already exceed the Inner buffer width and have trees large enough to provide structural large wood on small streams from throughout the buffer.
- Because the buffer in Variant 11 is narrow, a higher proportion of the fallen trees recruited to the stream channel than from wider buffers.

Shade (canopy closure)

- What level of shade is associated with the RMZs left by the various prescriptions 3 – 6 years after harvest?
  - Canopy closures in RMZs on Type F and S streams in western Washington 3 to 6 years after harvest are very high, with a weighted median value of 96.4% (range: 35% - 100%).
  - Medians and means for all prescriptions are over 89%
  - 89% of the sites exceeded the FP HCP target minimum of 85% shade and 90% of sites exceeded the target shades specified by the canopy closure shade-elevation nomograph. Sites that did not meet their shade targets tended to be either very large streams or small streams that experienced high buffer mortalities.
  - The current high levels of shade (average of 89% for all variants) in the study streams are consistent with the high shade levels observed in the stem-exclusion phase of early-to mid-successional even-aged riparian forests investigated in other Western Washington CMER studies (Schuett-Hames and Stewart 2019; Schuett-Hames and Stewart 2021).
- What is the magnitude of shade variability within and differences among prescription variants?
  - Interquartile ranges were 3 to 13% for most prescriptions and 21% for one (not statistically significant).
- Are there any prescriptions for which either is markedly different than for the others?
  - None of the prescriptions was significantly different from the others
- How does shade differ between sites with and without Inner Zone harvest?
  - The Inner Zone harvest prescription made no apparent difference to shade retention.
- What are effects of windthrow and residual stand structure on stream shading provided by the RMZs?

- Post-harvest mortality was also not a good predictor of shade levels. Despite high mortality on many narrow Rx 11 buffers, canopy closure remained higher than 85% on all but one, which was 60%. We hypothesized that impacts of windthrow had the potential to be especially detrimental to riparian functions provided by narrow buffers for Site Classes IV and V, however that was not generally supported by these results. While windthrow was high for the Site Class V - Small Stream prescription (Rx 11), the shade remained high afterward (Figure 33; Figure 17-A; Figure 31).
- There were nine sites that had canopy closures of less than 80%. All had stand densities below 250 trees per acre (Figure 32). While stem density was the stand characteristic most highly correlated with canopy closure and ranged from 50 to 850 trees per acre, it was not a good predictor of the occurrence of low canopy closure.

Sediment Delivery

No streambank erosion or sediment input to stream channels was evident from overland, non-road related sources, regardless of whether there was harvest in the Inner Zone. There was no evidence that any of the Type F riparian prescription variants had destabilized stream banks with sediment delivery in the first three years after harvest, although seven trees were recorded as having fallen due to undercutting of the stream bank. The 50-foot no-cut Core Zones plus any of the Inner Zone widths, along with limitations on yarding corridors, in all the western Washington Type F/S prescriptions appeared to be adequately applied at all sites. Because our sites were evaluated 3 to 6 years after the timber harvest, we cannot know if sediment was contributed between the harvest and our data collection. Our findings indicate that FFR riparian buffers on the fish bearing streams in this study appear to have prevented chronic sources of sediment to those streams.

9.5 Implications for Follow-on Study

The findings from this study are that none of the RMZ prescriptions investigated stand out as greatly different from the others and suggesting they should be the focus of a more intensive study. All prescriptions have similar findings, within the large variabilities observed. This finding was not expected, is important, and will be very helpful when planning that study. The variabilities in the various stand and function metrics will be used in the design of that and other studies of RMZs.

9.6 Study Scope of Inference and Limitations

The scope of inference is limited to the eleven most commonly implemented harvest prescriptions as represented by the randomly selected study sites from each prescription in the sample frame. Given the elimination of confounding factors in the site selection, the approximate balance in sample sizes among prescriptions (strata), and the appropriate selection of prescriptions to use in each comparison, we can have high confidence in the comparative findings of riparian stand conditions and functions among the prescriptions sampled. However, extrapolation of the findings to the greater population of Type F and S streams with RMZs should be treated with caution because sample size was relatively small and not inclusive of the wide variability of channel/valley morphologies where Type F and S RMZs are implemented. We would have low confidence in making inferences about conditions in unsampled prescriptions, though we do know that the ones not sampled are rarely applied and therefore must represent a small portion of FFR stream buffers. However, we also do not know how the population of FPA prescriptions relates to stream length on the FP HCP landscape and at this point are unable to estimate that.

Importantly, we cannot attribute cause of any given results to a treatment effect based on the data from this study. Although we can say there were differences among the RMZs after applying some prescriptions, we do not have the sampling design and data to be able to state that any differences are due to the prescription applied. On the other hand, when harvest prescriptions leave functioning buffers that meet a given target of the FP HCP, then we *can* say the application of a prescription was not responsible for the level of function falling below that target.

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Appendix A. Site Variables and Data

The following tables compile the characteristics and measured parameters at each site. Sites are organized by prescription variant.

Table A-1 describes the attributes and variables measured and calculated for each site.

Table A-2 shows how calculated metrics are derived.

Table A-3 presents general attributes of each site, including whether it was selected for the resurvey.

Table A-4 presents riparian buffer stand characteristics prior to harvest (for sites with Inner Zone harvest, where DFC data are available), immediately post-harvest (IPH) and at the study sampling (Yr3) approximately three years post-harvest. IPH characteristics are calculated from sampled live tree, dead standing, and fallen tree data.

Table A-5 presents data on mortality, fallen trees, wood recruitment, and shade.

A-1. Variables Calculated for Each Study Site.

Table A-1. Variables calculated for each study site. "Yr3" refers to study survey, which ranges between 3 and 6 years post-harvest.

Topic	Variable	Definition and Time Frame
Site Attributes		
	Site ID	
	Prescription Variant	
	Site Class	As determined from DNR Site Class GIS layer
	Stream Width Category	Small (cw<10 ft) or Large (cw >= 10 ft)
	Inner Zone Treatment	No Harvest, LTCW (leave trees closest to water), or TFB (thin from below)
	Outer Zone Treatment	Type of harvest in the outer buffer zone
	Stand Age	Stand age at harvest For sites without IZ harvest, assessed by field crew by counting rings in cut stumps For Inner Zone harvest sites, by adding the years between the DFC run date in the FPA document and the estimated harvest year to the stand age reported by the landowner on the DFC data sheet
	Plot Length (ft)	300 ft for all sites, per our sample design
	Core Zone Width (ft)	50 ft for all sites, per Forests & Fish rule
	Core Zone Area (Acre)	Core Zone Width * Plot Length, converted to acres
	Inner Zone Width (ft)	Varies according to prescription variant
	Inner Zone Area (Acre)	Inner Zone Width * Plot Length, converted to acres
	Core + Inner Width (ft)	Total width of the Core and Inner Zones
	Core + Inner Area (Acre)	Total area of the Core and Inner Zones

Topic	Variable	Definition and Time Frame
Standing Trees (only those on the Species List)		
	YR3 Live TPA	# of live standing trees at sampling in YR3, per acre
	YR3 LiveBAPA	BA of live standing trees at YR3 sampling per acre
	YR3 Live QMD	Sqrt(Total basal area of live trees/Total # of trees at YR3/.005454)
	YR3 Live Count/100ft	# of live standing trees at YR3 sampling per 100' of stream length
	YR3 Live BA/100ft	BA of live standing trees at YR3 sampling per 100' of stream length
	YR3 Percent Conifer	Percent of total live trees and basal area at YR3 made up by conifer trees (two metrics)
	IPH Live TPA	Number of live trees per acre at IPH (calc as above)
	IPH Live BAPA	Live tree basal area per acre at IPH (calc as above)
	IPH Live QMD	Sqrt(Basal area/acre of live trees/TPA at IPH/.005454)
	IPH Live Count/100ft	Number of live trees per 100' of stream length at IPH Equals Live Count at Yr3 sampling + Mortality
	IPH Live BA/100ft	Basal area of live trees per 100' at IPH (calc as above)
	IPH Species Richness	Count of unique tree species present at IPH
	IPH Percent Conifer	Percent of total live trees and basal area at IPH made up by conifer trees (two metrics)
	IPH Dominant Species	Calculated by identifying the species having the most trees and the most basal area at IPH (two metrics)
	Mortality TPA	# of trees that were determined to have died in the early post-harvest period (between harvest and study survey), divided by the total number of standing live trees immediately after harvest (at IPH), per acre
	Mortality BAPA	Basal area of trees that were determined to have died in the early post-harvest period, per acre
	Mortality QMD	Sqrt(Total Mortality basal area/Total # of trees that died in the early post-harvest period between harvest and survey/.005454)
	Mortality Count/100ft	# of trees that were determined to have died in the early post-harvest period per 100' of stream length
	Mortality BA/100ft	Basal area of trees that were determined to have died in the early post-harvest period per 100' of stream length
	Mortality % IPH Live Count	# of trees that died in the early post-harvest period (between harvest and survey)/ # of IPH live trees
	Mortality % IPH Live BA	BA of trees that died in the early post-harvest period / BA of live trees at IPH
Fallen Trees and Broken Pieces		
	Fallen Count/100ft (all)	IPH-YR3
	Fallen BA/100ft (all)	IPH-YR3
	Fallen BAPA (all)	IPH-YR3
	Fallen TPA (all)	IPH-YR3
	Fallen DBH (all)	IPH-YR3
	Fallen Count/100ft (recruiting)	IPH-YR3

Topic	Variable	Definition and Time Frame
	Fallen # (>24" DBH)	IPH-YR3
	Fallen BA/100ft (recruiting)	IPH-YR3
	Fallen BAPA (recruiting)	IPH-YR3
	Fallen TPA (recruiting)	IPH-YR3
	Fallen DBH (recruiting)	IPH-YR3
Recruited Wood		
	Recruited wood pieces/100ft	# of pieces of wood that extends any length over or into the channel from all large pieces of wood in the riparian zone, expressed per 100 ft of channel, that was recruited in the early post-harvest period
	Recruited wood volume/100ft	Volume of wood that extends any length over or into the channel from all large pieces of wood in the riparian zone, expressed per 100 ft of channel, that was recruited in the early post-harvest period
	Recruited BFW LWD pieces/100ft	Number of wood pieces that have more than 4”x6’ in or over the channel/100 ft of channel that were recruited in the early post-harvest period
	Recruited BFW LWD volume/100ft	Volume of only pieces that have more than 4”x6’ in or over the channel/100 ft of channel that were recruited in the early post-harvest period
Shade		
	Shade1 (4-direction)	YR3
	Shade2 (toward buffer)	YR3
Abbreviations	**Definition**	
BA	basal area (ft^2)	
BAPA	basal area per acre (ft^2)	
DBH	diameter at breast height (in)	
QMD	quadratic mean diameter (in)	
TPA	trees per acre	
IPH	immediately post-harvest (these values are calculated/reconstructed)	
YR3	values collected at study survey, 3-6 years post-harvest	
IPH-YR3	change from immediately post-harvest to the time of study sampling (in the early post-harvest period)	

A-2. Methods and Equations Used to Calculate Metrics Used in Analyses

Table A-2. Methods and equations used to calculate metrics used in analyses

Metric	Calculation	Units
General		
Weighted Median	Calculated weights for values in each prescription by dividing the fraction of the total (estimated) population buffers in each prescription identified in the desktop analysis of Appendix C and Table 2 by the fraction of sample sites in that prescription $\textbf{Value Weight} = \left[\frac{\left(\frac{Rx\ segment\ count}{\sum segments}\right)}{\frac{Rx\ sample\ size}{\sum samples}}\right]\frac{1}{\sum samples}$ $= \left[\frac{\left(\frac{Rx\ segment\ count}{530}\right)}{\frac{Rx\ sample\ size}{106}}\right]\frac{1}{106}$ (DataStar 2017)	
Stand structure		
Stem density (TPA)	Live stem count divided by acreage (by Core and Inner Zone)	trees/acre
Basal area (BA)	Calculated basal area for each live tree using the formula: *basal area* (ft^2) *= 0.005454*dbh*^{2} *(inches).* Sum live tree basal area for each site (by Core and Inner Zone).	ft^2
Basal area per acre (BAPA)	Calculated basal area for each live tree using the formula: *basal area* (ft^2) *= 0.005454*dbh*^{2} *(inches).* Sum live tree basal area for each segment and divide by acreage (by core and inner zone).	ft^2/acre
Quadratic Mean [stand] Diameter (QMD)	Derived from the basal area per acre divided by the number of trees per acre (QMD = Sqrt(BAPA/TPA/.005454154)	inches
Stand Height	Applied established tree height equations (Table 12)to the diameters of dominant trees (DF, WH, Sitka spruce, western redcedar, red alder) and calculated average for the species that was dominant at each site.	ft
Curtis' Relative Density (RD)	Summation method (Curtis 2010): $RD_{sum} = 0.00545415 \times \sum (d_i^{1.5})/area$	RDxx (unitless index based on acres and diameter in inches)
Mortality		
Cumulative mortality as percent of initial live stem count	*Number of trees that died or fell since harvest divided by the calculated immediately post-harvest (=IPH) standing live tree count* *Post-Harvest Mortality Tree Count / (Post-Harvest Mortality Tree Count + Yr3_Standing Live Tree Count)*	%stems

Cumulative mortality as percent of initial live basal area	*tree basal area of trees that died in the studied post-harvest period/beginning live tree basal area* *Mortality_BA / IPH_BA*	%basal area
Mortality rate as percent of initial live stem count	Calculated as an annualized rate: *%count/yr = 1- ([ending live tree count/immediate post harvest live tree count]^[1/number of years in period])*	%stems/yr
Mortality rate as percent of initial live basal area	Calculated as an annualized rate: *%basal area/yr = 1- ([ending live tree basal area/beginning live tree basal area]^[1/number of years in period])*	%basal area/yr
Large wood recruitment		
LW recruitment rate by piece count	Calculated as a rate: LW pieces recruited/100m/yr = ([LW pieces/reach length in m]*100)/years in period	pieces/100 m/yr
LW recruitment rate by volume	Calculated as a rate: ([LW volume in m^3/reach length in m]*100)/years in period	m^3/100 m/yr
Shade		
Percent canopy closure- 4 directions (Shade1)	Sum the counts of obstructed points for each of the 4 readings at each station. Divide by 4 and multiply by 1.04. Average the station values to calculate the mean for each study reach. (Lemmon 1957)	% 4d canopy closure
Percent canopy closure-towards RMZ (Shade2)	Count the number of obstructed points (out of 17 possible) and multiply by 5.88. Average the station values to calculate the mean for each study reach. (Platts et al. 1987)	% RMZ canopy closure
Soil disturbance		
Erosion surface area	Sum the surface area (m^2) of sediment delivering erosion features, divide by study reach length in m and multiply by 100.	m^2/100 m
Trajectory to DFC		
BAPA at stand age of 140 yrs	Run DFC worksheet using live tree list for each study reach to obtain the projected basal area per acre at stand age of 140 years determine if basal area meets or exceeds DFC target (325 ft^2/acre at age 140). Calculate the proportion of segments in each strata projected to meet the target.	ft^2/acre
% by which BAPA-projected to exceed DFC performance target	(Projected BAPA_140 – target value of 325 ft^2/acre) / target 325 ft^2/acre	%
Proportion of sites projected to meet target	count overall sites projected to meet or exceed target / count of sites For overall count; sites with/without IZ harvest; and each variant	%

A-3. Study Site Characteristics.

Table A-3. Site characteristics and RMZ configuration. Darkly greyed out sites at the bottom are those that were discovered during analysis did not meet study requirements.

SiteID	Rx Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone Leave Trees	Stream Bank [River Rt, River Left]	Survey Date	Resurvey	Elev [ft]	Stand Age at Hvst	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
1a	1	II	large	No harvest	Dispersed	RR	8/15/2019		2518	47	50	78	128	0.882
1b	1	II	large	No harvest	Combo	RL	7/24/2019		567	75	50	78	128	0.882
1c	1	II	large	No harvest	Dispersed	RL	8/15/2019		1198	42	50	78	128	0.882
1d	1	II	large	No harvest	Dispersed	RL	5/28/2019	R	201	31.5	50	78	128	0.882
1e	1	II	large	No harvest	Combo	RR	7/24/2019		247	52	50	78	128	0.882
1f	1	II	large	No harvest	Dispersed	RR	8/13/2019		504	42	50	78	128	0.882
1g	1	II	large	No harvest	Dispersed	RL	8/22/2019		995	53	50	78	128	0.882
1h	1	II	large	No harvest	Combo	RL	7/31/2019		482	38	50	78	128	0.882
1i	1	II	large	No harvest	Combo	RL	7/23/2019		165	69	50	78	128	0.882
1j	1	II	large	No harvest	Clumped	RL	8/8/2019		1303	76	50	78	128	0.882
2a	2	II	large	LTCW	Xchnged4IZ	RL	6/11/2019		882	44	50	78	128	0.882
2b	2	II	large	LTCW	Clumped	RR	6/12/2019	R	1138	42	50	78	128	0.882
2c	2	II	large	LTCW	Clumped	RL	6/12/2019		1525	46	50	78	128	0.882
2d	2	II	large	LTCW	Dispersed	RR	8/7/2019		1740	41	50	78	128	0.882
2e	2	II	large	LTCW	Combo	RR	6/21/2019		1057	48	50	78	128	0.882
2f	2	II	large	LTCW	Dispersed	RL	8/21/2019		747	38	50	78	128	0.882
2g	2	II	large	LTCW	Combo	RR	8/2/2019		1309	59	50	78	128	0.882
2h	2	II	large	LTCW	Clumped	RR	6/18/2019		281	42	50	78	128	0.882
2i	2	II	large	LTCW	Clumped	RL	8/6/2019		1997	41	50	78	128	0.882
2j	2	II	large	LTCW	Clumped	RL	7/30/2019		1098	42	50	78	128	0.882
2k	2	II	large	LTCW	Clumped	RR	8/8/2019		2511	54	50	63	113	0.778
3a	3	II	small	No harvest	Dispersed	RL	7/17/2019		83	35	50	63	113	0.778
3b	3	II	small	No harvest	Dispersed	RR	5/29/2019		36	35	50	63	113	0.778
3c	3	II	small	No harvest	Dispersed	RL	5/30/2019		321	33	50	63	113	0.778
3d	3	II	small	No harvest	Dispersed	RL	5/29/2019		106	51	50	63	113	0.778
3e	3	II	small	No harvest	Dispersed	RL	8/7/2019		1674	37	50	63	113	0.778

SiteID	Rx Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone Leave Trees	Stream Bank [River Rt, River Left]	Survey Date	Resurv ey	Elev [ft]	Stand Age at Hvst	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
3f	3	II	small	No harvest	Combo	RR	5/24/2019		343	37	50	63	113	0.778
3g	3	II	small	No harvest	Dispersed	RR	5/28/2019		703	35	50	63	113	0.778
3h	3	II	small	No harvest	Combo	RR	5/14/2019		227	44	50	63	113	0.778
3i	3	II	small	No harvest	Dispersed	RL	5/30/2019		284	35	50	63	113	0.778
3j	3	II	small	No harvest	Dispersed	RR	8/7/2019	R	1218	41	50	63	113	0.778
4b	4	II	small	LTCW	Dispersed	RR	8/7/2019		1714	40	50	63	113	0.778
4c	4	II	small	LTCW	Clumped	RL	8/20/2019		559	72	50	63	113	0.778
4d	4	II	small	LTCW	Xchnged4IZ	RR	5/31/2019		1308	40	50	63	113	0.778
4f	4	II	small	LTCW	Combo	RL	8/16/2019		1473	42	50	63	113	0.778
4g	4	II	small	LTCW	Combo	RL	8/13/2019	R	496	40	50	63	113	0.778
4h	4	II	small	LTCW	Combo	RR	7/25/2019		356	40	50	63	113	0.778
4i	4	II	small	LTCW	Combo	RR	7/16/2019		679	41	50	63	113	0.778
4j	4	II	small	LTCW	Dispersed	RL	8/2/2019		467	56	50	63	113	0.778
5a	5	III	large	No harvest	Dispersed	RR	8/8/2019		1576	53	50	55	105	0.723
5b	5	III	large	No harvest	Dispersed	RL	7/31/2019		89	116	50	55	105	0.723
5c	5	III	large	No harvest	Dispersed	RR	7/17/2019		165	39	50	55	105	0.723
5d	5	III	large	No harvest	Clumped	RR	5/17/2019		372	43	50	55	105	0.723
5e	5	III	large	No harvest	Clumped	RR	7/9/2019		736	52	50	55	105	0.723
5f	5	III	large	No harvest	Combo	RR	8/14/2019		1124	42	50	55	105	0.723
5g	5	III	large	No harvest	Dispersed	RR	5/21/2019	R	88	37	50	55	105	0.723
5h	5	III	large	No harvest	Combo	RR	5/23/2019		212	39	50	55	105	0.723
5i	5	III	large	No harvest	Dispersed	RL	6/19/2019		387	46	50	55	105	0.723
5j	5	III	large	No harvest	Combo	RL	6/20/2019		1109	41	50	55	105	0.723
6b	6	III	large	TFB	Dispersed	RR	6/25/2019		691	45	50	55	105	0.723
6c	6	III	large	TFB	Dispersed	RR	5/2/2019		51	36	50	55	105	0.723
6d	6	III	large	TFB	Dispersed	RR	5/8/2019		213	50	50	55	105	0.723
6e	6	III	large	TFB	Dispersed	RR	6/4/2019		319	46	50	55	105	0.723
6f	6	III	large	TFB	Dispersed	RL	5/1/2019		165	43	50	55	105	0.723
6g	6	III	large	TFB	Clumped	RL	7/10/2019	R	468	52	50	55	105	0.723

SiteID	Rx Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone Leave Trees	Stream Bank [River Rt, River Left]	Survey Date	Resurvey	Elev [ft]	Stand Age at Hvst	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
6h	6	III	large	TFB	Clumped	RR	5/15/2019		393	42	50	55	105	0.723
6i	6	III	large	TFB	Clumped	RR	5/8/2019		196	47	50	55	105	0.723
6j	6	III	large	TFB	Clumped	RR	6/4/2019		305	41	50	55	105	0.723
7a	7	III	small	No harvest	Dispersed	RL	8/1/2019		157	30	50	43	93	0.640
7b	7	III	small	No harvest	Dispersed	RR	6/6/2019		403	41	50	43	93	0.640
7c	7	III	small	No harvest	Dispersed	RL	7/12/2019		163	44	50	43	93	0.640
7d	7	III	small	No harvest	Clumped	RR	6/20/2019		902	40	50	43	93	0.640
7e	7	III	small	No harvest	Clumped	RL	5/22/2019		673	43	50	43	93	0.640
7f	7	III	small	No harvest	Dispersed	RL	10/18/2018		74	41	50	43	93	0.640
7g	7	III	small	No harvest	Clumped	RL	7/23/2019		236	48	50	43	93	0.640
7h	7	III	small	No harvest	Clumped	RL	7/18/2019		308	53	50	43	93	0.640
7i	7	III	small	No harvest	Combo	RL	5/22/2019	R	345	38	50	43	93	0.640
7j	7	III	small	No harvest	Combo	RR	5/23/2019		159	43	50	43	93	0.640
8b	8	III	small	LTCW	Dispersed	RL	5/1/2019	R	545	52	50	43	93	0.640
8c	8	III	small	LTCW	Dispersed	RR	5/8/2019		197	36	50	43	93	0.640
8d	8	III	small	LTCW	Dispersed	RR	5/9/2019		311	50	50	43	93	0.640
8e	8	III	small	LTCW	Dispersed	RR	7/25/2019		246	40	50	43	93	0.640
8f	8	III	small	LTCW	Dispersed	RL	5/2/2019		313	38	50	43	93	0.640
8g	8	III	small	LTCW	Dispersed	RL	6/28/2019		888	39	50	43	93	0.640
8h	8	III	small	LTCW	Dispersed	RR	6/27/2019		1011	33	50	43	93	0.640
8i	8	III	small	LTCW	Clumped	RL	7/19/2019		330	57	50	43	93	0.640
8j	8	III	small	LTCW	Clumped	RL	7/9/2019		105	35	50	43	93	0.640
9a	9	IV	large	No harvest	Dispersed	RR	8/6/2019		3399	56	50	33	83	0.572
9b	9	IV	large	No harvest	Combo	RR	7/31/2019		455	51	50	33	83	0.572
9c	9	IV	large	No harvest	Clumped	RR	8/9/2019		2797	48	50	33	83	0.572
9d	9	IV	large	No harvest	Dispersed	RR	7/11/2019		456	49	50	33	83	0.572
9e	9	IV	large	No harvest	Clumped	RL	7/10/2019		308	49	50	33	83	0.572
9f	9	IV	large	No harvest	Dispersed	RR	7/30/2019	R	118	105	50	33	83	0.572

SiteID	Rx Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone Leave Trees	Stream Bank [River Rt, River Left]	Survey Date	Resurv ey	Elev [ft]	Stan d Age at Hvst	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
9g	9	IV	large	No harvest	Dispersed	RR	6/13/2019		2352	68	50	33	83	0.572
9i	9	IV	large	No harvest	Combo	RL	8/1/2019		2132	40	50	33	83	0.572
9j	9	IV	large	No harvest	Clumped	RL	7/19/2019		19	49	50	33	83	0.572
10a	10	V	large	No harvest	Clumped	RL	7/2/2019		2110	41	50	18	68	0.468
10b	10	V	large	No harvest	Dispersed	RR	7/11/2019		142	39	50	18	68	0.468
10c	10	V	large	No harvest	Dispersed	RL	6/7/2019		254	39	50	18	68	0.468
10d	10	V	large	No harvest	Dispersed	RR	6/5/2019		358	35	50	18	68	0.468
10e	10	V	large	No harvest	Dispersed	RR	4/30/2019		384	102	50	18	68	0.468
10f	10	V	large	No harvest	Dispersed	RL	7/19/2019		311	35	50	18	68	0.468
10g	10	V	large	No harvest	Clumped	RL	5/15/2019		169	45	50	18	68	0.468
10h	10	V	large	No harvest	Dispersed	RL	7/24/2019	R	316	71	50	18	68	0.468
10i	10	V	large	No harvest	Dispersed	RL	5/3/2019		235	36	50	18	68	0.468
10j	10	V	large	No harvest	Clumped	RL	7/3/2019		2430	50	50	18	68	0.468
11a	11	V	small	No harvest	Dispersed	RL	5/7/2019		148	35	50	10	60	0.413
11b	11	V	small	No harvest	Dispersed	RL	6/26/2019	R	424	33	50	10	60	0.413
11c	11	V	small	No harvest	Dispersed	RR	5/1/2019		276	40	50	10	60	0.413
11d	11	V	small	No harvest	Dispersed	RL	6/26/2019		261	42	50	10	60	0.413
11e	11	V	small	No harvest	Dispersed	RR	7/18/2019		321	36	50	10	60	0.413
11f	11	V	small	No harvest	Combo	RR	6/6/2019		813	45	50	10	60	0.413
11g	11	V	small	No harvest	Dispersed	RR	5/16/2019		171	42	50	10	60	0.413
11h	11	V	small	No harvest	Dispersed	RR	7/25/2019		358	40	50	10	60	0.413
11i	11	V	small	No harvest	Combo	RL	7/30/2019		481	47	50	10	60	0.413
11j	11	V	small	No harvest	Dispersed	RR	4/29/2019		404	35	50	10	60	0.413
4a	Re-assigned to variant 2 based on correction of channel width													
4e	Deleted; channel was reclassified to Type N based on water type modification prior to harvest; buffer is not Type F prescription													
6a	6	III	large	TFB	FPA under old DFC rule									
8a	8	III	small	LTCW	FPA under old DFC rule									
9h	9	IV	large	No harvest	data were collected from channel zone, not RMZ									

1

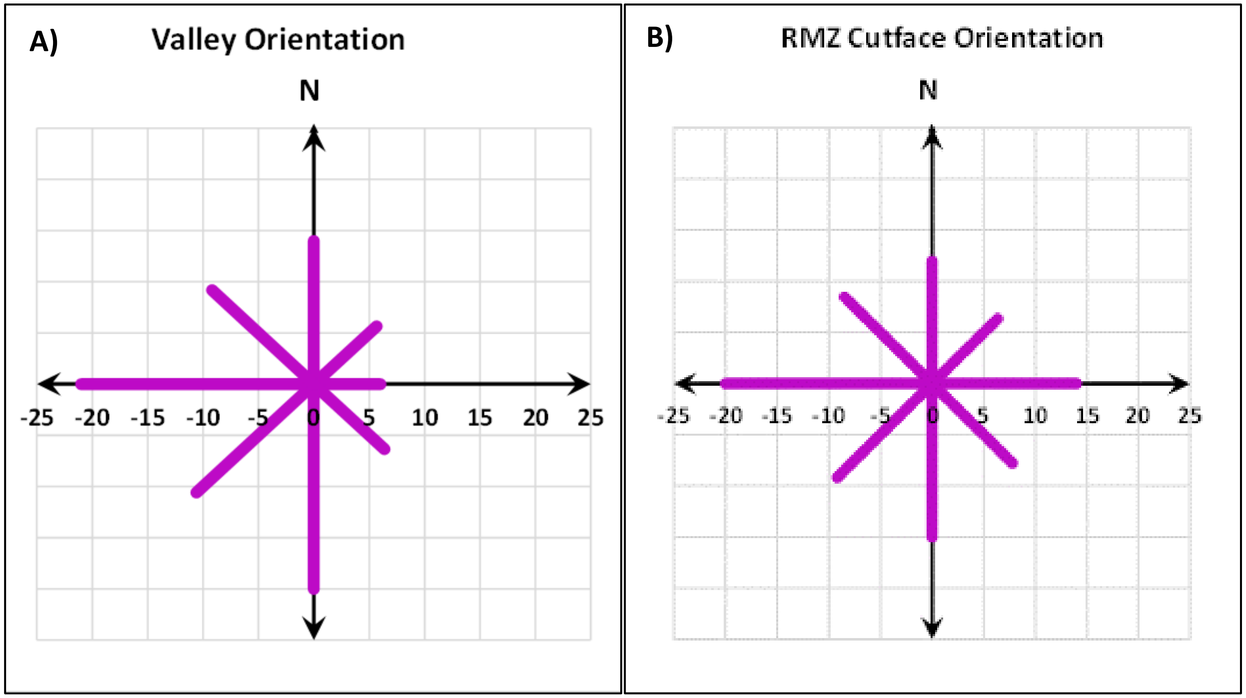


Figure A-3- 1. Site valley orientation (stream direction) (A) and RMZ Cut Face Exposure direction (B). The lengths of the rays indicate the number of sites and RMZ cut faces oriented toward each compass direction.

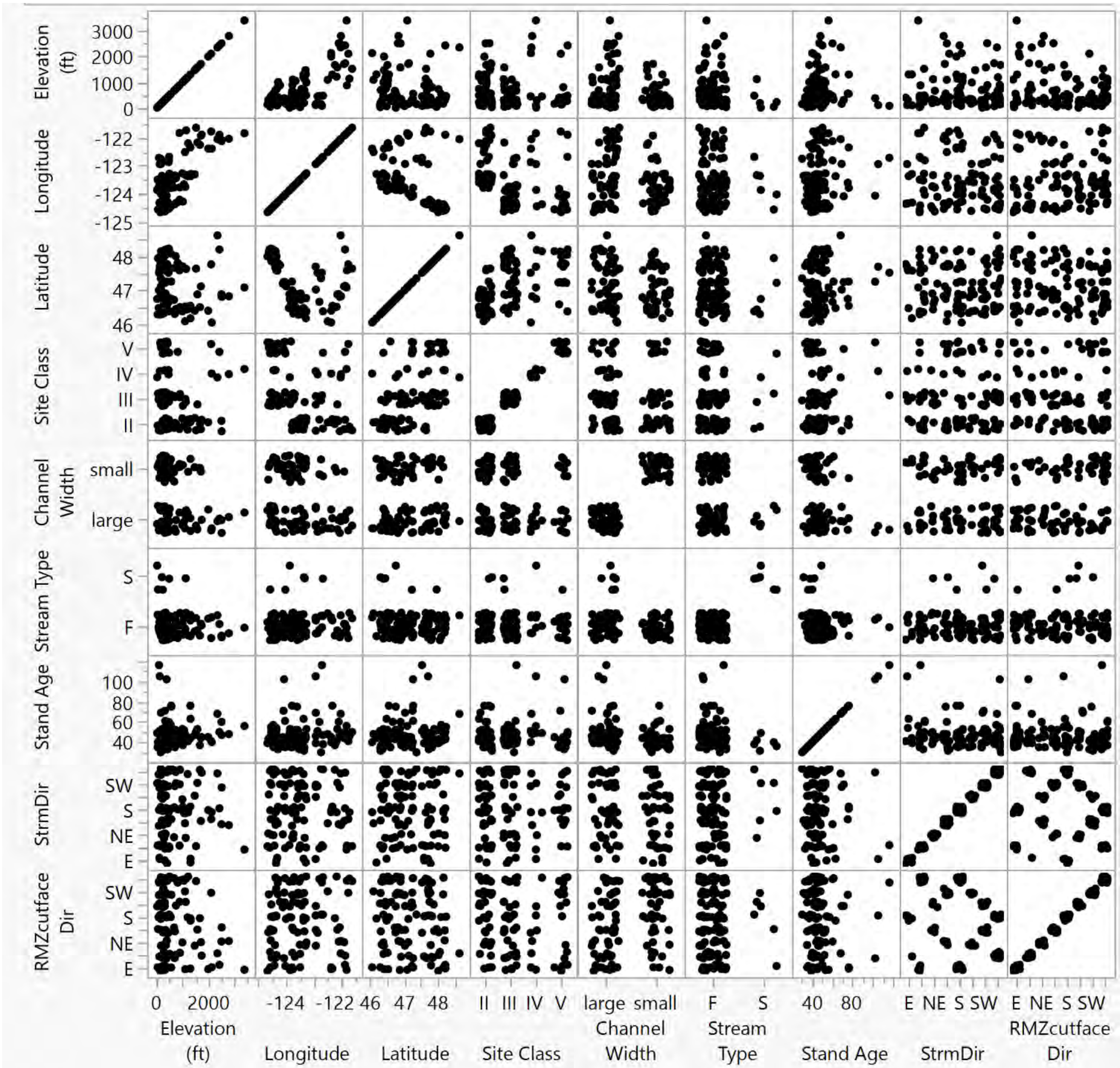


Figure A-3- 2. Crossplots of site characteristics.

A-4. Riparian Stand Characteristics

Table A-4. Riparian stand characteristics immediately post-harvest (IPH), and at survey date three to six years after harvest (Yr3).

SiteID	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer by BA	IPH RD	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	IPH Std Dev of Stem dbh [in]	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]	Yr3 %Conifer by BA	Yr3 RD	Avg RMZ Tree Height [ft]
1a	260	314.5	14.9	97%	78	PSME	4	5.5	231	305.3	15.6	98%	74	95
1b	110	175.5	17.1	57%	41	ALRU	6	6.9	103	171.2	17.4	55%	39	80
1c	295	251.5	12.5	95%	66	TSHE	4	4.9	279	241.5	12.6	95%	63	82
1d	151	183.7	14.9	35%	42	ALRU	5	8.0	145	179.9	15.1	36%	40	73
1e	175	223.9	15.3	64%	55	PSME	6	5.6	163	215.7	15.6	63%	53	81
1f	187	191.4	13.7	68%	46	PSME	7	7.2	186	189.8	13.7	68%	46	66
1g	177	258.0	16.3	26%	58	ALRU	5	8.2	161	246.7	16.8	25%	54	79
1h	329	202.3	10.6	81%	58	PSME	6	4.1	250	169.8	11.2	78%	47	68
1i	99	171.3	17.8	12%	39	ALRU	5	6.6	95	168.6	18.0	12%	38	85
1j	204	198.7	13.4	66%	49	TSHE	5	6.6	157	162.4	13.8	63%	39	72
2a	201	226.6	14.4	86%	59	PSME	5	4.0	169	204.6	14.9	84%	52	86
2b	345	320.7	13.1	99%	83	TSHE	4	5.5	301	294.9	13.4	99%	75	82
2c	278	305.1	14.2	93%	80	TSHE	4	4.1	250	281.8	14.4	93%	73	86
2d	175	231.1	15.6	92%	56	PSME	4	5.3	162	222.9	15.9	94%	54	77
2e	185	257.6	16.0	97%	62	TSHE	7	5.5	180	255.3	16.1	97%	61	95
2f	182	222.2	15.0	78%	57	PSME	4	4.2	176	220.8	15.2	78%	56	91
2g	200	188.2	13.1	49%	50	ALRU	5	4.7	177	178.8	13.6	48%	46	78
2h	180	213.4	14.7	100%	52	TSHE	5	6.3	162	202.5	15.1	100%	48	99
2i	378	234.2	10.7	89%	67	PSME	4	3.9	331	222.9	11.1	89%	63	71
2j	238	231.0	13.3	92%	61	PSME	4	4.6	222	227.2	13.7	92%	59	79
2k	533	365.0	11.2	99%	89	TSHE	5	4.6	466	350.5	11.7	99%	85	72
3a	217	176.5	12.2	88%	50	PSME	5	3.4	146	132.8	12.9	88%	37	78
3b	157	160.2	13.7	0%	41	ALRU	3	5.1	152	158.8	13.9	0%	40	76
3c	266	143.4	9.9	60%	41	TSHE	5	4.5	260	143.4	10.1	60%	40	74
3d	179	235.1	15.5	84%	56	TSHE	6	6.4	163	225.3	15.9	86%	53	99

SiteID	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer by BA	IPH RD	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	IPH Std Dev of Stem dbh [in]	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]	Yr3 %Conifer by BA	Yr3 RD	Avg RMZ Tree Height [ft]
3e	213	192.4	12.9	16%	52	ALRU	5	4.0	200	186.9	13.1	16%	50	77
3f	149	201.8	15.8	87%	49	PSME	7	5.1	139	197.3	16.1	87%	47	96
3g	243	191.8	12.0	49%	51	ALRU	7	5.1	216	179.1	12.3	47%	47	73
3h	162	190.2	14.7	92%	48	PSME	5	5.2	72	100.8	16.0	85%	24	101
3i	170	166.7	13.4	57%	44	PSME	5	5.1	161	164.7	13.7	57%	43	92
3j	154	171.7	14.3	47%	40	ALRU	7	7.6	113	146.3	15.4	55%	32	75
4b	126	185.0	16.4	97%	44	PSME	3	5.9	116	175.1	16.7	97%	41	81
4c	145	196.5	15.8	100%	44	PSME	2	7.6	126	165.2	15.5	100%	37	104
4d	177	177.2	13.5	81%	45	PSME	4	5.7	122	144.5	14.7	78%	35	92
4f	137	262.3	18.7	100%	60	PSME	3	4.6	132	257.6	18.9	100%	58	104
4g	152	179.2	14.7	99%	46	PSME	3	3.9	103	144.3	16.0	99%	36	92
4h	162	268.4	17.4	100%	63	TSHE	2	4.6	82	154.5	18.6	100%	35	99
4i	202	202.7	13.6	100%	54	PSME	2	3.6	154	166.4	14.1	100%	44	83
4j	123	217.6	18.0	80%	48	PSME	5	7.6	107	198.4	18.5	87%	43	71
5a	167	293.2	17.9	97%	66	PSME	4	6.8	140	258.6	18.4	97%	57	104
5b	115	248.4	19.9	51%	51	PSME	6	9.5	113	247.0	20.0	51%	51	81
5c	252	276.4	14.2	94%	63	TSHE	8	7.8	236	250.9	13.9	93%	58	77
5d	213	283.0	15.6	87%	69	TSHE	6	5.1	206	275.1	15.6	86%	66	87
5e	201	197.9	13.5	90%	51	PSME	5	5.4	187	190.9	13.7	89%	49	85
5f	283	314.3	14.3	94%	80	PSME	3	5.1	271	308.0	14.4	94%	78	82
5g	261	217.9	12.4	78%	52	PSME	6	7.1	243	210.5	12.6	80%	49	91
5h	184	230.3	15.2	82%	58	PSME	5	4.7	181	229.3	15.2	82%	57	94
5i	348	248.4	11.4	100%	69	TSHE	4	4.3	289	213.1	11.6	100%	58	76
5j	241	194.3	12.2	100%	53	TSHE	5	4.4	228	188.7	12.3	100%	51	81
6b	353	321.4	12.9	86%	83	TSHE	4	5.4	311	308.6	13.5	87%	51	82
6c	138	299.5	19.9	44%	61	ALRU	5	9.5	136	294.1	19.9	45%	60	83
6d	158	267.5	17.6	98%	60	TSHE	4	6.2	153	266.0	17.8	98%	60	102
6e	357	288.3	12.2	70%	80	TSHE	5	3.9	340	285.6	12.4	70%	79	79
6f	171	261.2	16.7	99%	62	TSHE	5	4.7	151	232.0	16.8	98%	55	94

SiteID	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer by BA	IPH RD	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	IPH Std Dev of Stem dbh [in]	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]	Yr3 %Conifer by BA	Yr3 RD	Avg RMZ Tree Height [ft]
6g	329	245.4	11.7	87%	70	TSHE	5	3.9	254	200.8	12.0	84%	56	78
6h	238	363.9	16.7	90%	85	TSHE	6	6.0	210	334.6	17.1	89%	77	92
6i	231	231.2	13.5	98%	54	PISI	6	7.3	185	216.0	14.6	99%	50	65
6j	328	245.7	11.7	79%	68	TSHE	4	4.5	307	238.9	11.9	80%	65	79
7a	276	127.8	9.2	35%	39	ALRU	7	3.7	264	127.1	9.4	35%	38	64
7b	269	211.1	12.0	61%	60	ALRU	4	4.0	225	191.7	12.5	62%	53	75
7c	194	229.2	14.7	85%	58	TSHE	4	4.9	172	209.7	15.0	84%	52	91
7d	264	321.6	15.0	100%	82	TSHE	5	4.4	242	301.6	15.1	100%	76	92
7e	170	193.7	14.4	77%	48	TSHE	5	6.1	167	192.4	14.5	77%	47	80
7f	315	251.7	12.1	99%	70	PSME	6	3.9	262	208.9	12.1	100%	59	73
7g	219	280.5	15.3	97%	70	TSHE	5	4.9	106	153.6	16.3	95%	37	93
7h	223	201.9	12.9	30%	54	ALRU	5	4.6	209	193.5	13.0	31%	51	78
7i	364	257.3	11.4	100%	74	PSME	4	3.6	322	245.6	11.8	100%	70	78
7j	187	180.0	13.3	90%	47	TSHE	3	4.6	47	57.3	15.0	76%	14	85
8b	339	318.3	13.1	94%	85	TSHE	4	4.6	275	276.4	13.6	93%	72	82
8c	295	262.6	12.8	81%	69	TSHE	3	5.2	275	246.8	12.8	80%	64	81
8d	367	204.3	10.1	99%	61	TSHE	4	3.0	342	194.1	10.2	99%	58	69
8e	486	216.4	9.0	100%	68	TSHE	3	3.2	233	121.6	9.8	100%	37	66
8f	217	240.7	14.3	99%	61	PSME	4	5.1	209	235.9	14.4	99%	59	81
8g	236	223.2	13.2	77%	59	TSHE	7	4.6	120	135.5	14.4	66%	34	89
8h	333	246.5	11.7	100%	71	PSME	3	3.2	300	237.0	12.0	100%	67	74
8i	230	217.1	13.2	98%	58	TSHE	5	4.4	170	178.9	13.9	98%	47	80
8j	323	334.7	13.8	69%	82	TSHE	3	6.4	297	324.4	14.2	69%	79	72
9a	269	258.6	13.3	100%	69	TSHE	6	4.1	264	256.0	13.3	100%	68	83
9b	215	288.1	15.7	86%	61	THPL	7	9.5	198	284.9	16.3	87%	60	64
9c	492	401.3	12.2	95%	108	PSME	6	4.8	436	367.7	12.4	96%	99	71
9d	338	329.8	13.4	97%	85	TSHE	6	5.2	269	297.6	14.2	97%	75	79
9e	247	322.5	15.5	85%	76	TSHE	5	7.1	234	313.1	15.6	85%	73	82
9f	100	189.8	18.7	33%	40	ACMA	4	9.7	68	146.4	19.8	34%	29	69

SiteID	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer by BA	IPH RD	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	IPH Std Dev of Stem dbh [in]	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]	Yr3 %Conifer by BA	Yr3 RD	Avg RMZ Tree Height [ft]
9g	724	371.9	9.7	98%	107	PSME	6	4.3	633	338.8	9.9	98%	96	51
9i	336	175.1	9.8	46%	52	ALRU	5	4.1	301	161.6	9.9	43%	47	63
9j	59	219.5	26.0	87%	35	PISI	5	17.1	59	219.9	26.0	87%	35	89
10a	419	244.1	10.3	100%	70	TSHE	5	4.1	275	174.1	10.8	100%	48	68
10b	414	289.6	11.3	53%	76	ALRU	3	5.5	386	280.5	11.5	51%	73	63
10c	587	379.6	10.9	59%	107	ALRU	5	4.4	500	343.5	11.2	57%	95	73
10d	331	413.0	15.1	82%	98	TSHE	4	6.8	314	405.9	15.4	82%	95	86
10e	463	289.7	10.7	99%	76	THPL	7	5.8	453	278.8	10.6	99%	73	53
10f	310	153.1	9.5	98%	45	TSHE	8	3.9	305	152.2	9.6	98%	44	60
10g	444	361.7	12.2	90%	98	TSHE	4	4.5	419	355.0	12.5	90%	95	76
10h	461	268.0	10.3	100%	74	TSHE	5	4.8	429	262.2	10.6	100%	72	65
10i	331	191.6	10.3	99%	56	PSME	4	3.5	329	192.9	10.4	99%	56	62
10j	931	405.4	8.9	95%	121	TSHE	4	3.7	846	388.4	9.2	95%	113	57
11a	358	297.8	12.3	90%	80	TSHE	4	4.8	271	257.1	13.2	89%	67	80
11b	339	329.7	13.4	97%	85	TSHE	7	5.1	332	327.6	13.5	97%	83	87
11c	244	255.1	13.8	97%	64	TSHE	5	5.6	215	234.4	14.1	96%	58	75
11d	820	368.0	9.1	98%	112	TSHE	5	3.5	607	303.5	9.6	98%	91	64
11e	450	160.3	8.1	99%	49	THPL	8	3.2	421	151.7	8.1	99%	46	47
11f	322	250.1	11.9	54%	70	ALRU	5	4.1	288	232.6	12.2	51%	64	75
11g	397	268.5	11.1	93%	74	PSME	6	4.4	172	108.7	10.8	91%	30	67
11h	264	229.1	12.6	100%	62	PSME	2	4.4	148	144.1	13.4	100%	38	87
11i	152	224.5	16.4	95%	53	PSME	5	5.8	99	162.7	17.3	92%	37	103
11j	617	298.0	9.4	100%	90	TSHE	5	3.4	595	293.75	9.51	100%	88	64
Wtd Median	**239.5**	**229.5**	**13.3**	**0.90**	**59**		**5**	**4.8**	**209.21**	**209.32**	**13.82**	**0.87**	**53**	**80**
Min	59	128	8.1	0.00	35		2	3.0	46.83	57.26	8.12	0.00	14	47
Max	931	413	26.0	1.00	121		8	17.1	845.57	405.94	26.03	1.00	113	104

1

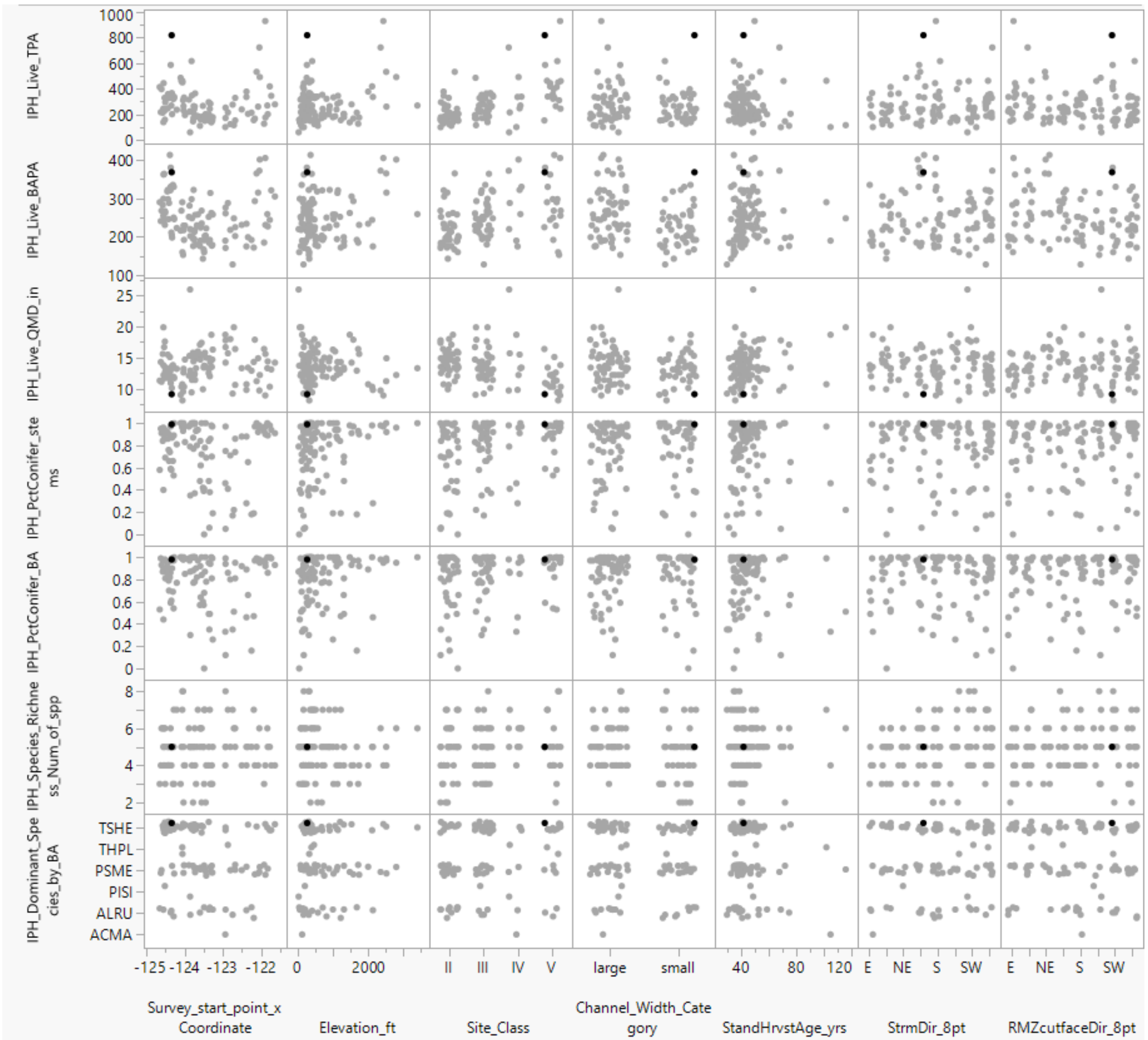


Figure A-4- 1. Crossplots of initial post-harvest riparian structure metrics versus site characteristics.

A-5. Riparian Function Metrics

Table A-5a. DFC and riparian function metrics – projected (DFC) basal area; mortality and windthrow.

Site ID	Age 140 Basal Area Projection Core	Age 140 Basal Area Projection Inner	Age 140 Basal Area Projection RMZ	Outer Zone Leave Trees	Stream Aspect	Buffer Face Aspect	Mortality % Trees	Annual Mortality % Trees/Yr low estimate	Annual Mortality % Trees/Yr high estimate	Mortality % BA	Wind Mortality % Trees	Stem Exclusion Mortality % of Trees
1a	416	461	423	Dispersed	SW	NW	11%	1.9%	3.8%	3%	3%	4%
1b	84	225	155	Combo	NW	SW	6%	1.1%	2.1%	3%	6%	0%
1c	394	381	387	Dispersed	W	S	5%	0.9%	1.8%	5%	2%	1%
1d	120	107	113	Dispersed	NW	SW	4%	0.6%	1.3%	2%	2%	0%
1e	222	360	291	Combo	SW	NW	6%	1.1%	2.2%	4%	1%	1%
1f	309	377	343	Dispersed	W	N	1%	0.1%	0.2%	1%	1%	0%
1g	152	104	128	Dispersed	SE	NE	9%	1.6%	3.1%	5%	7%	1%
1h	392	400	396	Combo	W	S	24%	4.5%	8.8%	17%	19%	4%
1i	1	61	31	Combo	SW	SE	3%	0.6%	1.2%	2%	2%	0%
1j	119	281	200	Clumped	S	E	23%	4.3%	8.5%	19%	22%	0%
2a	334	409	371	Exchanged for IZ	N	W	16%	2.8%	5.6%	10%	9%	5%
2b	410	370	390	Clumped	S	W	13%	2.3%	4.5%	9%	9%	0%
2c	376	391	383	Clumped	N	W	10%	1.8%	3.5%	8%	6%	0%
2d	426	409	418	Dispersed	W	N	7%	1.2%	2.4%	4%	6%	1%
2e	380	370	375	Combo	S	W	2%	0.4%	0.8%	1%	1%	1%
2f	274	425	349	Dispersed	SW	SE	3%	0.5%	1.1%	1%	0%	2%
2g	180	256	218	Combo	E	S	11%	2.0%	3.9%	5%	5%	3%
2h	413	414	414	Clumped	NE	SE	10%	1.8%	3.5%	5%	9%	1%
2i	408	404	406	Clumped	S	E	12%	2.2%	4.3%	6%	2%	7%
2j	379	414	396	Clumped	NW	SW	7%	1.1%	2.3%	2%	1%	5%
2k	394	402	398	Clumped	NW	NE	13%	2.2%	4.4%	5%	7%	5%
3a	401	408	404	Dispersed	NW	SW	33%	6.4%	12.3%	25%	27%	2%
3b	0	0	0	Dispersed	N	E	3%	0.6%	1.1%	1%	2%	0%
3c	491	557	524	Dispersed	N	W	2%	0.4%	0.8%	1%	1%	0%
3d	312	369	340	Dispersed	SW	SE	9%	1.5%	3.0%	5%	9%	0%
3e	3	204	103	Dispersed	W	S	6%	1.0%	2.0%	3%	2%	1%
3f	369	430	399	Combo	SE	SW	7%	1.2%	2.4%	3%	0%	2%

Site ID	Age 140 Basal Area Projection Core	Age 140 Basal Area Projection Inner	Age 140 Basal Area Projection RMZ	Outer Zone Leave Trees	Stream Aspect	Buffer Face Aspect	Mortality % Trees	Annual Mortality % Trees/Yr low estimate	Annual Mortality % Trees/Yr high estimate	Mortality % BA	Wind Mortality % Trees	Stem Exclusion Mortality % of Trees
3g	306	305	305	Dispersed	SW	NW	11%	1.9%	3.9%	7%	7%	2%
3h	314	349	332	Combo	SE	SW	56%	12.6%	23.7%	47%	53%	2%
3i	86	409	247	Dispersed	SE	NE	5%	0.9%	1.8%	2%	2%	2%
3j	220	217	218	Dispersed	S	W	27%	5.0%	9.8%	15%	27%	0%
4b	397	423	410	Dispersed	NW	NE	8%	1.4%	2.8%	6%	7%	0%
4c	359	292	326	Clumped	S	E	13%	2.3%	4.6%	16%	9%	0%
4d	313	374	344	Exchanged for IZ	E	S	31%	6.0%	11.7%	19%	28%	1%
4f	435	434	434	Combo	SE	NE	4%	0.6%	1.3%	2%	0%	3%
4g	414	387	400	Combo	N	W	32%	6.3%	12.2%	20%	12%	0%
4h	428	313	370	Combo	SE	SW	49%	10.7%	20.2%	43%	43%	0%
4i	418	389	403	Combo	S	W	24%	4.4%	8.6%	18%	21%	3%
4j	339	360	350	Dispersed	N	W	14%	2.4%	4.7%	9%	10%	0%
5a	401	435	418	Dispersed	SW	NW	17%	3.0%	5.8%	12%	13%	2%
5b	129	346	238	Dispersed	N	W	1%	0.2%	0.4%	1%	1%	0%
5c	398	349	373	Dispersed	SW	NW	6%	1.0%	2.1%	10%	4%	0%
5d	326	394	360	Clumped	N	E	3%	0.5%	1.1%	3%	3%	0%
5e	333	397	364	Clumped	W	N	7%	1.2%	2.4%	4%	3%	1%
5f	429	423	426	Combo	NE	SE	4%	0.7%	1.5%	2%	2%	0%
5g	375	719	397	Dispersed	S	W	7%	1.2%	2.3%	4%	1%	1%
5h	210	429	220	Combo	W	N	2%	0.3%	0.5%	1%	0%	0%
5i	376	374	375	Dispersed	W	S	17%	3.1%	6.0%	15%	15%	1%
5j	366	372	369	Combo	S	E	5%	0.9%	1.8%	3%	2%	0%
6b	321	358	340	Dispersed	W	N	12%	2.1%	4.1%	4%	8%	2%
6c	249	144	197	Dispersed	SW	NW	2%	0.3%	0.7%	2%	1%	1%
6d	367	361	364	Dispersed	SW	NW	3%	0.4%	0.9%	1%	0%	3%
6e	359	344	351	Dispersed	N	E	5%	0.8%	1.6%	1%	2%	2%
6f	400	274	337	Dispersed	SE	NE	12%	2.1%	4.2%	11%	12%	0%
6g	368	324	346	Clumped	W	S	23%	4.2%	8.2%	19%	19%	1%
6h	392	380	386	Clumped	NW	NE	12%	2.0%	4.0%	8%	12%	0%

Site ID	Age 140 Basal Area Projection Core	Age 140 Basal Area Projection Inner	Age 140 Basal Area Projection RMZ	Outer Zone Leave Trees	Stream Aspect	Buffer Face Aspect	Mortality % Trees	Annual Mortality % Trees/Yr low estimate	Annual Mortality % Trees/Yr high estimate	Mortality % BA	Wind Mortality % Trees	Stem Exclusion Mortality % of Trees
6i	387	310	349	Clumped	NE	SE	20%	3.6%	7.1%	7%	17%	3%
6j	348	375	361	Clumped	W	N	6%	1.1%	2.2%	3%	3%	1%
7a	248	360	304	Dispersed	W	S	5%	0.8%	1.5%	2%	0%	5%
7b	302	297	299	Dispersed	E	S	16%	2.9%	5.8%	10%	13%	2%
7c	309	350	329	Dispersed	W	S	11%	2.0%	3.9%	9%	9%	1%
7d	380	439	410	Clumped	W	N	8%	1.4%	2.8%	7%	6%	0%
7e	282	334	308	Clumped	NE	NW	2%	0.3%	0.6%	1%	2%	0%
7f	401	415	408	Dispersed	W	S	17%	3.0%	6.0%	18%	11%	0%
7g	284	329	307	Clumped	N	W	51%	11.3%	21.4%	45%	49%	0%
7h	20	218	119	Clumped	S	E	6%	1.1%	2.1%	5%	5%	1%
7i	412	417	414	Combo	NE	NW	12%	2.0%	4.0%	5%	4%	1%
7j	44	248	146	Combo	S	W	75%	20.6%	37.0%	68%	73%	0%
8b	389	364	377	Dispersed	W	S	19%	3.4%	6.7%	14%	16%	1%
8c	400	407	403	Dispersed	W	N	7%	1.2%	2.3%	7%	6%	1%
8d	381	358	370	Dispersed	E	S	7%	1.2%	2.3%	6%	6%	0%
8e	368	333	351	Dispersed	NE	SE	52%	11.5%	21.8%	44%	51%	0%
8f	387	353	370	Dispersed	NE	NW	4%	0.6%	1.2%	2%	1%	1%
8g	274	180	227	Dispersed	SW	SE	49%	10.6%	20.1%	40%	48%	0%
8h	389	385	387	Dispersed	S	W	10%	1.7%	3.4%	4%	3%	1%
8i	391	329	360	Clumped	N	W	26%	4.9%	9.5%	18%	22%	2%
8j	297	392	345	Clumped	E	N	8%	1.4%	2.8%	4%	7%	1%
9a	361	385	373	Dispersed	N	E	2%	0.3%	0.7%	2%	0%	0%
9b	436	333	384	Combo	SW	NW	8%	1.4%	2.8%	1%	2%	2%
9c	422	410	416	Clumped	NW	NE	11%	2.0%	3.9%	9%	6%	5%
9d	386	378	382	Dispersed	S	W	20%	3.7%	7.2%	10%	15%	1%
9e	385	334	360	Clumped	NE	NW	5%	0.8%	1.7%	3%	4%	0%
9f	101	37	84	Dispersed	E	S	32%	6.1%	11.9%	23%	26%	0%
9g	392	404	398	Dispersed	W	N	13%	2.2%	4.4%	10%	9%	1%
9i	188	340	264	Combo	S	E	10%	1.8%	3.6%	9%	6%	3%

Site ID	Age 140 Basal Area Projection Core	Age 140 Basal Area Projection Inner	Age 140 Basal Area Projection RMZ	Outer Zone Leave Trees	Stream Aspect	Buffer Face Aspect	Mortality % Trees	Annual Mortality % Trees/Yr low estimate	Annual Mortality % Trees/Yr high estimate	Mortality % BA	Wind Mortality % Trees	Stem Exclusion Mortality % of Trees
9j	210	224	272	Clumped	SW	SE	0%	0.0%	0.0%	0%	0%	0%
10a	380	370	375	Clumped	NW	SW	34%	6.7%	13.0%	29%	33%	1%
10b	319	360	339	Dispersed	N	E	7%	1.1%	2.3%	4%	4%	1%
10c	389	325	357	Dispersed	NW	SW	15%	2.7%	5.2%	10%	10%	0%
10d	355	347	336	Dispersed	NW	NE	5%	0.9%	1.8%	2%	1%	1%
10e	355	347	336	Dispersed	W	N	2%	0.4%	0.8%	5%	1%	0%
10f	364	403	383	Dispersed	SW	SE	1%	0.2%	0.5%	2%	1%	0%
10g	419	414	417	Clumped	S	E	6%	1.0%	2.0%	2%	4%	1%
10h	394	343	363	Dispersed	SW	SE	7%	1.2%	2.4%	3%	6%	0%
10i	389	388	388	Dispersed	S	E	1%	0.1%	0.2%	0%	0%	1%
10j	408	402	405	Clumped	S	E	9%	1.6%	3.2%	5%	4%	3%
11a	400	434	417	Dispersed	W	S	24%	4.5%	8.9%	14%	19%	3%
11b	483	480	482	Dispersed	NW	SW	2%	0.4%	0.7%	1%	1%	0%
11c	401	396	399	Dispersed	W	N	12%	2.1%	4.1%	9%	12%	0%
11d	400	396	398	Dispersed	NW	SW	26%	4.9%	9.5%	18%	23%	1%
11e	375	380	377	Dispersed	SE	SW	6%	1.1%	2.2%	7%	2%	1%
11f	264	408	327	Combo	S	W	11%	1.8%	3.6%	8%	9%	0%
11g	345	93	219	Dispersed	SE	SW	57%	13.0%	24.4%	60%	57%	0%
11h	374	332	353	Dispersed	S	W	44%	9.2%	17.6%	37%	41%	0%
11i	337	361	349	Combo	N	W	35%	6.9%	13.3%	28%	24%	0%
11j	401	396	398	Dispersed	S	W	4%	0.6%	1.2%	1%	4%	0%
Wtd Median							**8.2%**	**1.4%**	**2.8%**	**4.9%**	**5.9%**	**0.6%**
Min							**0%**	**0%**	**0%**	**0%**	**0%**	**0.0%**
Max							**75%**	**20.6%**	**37%**	**68%**	**73%**	**6.6%**

Table A-5b. Site function metrics – fallen trees, wood recruitment, shade, and soil disturbance/sediment. Wood recruitment and shade are calculated and reported using two different methods (see Methods section).

SiteID	Future Potential Recruitmt trees/100'	Fallen Trees /100'	Fallen mean dbh [in]	Fallen Trees reaching Channel/ 100'	FPW-LW Recruitment [pcs/100']	FPW-LW Recruitment [ft^3/100']	BFW-LW Recruitment [pcs/100']	BFW-LW Recruitment [ft^3/100']	Canopy Closure 4-direction [%]	Canopy Closure Looking into RMZ [%]	Soil Disturbance Area [ft^2]	Sediment Contributed to Stream [yd^3]
1a	68.0	Fallen Trees/ 100ft	9.1	0.67	1.0	1.7	1.0	1.7	93%	94%	0	0
1b	30.3	2.7	12.8	0.33	0.3	0.9	0.3	0.9	65%	83%	0	0
1c	82.0	2.7	11.4	0.67	0.3	1.4	0.3	1.4	80%	83%	0	0
1d	42.7	2.0	12.9	0.33	0.3	2.2	0.3	2.2	32%	67%	0	0
1e	48.0	0.7	9.0	0.00	0.0	0.0	0.0	0.0	99%	99%	0	0
1f	54.7	0.7	20.0	0.00	0.0	0.0	0.0	0.0	80%	87%	0	0
1g	47.3	0.3	11.4	0.33	0.0	0.0	0.0	0.0	91%	96%	0	0
1h	73.3	3.3	9.1	1.67	0.7	1.9	0.7	1.9	37%	95%	0	0
1i	28.0	17.7	13.5	0.67	0.0	0.0	0.0	0.0	95%	95%	0	0
1j	46.0	1.3	11.6	0.33	0.7	2.1	0.7	2.1	76%	98%	0	0
2a	49.7	12.3	12.0	1.00	0.0	0.0	0.0	0.0	99%	100%	0	0
2b	88.3	6.3	10.8	0.00	0.0	0.0	0.0	0.0	73%	96%	0	0
2c	73.3	9.3	10.9	1.33	1.3	5.2	1.3	5.2	99%	96%	0	0
2d	47.7	3.7	10.9	1.00	1.0	2.8	1.0	2.8	98%	99%	0	0
2e	53.0	3.3	15.9	0.00	0.0	0.0	0.0	0.0	36%	66%	0	0
2f	51.7	0.7	8.5	0.33	0.7	3.3	0.7	3.3	99%	98%	0	0
2g	52.0	0.7	11.7	0.67	0.7	1.1	0.7	1.1	95%	92%	0	0
2h	47.7	4.3	10.5	1.00	1.0	9.2	1.0	9.2	89%	87%	0	0
2i	97.3	5.0	7.7	0.67	0.3	0.7	0.3	0.7	94%	90%	0	0
2j	65.3	4.0	7.8	0.00	0.0	0.0	0.0	0.0	100%	98%	0	0
4a	121.0	0.7	7.5	2.33	1.0	2.0	1.0	2.0	96%	92%	0	0
3a	38.0	9.3	10.9	7.33	1.7	2.7	1.7	2.7	97%	95%	0	0
3b	39.3	15.0	10.5	0.00	0.0	0.0	0.0	0.0	99%	99%	0	0
3c	67.3	1.3	6.1	0.33	0.3	0.5	0.3	0.5	96%	100%	0	0
3d	42.3	1.7	10.3	1.00	0.3	0.9	0.3	0.9	99%	99%	0	0

SiteID	Future Potential Recruitmt trees/100'	Fallen Trees /100’	Fallen mean dbh [in]	Fallen Trees reaching Channel/ 100’	FPW-LW Recruitment [pcs/100']	FPW-LW Recruitment [ft³/100']	BFW-LW Recruitment [pcs/100']	BFW-LW Recruitment [ft³/100']	Canopy Closure 4-direction [%]	Canopy Closure Looking into RMZ [%]	Soil Disturbance Area [ft²]	Sediment Contributed to Stream [yd³]
3e	52.0	4.3	10.8	0.00	0.0	0.0	0.0	0.0	98%	96%	0	0
3f	36.0	1.7	0.0	0.00	0.0	0.0	0.0	0.0	95%	100%	0	0
3g	56.0	0.0	9.4	1.67	0.7	2.0	0.7	2.0	99%	100%	0	0
3h	18.7	5.3	12.9	13.33	5.3	34.9	5.3	34.9	95%	87%	0	0
3i	41.7	21.0	6.3	0.00	0.0	0.0	0.0	0.0	99%	100%	0	0
3j	29.3	0.7	10.1	3.67	2.0	6.8	2.0	6.8	87%	83%	0	0
4b	30.0	12.3	13.9	0.00	0.0	0.0	0.0	0.0	96%	99%	0	0
4c	32.7	2.0	17.0	0.67	0.0	0.0	0.0	0.0	65%	88%	0	0
4d	31.7	3.0	10.3	5.33	2.3	11.1	2.3	11.1	98%	98%	0	0
4f	34.3	13.0	0.0	0.00	0.0	0.0	0.0	0.0	96%	89%	0	0
4g	26.7	0.0	10.7	4.67	0.7	2.9	0.7	2.9	96%	89%	0	0
4h	21.3	7.0	15.9	12.00	0.3	0.6	0.3	0.6	94%	89%	0	0
4i	40.0	17.7	12.0	6.00	1.7	18.9	1.7	18.9	87%	86%	0	0
4j	27.7	12.0	14.1	1.33	0.3	0.5	0.3	0.5	98%	96%	0	0
5a	33.7	3.7	15.2	2.67	3.0	24.9	3.0	24.9	89%	87%	0	0
5b	27.3	5.0	16.0	0.33	0.3	5.8	0.3	5.8	89%	92%	0	0
5c	57.0	0.3	16.0	0.00	0.0	0.0	0.0	0.0	4%	36%	0	0
5d	49.7	4.0	15.3	1.00	0.7	1.7	0.7	1.7	95%	96%	0	0
5e	45.0	1.7	9.5	0.00	0.0	0.0	0.0	0.0	99%	96%	0	0
5f	65.3	1.7	8.1	0.00	0.0	0.0	0.0	0.0	93%	100%	0	0
5g	58.7	1.3	9.7	1.33	1.3	23.7	1.3	23.7	96%	99%	0	0
5h	43.7	3.0	20.0	0.00	0.0	0.0	0.0	0.0	97%	98%	0	0
5i	69.7	0.3	10.4	3.33	1.3	13.2	1.3	13.2	80%	89%	0	0
5j	55.0	13.3	11.4	0.67	0.0	0.0	0.0	0.0	98%	96%	0	0
6b	75.0	1.7	6.3	0.67	0.7	0.8	0.3	0.8	96%	92%	0	0
6c	32.7	6.0	28.0	0.00	0.0	0.0	0.0	0.0	52%	88%	0	0
6d	37.0	0.3	0.0	0.00	0.0	0.0	0.0	0.0	98%	94%	0	0
6e	82.0	0.0	8.2	0.33	0.3	5.0	0.3	5.0	100%	100%	0	0
6f	36.3	1.7	16.2	1.00	0.7	7.4	0.7	7.4	88%	73%	0	0

SiteID	Future Potential Recruitmt trees/100'	Fallen Trees /100’	Fallen mean dbh [in]	Fallen Trees reaching Channel/ 100’	FPW-LW Recruitment [pcs/100']	FPW-LW Recruitment [ft^3/100']	BFW-LW Recruitment [pcs/100']	BFW-LW Recruitment [ft^3/100']	Canopy Closure 4-direction [%]	Canopy Closure Looking into RMZ [%]	Soil Disturbance Area [ft^2]	Sediment Contributed to Stream [yd^3]
6g	61.3	5.3	10.4	1.33	0.3	3.0	0.3	3.0	98%	100%	0	0
6h	50.7	14.0	13.3	2.00	1.3	6.3	1.3	6.3	89%	99%	0	0
6i	44.7	6.3	7.6	1.00	0.7	2.9	0.7	2.9	99%	100%	0	0
6j	74.0	8.0	8.8	1.33	1.3	12.0	1.3	12.0	99%	100%	0	0
7a	56.3	3.3	0.0	0.00	0.0	0.0	0.0	0.0	99%	100%	0	0
7b	48.0	0.0	9.3	1.67	1.3	5.4	1.3	5.4	99%	99%	0	0
7c	36.7	7.3	13.1	2.33	1.3	2.3	1.3	2.3	99%	100%	0	0
7d	51.7	4.3	13.2	2.00	2.0	26.9	2.0	26.9	94%	94%	0	0
7e	35.7	3.3	11.1	0.33	0.0	0.0	0.0	0.0	99%	96%	0	0
7f	56.0	0.7	12.5	0.67	0.3	3.9	0.3	3.9	80%	94%	0	0
7g	22.7	8.0	13.8	11.67	5.7	35.6	5.7	35.6	91%	100%	0	0
7h	44.7	22.7	13.0	1.67	1.0	4.0	1.0	4.0	95%	95%	0	0
7i	68.7	1.7	8.3	2.33	1.3	7.1	1.3	7.1	99%	98%	0	0
7j	10.0	4.3	12.1	14.00	2.7	8.2	2.7	8.2	92%	96%	0	0
8b	58.7	28.7	10.4	4.33	2.0	7.5	2.0	7.5	97%	95%	0	0
8c	58.7	10.7	12.6	0.67	0.0	0.0	0.0	0.0	99%	99%	0	0
8d	73.0	4.3	9.0	1.00	0.3	0.8	0.3	0.8	99%	99%	0	0
8e	49.7	5.0	8.0	25.33	4.3	13.3	4.3	13.3	98%	98%	0	0
8f	44.7	51.3	10.6	1.00	1.0	8.5	1.0	8.5	98%	94%	0	0
8g	25.7	1.3	11.5	14.00	3.3	10.8	3.3	10.8	86%	72%	0	0
8h	64.0	23.7	7.4	0.67	0.0	0.0	0.0	0.0	98%	96%	0	0
8i	36.3	2.7	10.6	3.33	2.3	14.5	2.3	14.5	96%	75%	0	0
8j	63.3	10.3	8.3	0.33	0.3	0.6	0.3	0.6	99%	98%	0	0
9a	50.3	5.0	5.2	0.33	0.0	0.0	0.0	0.0	74%	87%	0	0
9b	37.7	0.3	6.4	1.00	0.3	0.4	0.3	0.4	54%	67%	0	0
9c	83.0	1.0	11.6	2.33	2.0	16.9	2.0	16.9	93%	96%	0	0
9d	51.3	5.7	9.1	0.67	0.0	0.0	0.0	0.0	93%	99%	0	0
9e	44.7	9.3	12.6	0.00	0.0	0.0	0.0	0.0	98%	99%	0	0
9f	13.0	1.7	15.1	3.33	3.0	24.6	3.0	24.6	68%	87%	0	0

SiteID	Future Potential Recruitmt trees/100'	Fallen Trees /100'	Fallen mean dbh [in]	Fallen Trees reaching Channel/ 100'	FPW-LW Recruitment [pcs/100']	FPW-LW Recruitment [ft^3/100']	BFW-LW Recruitment [pcs/100']	BFW-LW Recruitment [ft^3/100']	Canopy Closure 4-direction [%]	Canopy Closure Looking into RMZ [%]	Soil Disturbance Area [ft^2]	Sediment Contributed to Stream [yd^3]
9g	120.7	5.3	8.0	4.00	3.0	21.5	3.0	21.5	74%	96%	0	0
9i	57.3	11.3	9.3	0.33	0.3	0.7	0.3	0.7	98%	100%	0	0
9j	11.3	4.0	31.5	0.00	0.0	0.0	0.0	0.0	24%	35%	0	0
10a	43.0	0.3	9.0	7.67	4.0	20.3	4.0	20.3	71%	99%	0	0
10b	60.3	21.3	8.8	0.33	0.0	0.0	0.0	0.0	99%	99%	0	0
10c	78.0	2.7	8.7	2.33	2.0	30.1	2.0	30.1	99%	98%	0	0
10d	49.0	8.3	16.9	0.33	0.3	0.9	0.3	0.9	98%	99%	0	0
10e	70.7	1.0	15.7	0.67	0.7	5.0	0.7	5.0	97%	89%	0	0
10f	47.7	1.0	5.5	0.00	0.0	0.0	0.0	0.0	85%	94%	0	0
10g	65.3	0.3	7.3	0.33	0.0	0.0	0.0	0.0	98%	96%	0	0
10h	67.0	1.7	8.2	2.00	0.7	5.1	0.7	5.1	90%	98%	0	0
10i	51.3	4.3	0.0	0.00	0.0	0.0	0.0	0.0	54%	100%	0	0
10j	132.0	0.0	6.8	1.67	0.0	0.0	0.0	0.0	75%	100%	0	0
11a	37.3	5.7	9.5	6.33	3.3	6.2	3.3	6.2	95%	98%	0	0
11b	45.7	8.7	10.3	0.00	0.0	0.0	0.0	0.0	99%	96%	0	0
11c	29.7	0.7	10.9	1.67	0.0	0.0	0.0	0.0	98%	99%	0	0
11d	83.7	3.7	7.6	18.67	12.7	44.0	12.7	44.0	96%	93%	0	0
11e	58.0	24.7	9.2	0.33	0.0	0.0	0.0	0.0	98%	100%	0	0
11f	39.7	1.3	9.2	0.67	0.7	2.2	0.7	2.2	99%	99%	0	0
11g	23.7	4.0	10.5	20.33	13.3	84.0	13.3	84.0	90%	87%	0	0
11h	20.3	31.3	11.2	13.33	6.7	35.9	6.7	35.9	85%	96%	0	0
11i	13.7	15.0	13.2	1.00	0.7	2.6	0.7	2.6	58%	60%	0	0
11j	82.0	5.3	5.9	0.67	0.0	0.0	0.0	0.0	100%	100%	0	0
Wtd Median	**48**	**2.9**	**10.9**	**3.0**	**1.0**	**2.8**				**96%**	**0**	**0**
Min	**10**	**0**	**5.2**	**0**	**0.0**	**0.0**				**35%**	**0**	**0**
Max	**132**	**51.3**	**31.5**	**22.0**	**25.3**	**91.6**				**100%**	**0**	**0**

1

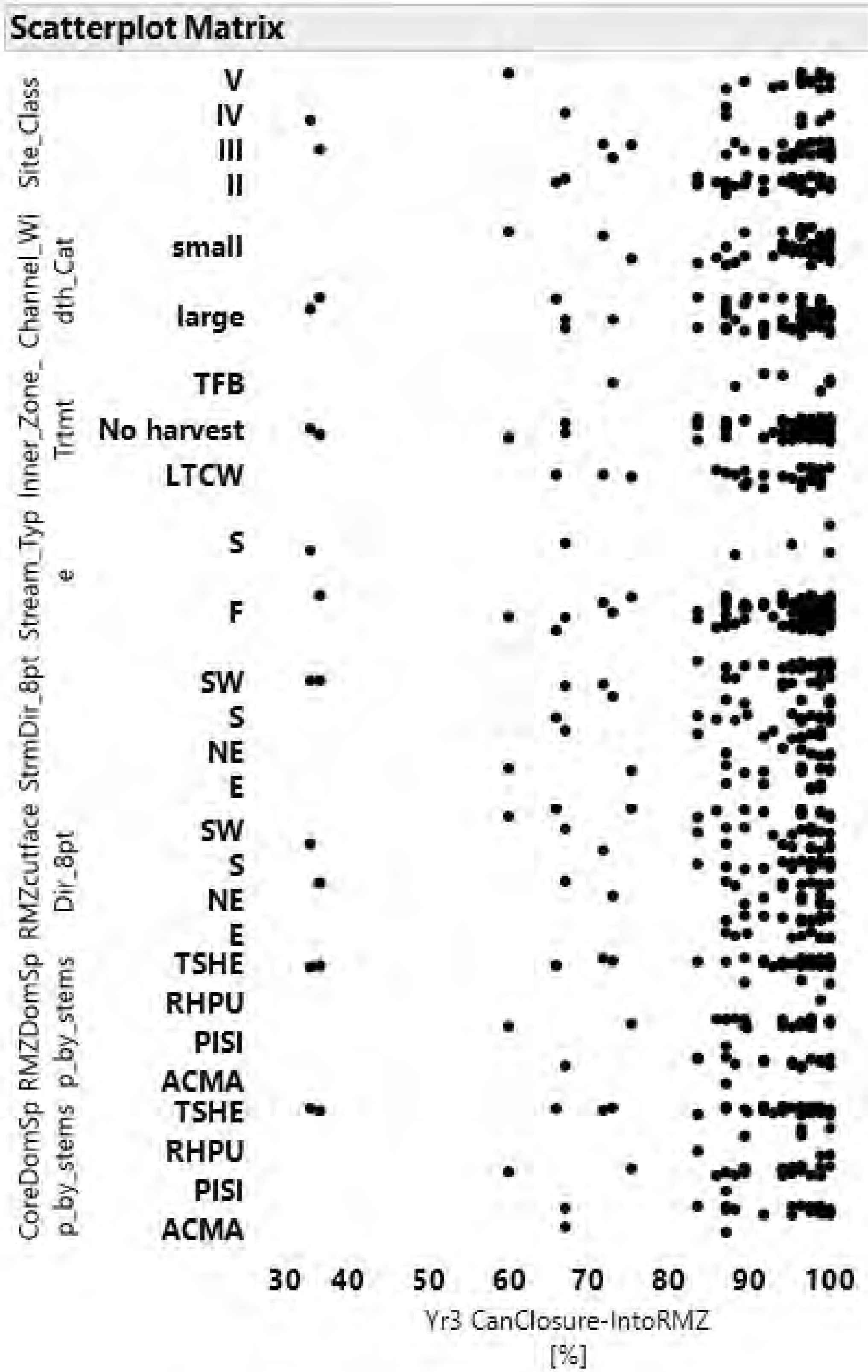


Figure A-5b-1. Scatterplot matrix of Canopy Closure looking into RMZ from stream edge versus categorical site and stand characteristics.

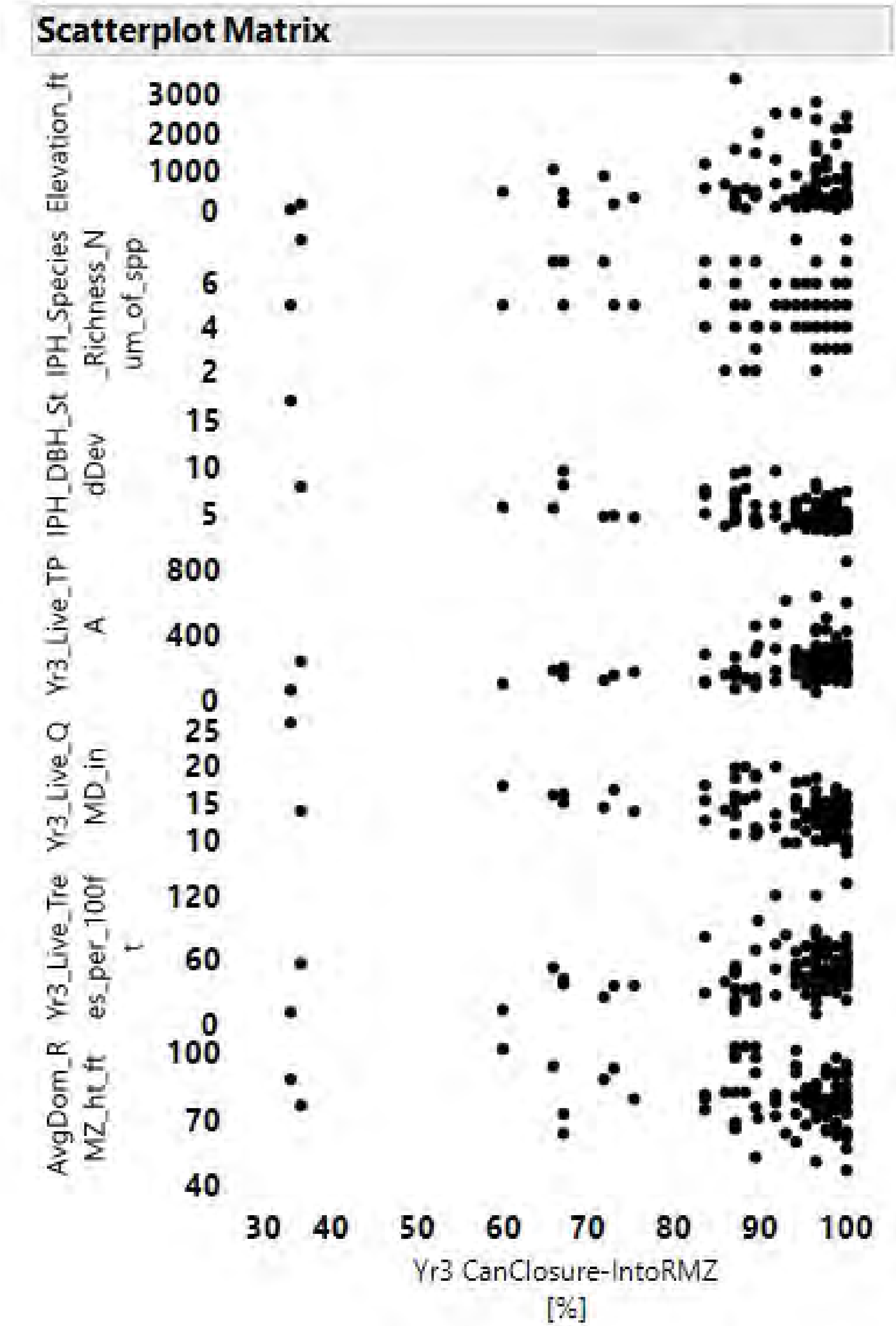


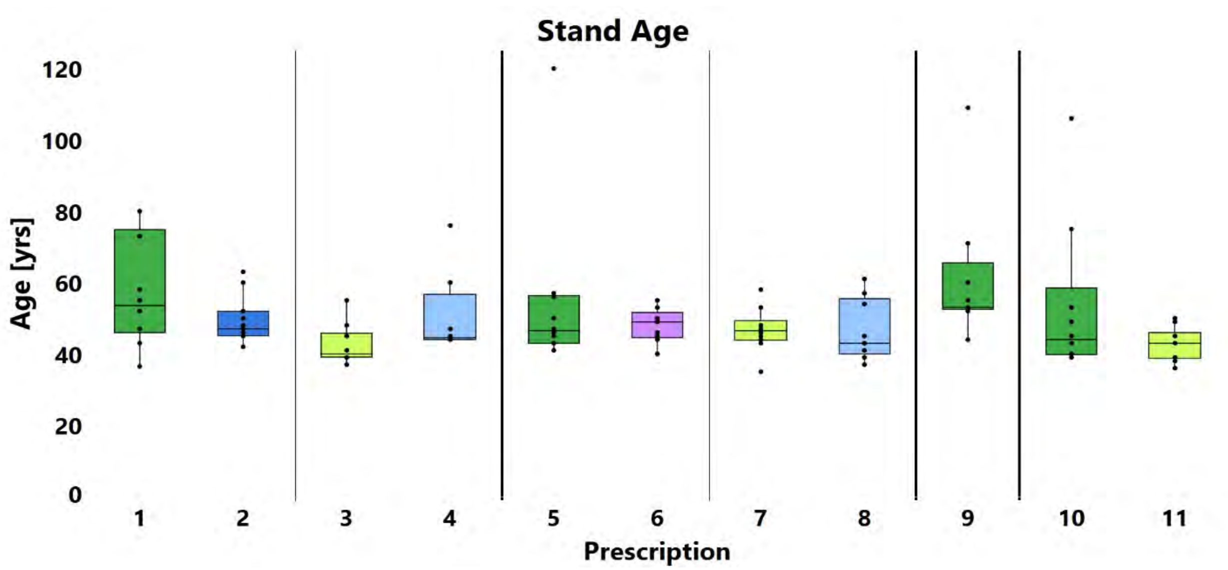
Figure A-5b-2. Scatterplot matrix of Canopy Closure looking into RMZ from stream edge versus continuous site and stand characteristics.

Appendix B. Data Distributions by Prescription Variant

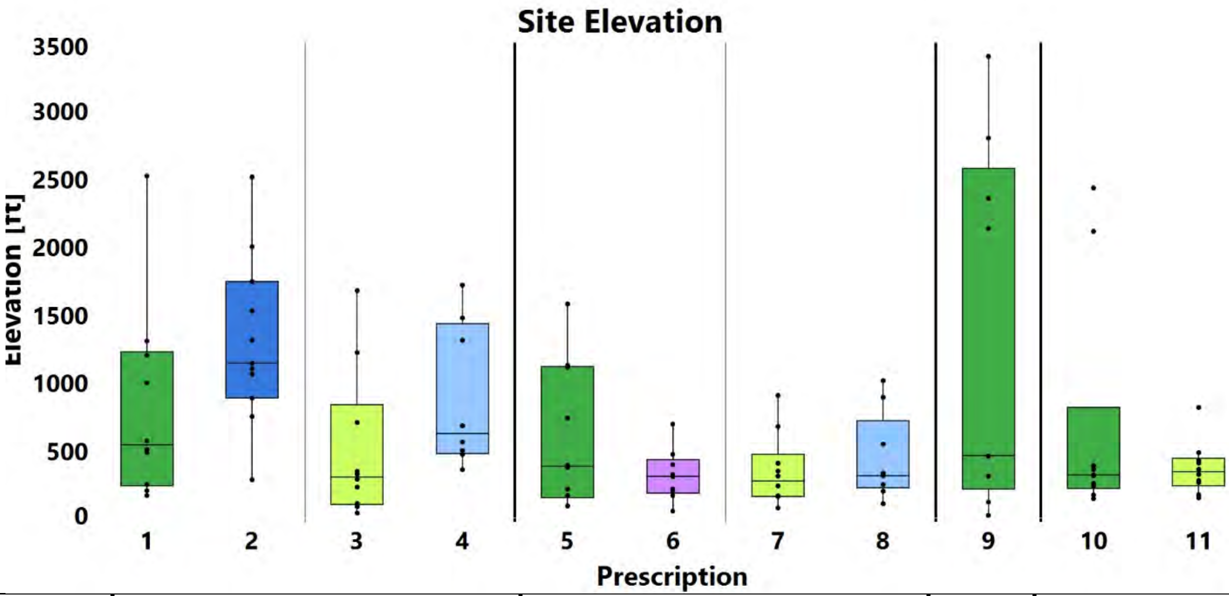
The following figures show distributions of the measured data for each prescription variant and by Core and Inner Zone within each variant. The horizontal bars in the middle of the boxplot boxes represent the median; the boxes range from the 25th to the 75th percentiles, the whiskers show the value range up to 1.5 times the box length, and outliers are plotted individually beyond that. Many of the boxplots also show a red line connecting mean values and diamonds indicating the 95% confidence intervals to facilitate identification of prescriptions differences.

In these figures, prescription variants that had no Inner Zone harvest are colored green and those that had harvest in the Inner Zones are colored blue (for leaving trees adjacent to the Core Zone, LTCW) or purple (for thin from below, TFB). Darker shades indicate "large" channels over 10 feet wide and lighter shades indicate "small" channels less than 10 feet wide (per FFR regulations).

B-1. Site Characteristics



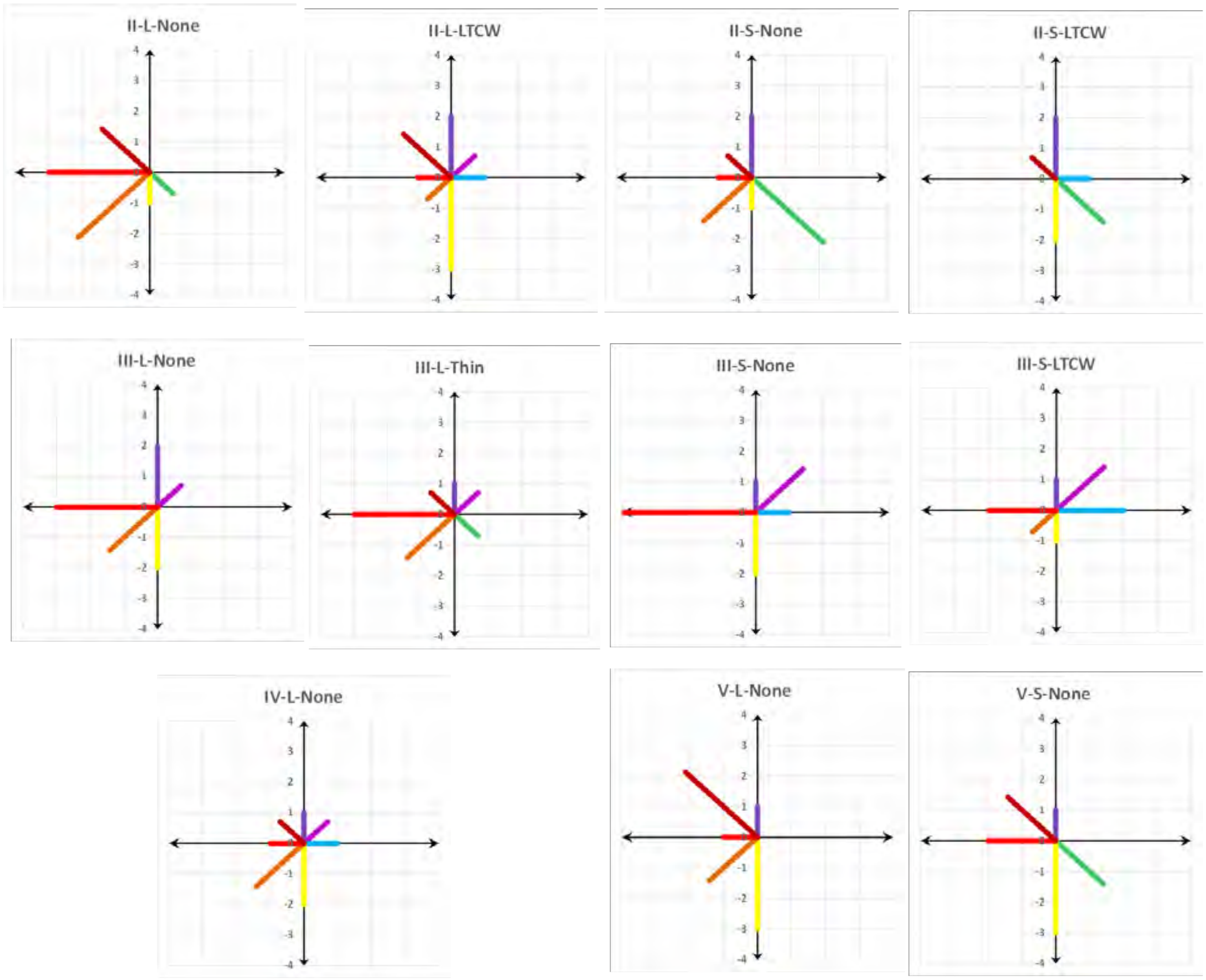
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
N	10	11	10	8	10	9	10	9	9	10	10



Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
N	10	11	10	8	10	9	10	9	9	10	10

Valley Orientation

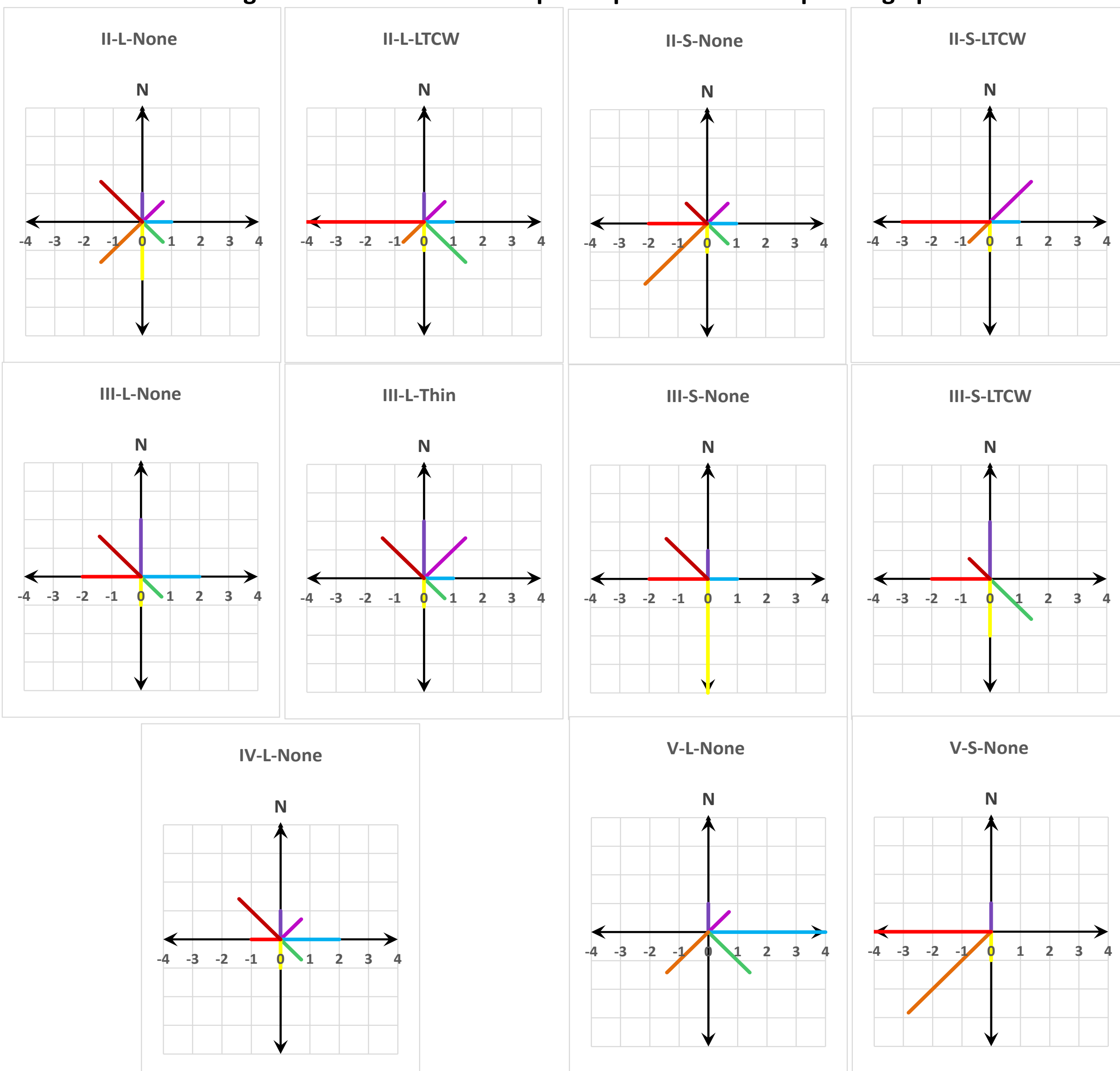
Number of sites facing each direction in tested prescriptions. Colors highlight the various compass directions and line lengths indicate the number of sites with each orientation. North pointing up.



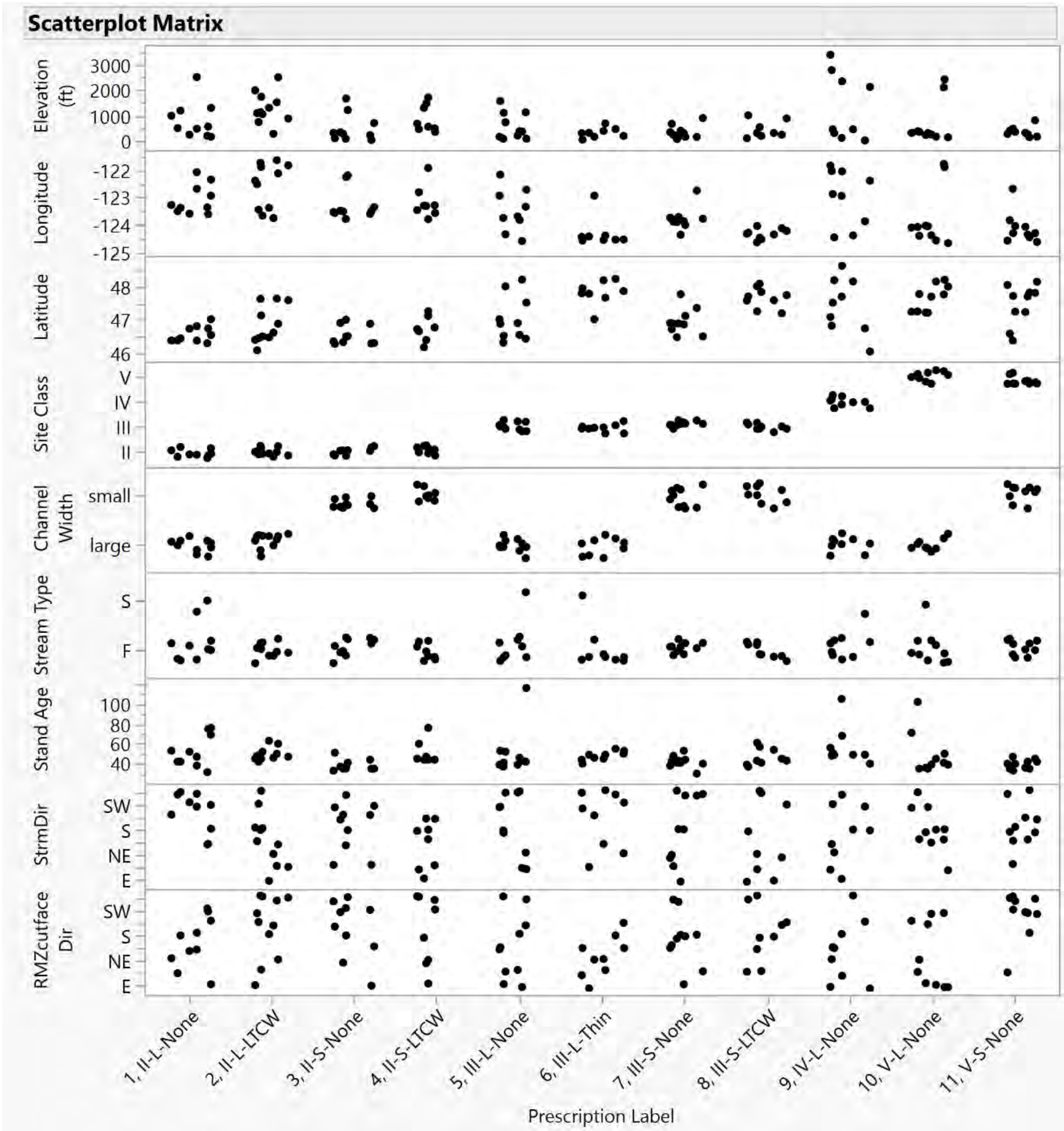
Valley Orientation	II-L-None	II-L-LTCW	II-S-None	II-S-LTCW	III-L-None	III-L-Thin	III-S-None	III-S-LTCW	IV-L-None	V-L-None	V-S-None
N	0	2	2	2	2	1	1	1	1	1	1
NE	0	1	0	0	1	1	2	2	1	0	0
E	0	1	0	1	0	0	1	2	1	0	0
SE	1	0	3	2	0	1	0	0	0	0	2
S	1	3	1	2	2	0	2	1	2	3	3
SW	3	1	2	0	2	2	0	1	2	2	0
W	3	1	1	0	3	3	4	2	1	1	2
NW	2	2	1	1	0	1	0	0	1	3	2
Total	**10**	**11**	**10**	**8**	**10**	**9**	**10**	**9**	**9**	**10**	**10**

RMZ Cut-Face Exposure Direction

Number of sites facing each direction in tested prescriptions. North is pointing up.

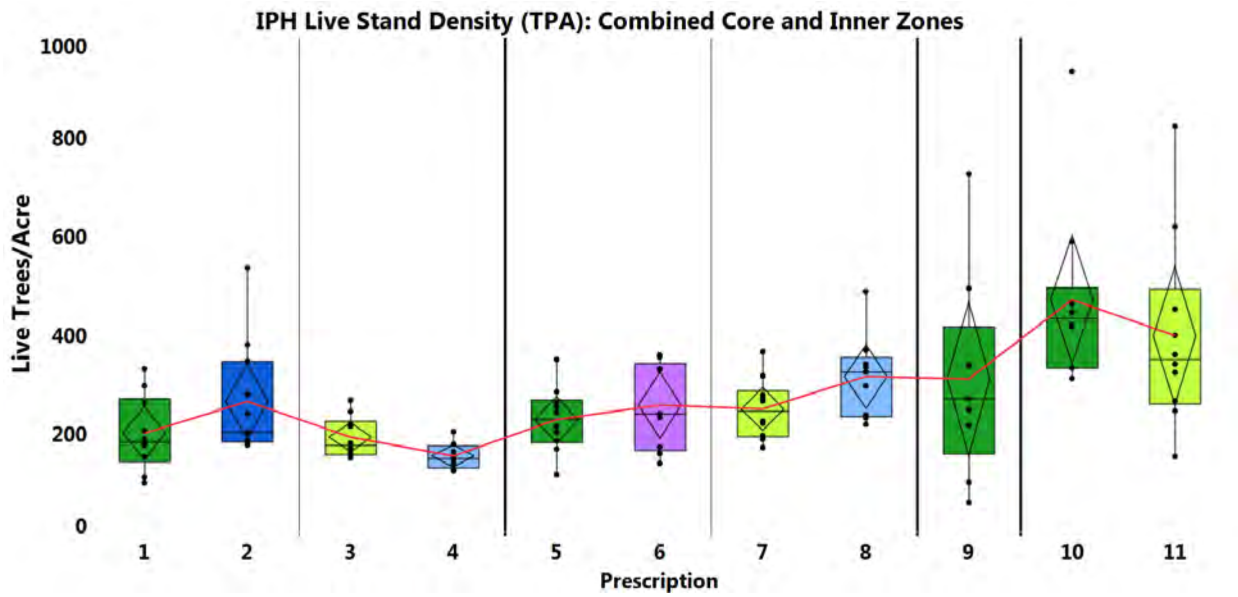


Valley Orientation	II-L-None	II-L-LTCW	II-S-None	II-S-LTCW	III-L-None	III-L-Thin	III-S-None	III-S-LTCW	IV-L-None	V-L-None	V-S-None
N	1	1	0	0	2	2	1	2	1	1	1
NE	1	1	1	2	0	2	0	0	1	1	0
E	1	1	1	1	2	1	1	0	2	4	0
SE	1	2	1	0	1	1	0	2	1	2	0
S	2	1	1	1	1	1	4	2	1	0	1
SW	2	1	3	1	0	0	0	0	0	2	4
W	0	4	2	3	2	0	2	2	1	0	4
NW	2	0	1	0	2	2	2	1	2	0	0
Total	**10**	**11**	**10**	**8**	**10**	**9**	**10**	**9**	**9**	**10**	**10**

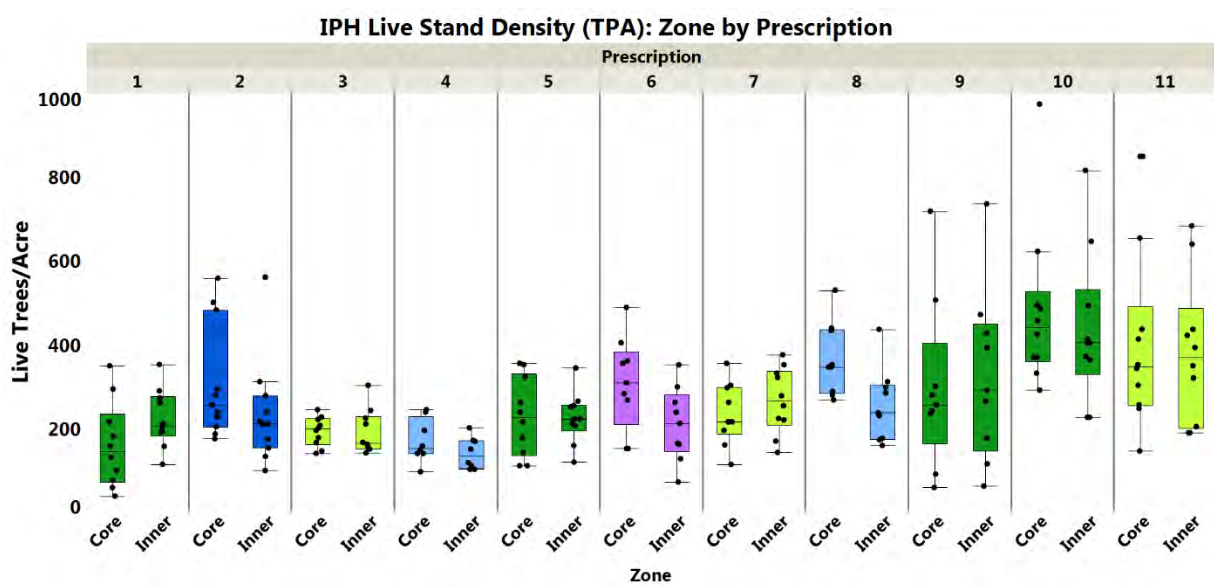


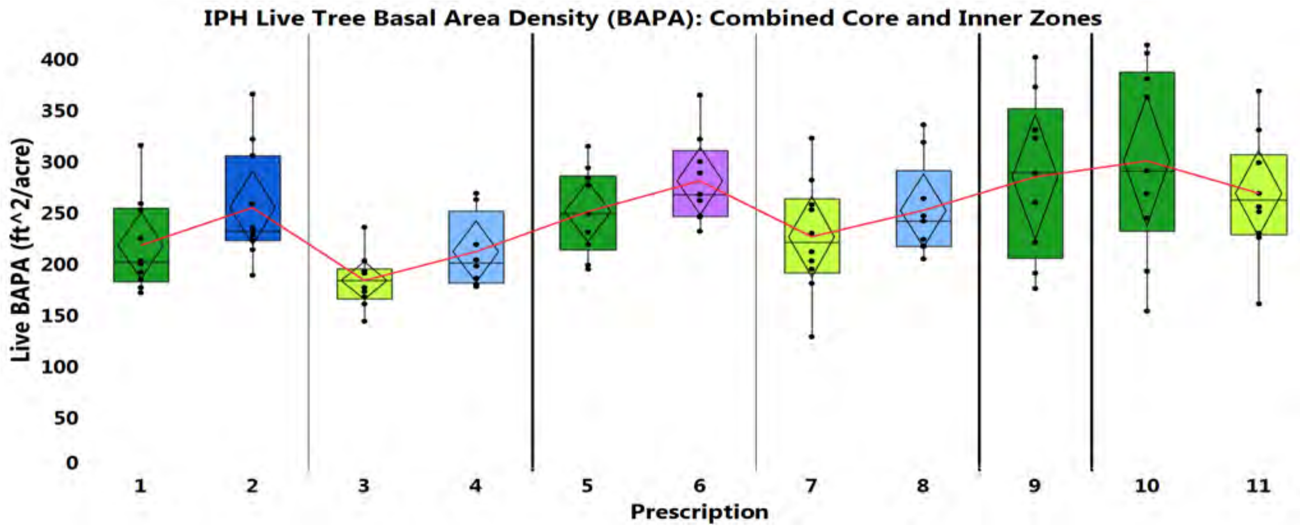
Crossplots of site characteristics by prescription.

B-2. Immediately Post-Harvest (IPH) Stand Metrics

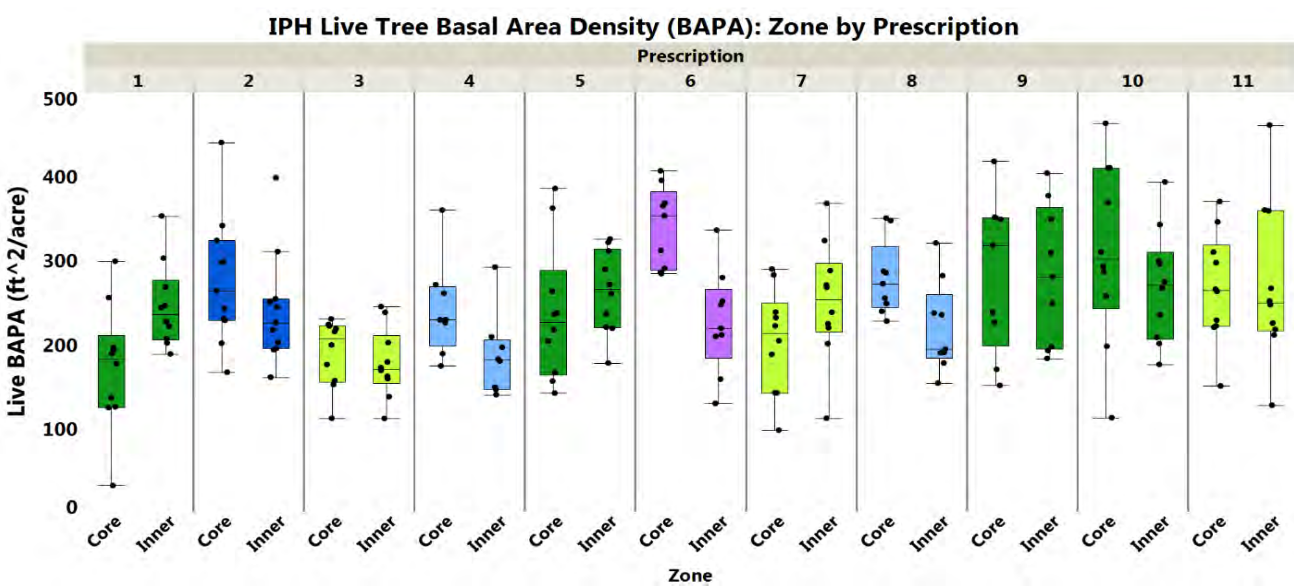


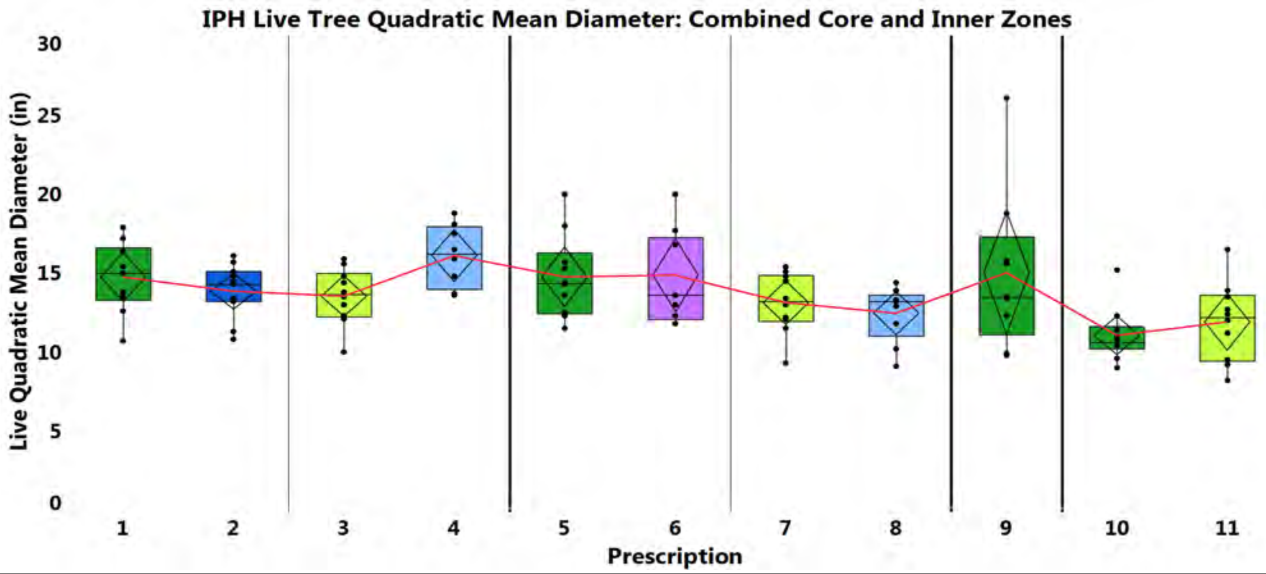
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
n	10	11	10	8	10	9	10	9	9	10	10
Median	182.0	201.0	174.5	148.5	227.0	238.0	243.5	323.0	269.0	431.5	348.5
Interquartile Rng	128.0	163.0	67.3	44.5	86.8	176.5	93.5	120.0	257.5	163.0	232.8
Mean	198.7	263.2	191.0	153.0	226.5	255.9	248.1	314.0	308.9	469.1	396.3
Std Err	23.9	34.2	13.0	9.5	20.7	29.3	19.3	28.0	67.5	57.4	61.6



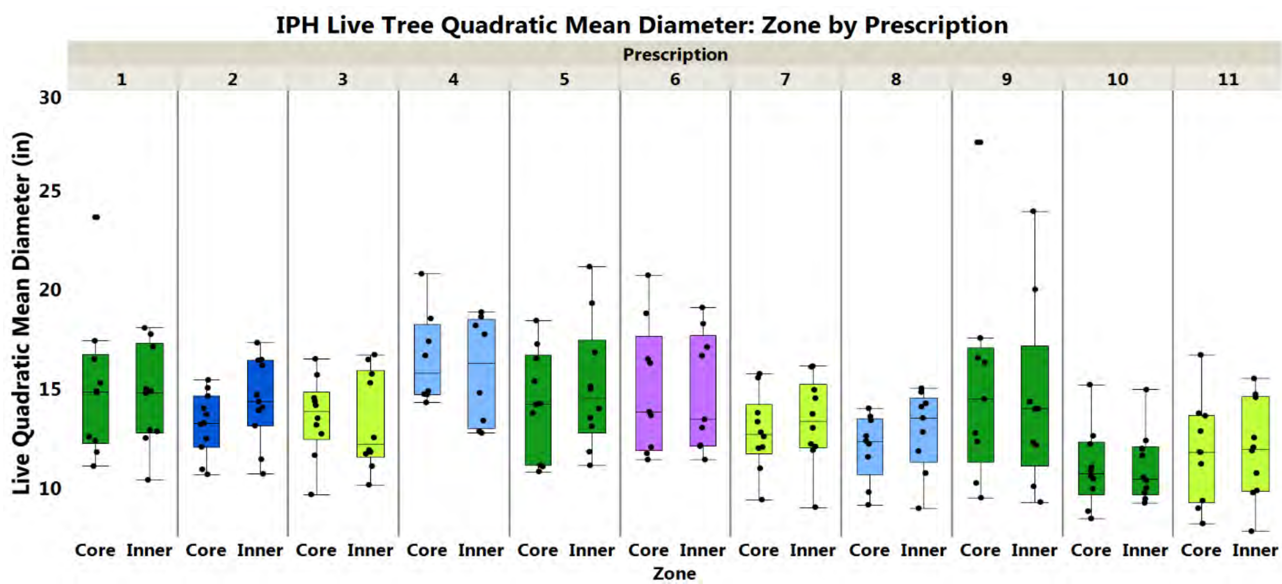


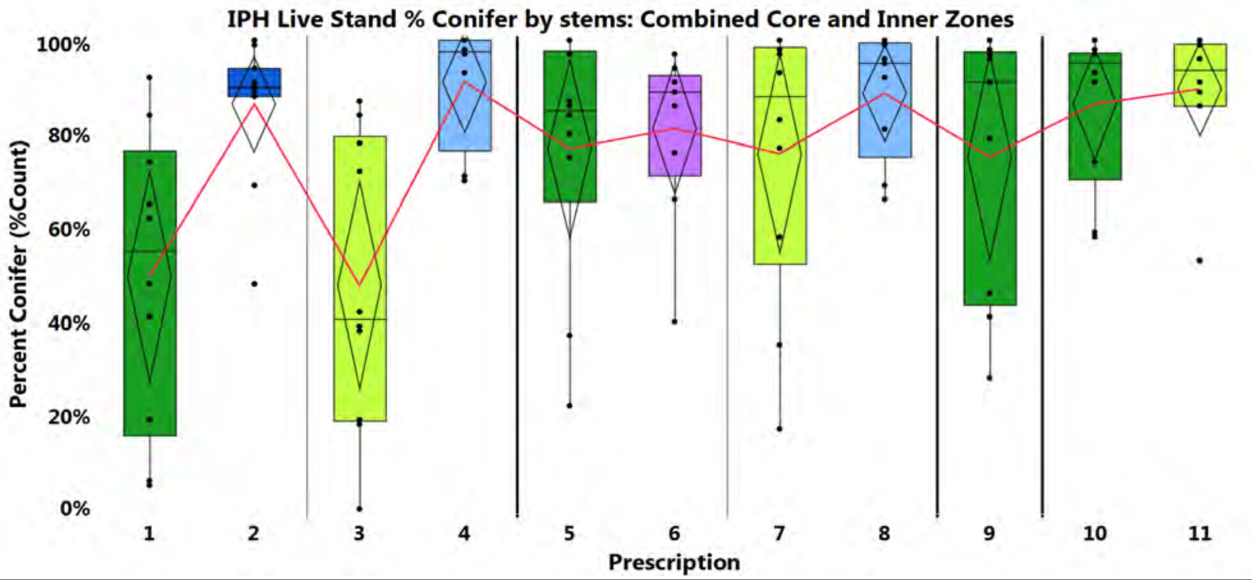
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
n	10	11	10	8	10	9	10	9	9	10	10
Median	200.50	231.00	183.00	200.00	248.00	267.00	220.00	241.00	288.00	290.00	261.50
Interquartile Rng	71.50	83.00	29.25	70.50	72.50	64.50	72.50	74.00	146.00	155.25	78.00
Mean	217.20	254.09	182.90	211.13	250.20	280.22	225.60	251.44	284.11	299.70	268.10
Std Err	14.40	16.15	8.05	12.69	12.90	14.18	17.46	15.45	26.47	28.22	18.61



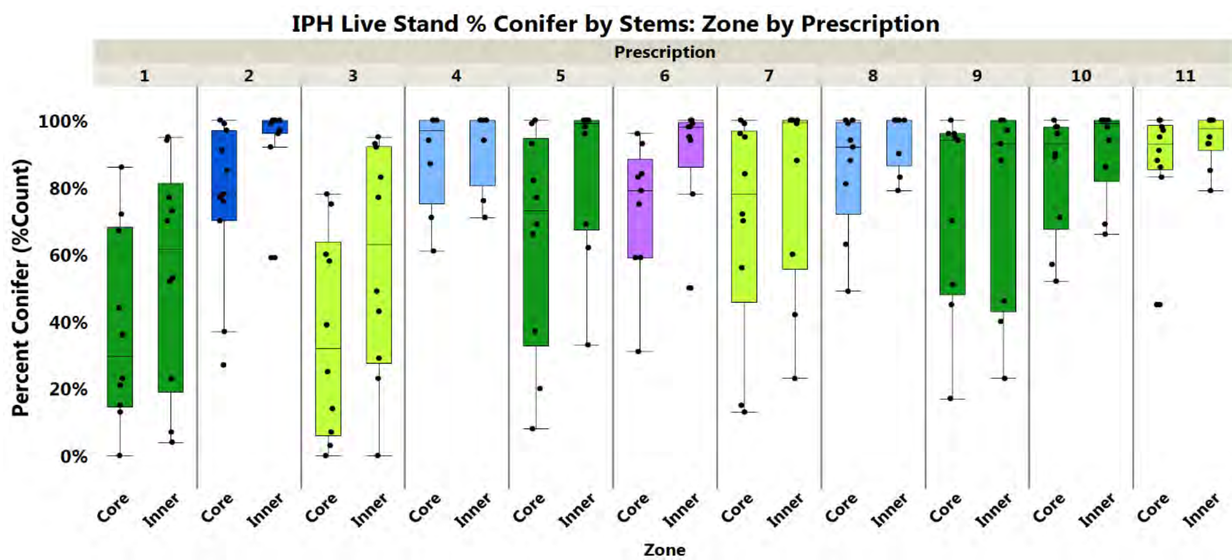


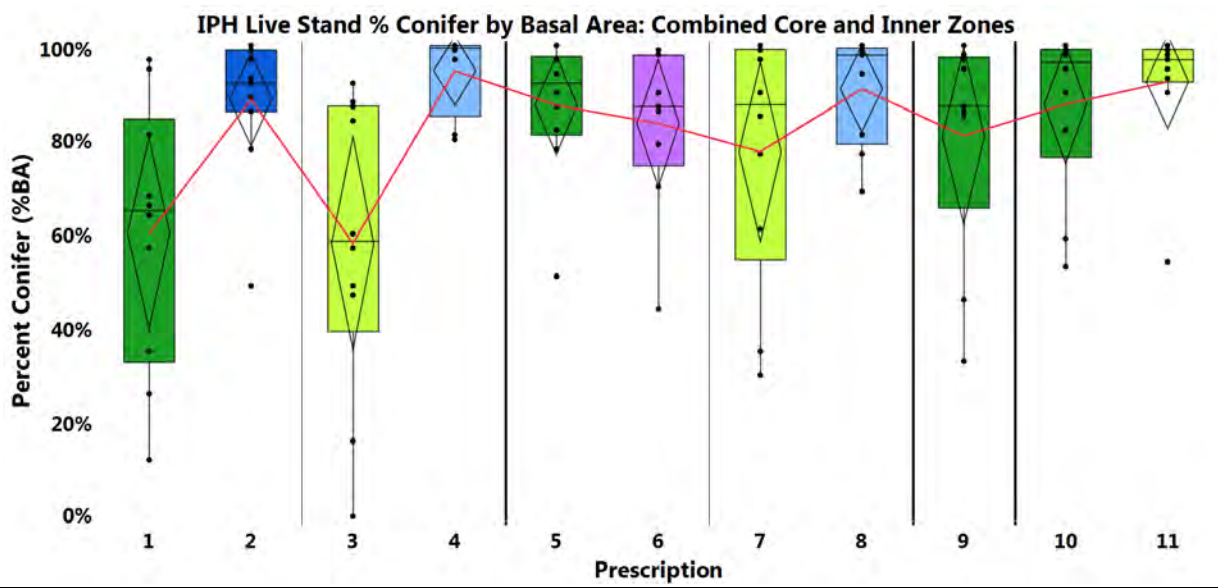
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
n	10	11	10	8	10	9	10	9	9	10	10
Median											
Interquartile Rng											
Mean											
Std Err											



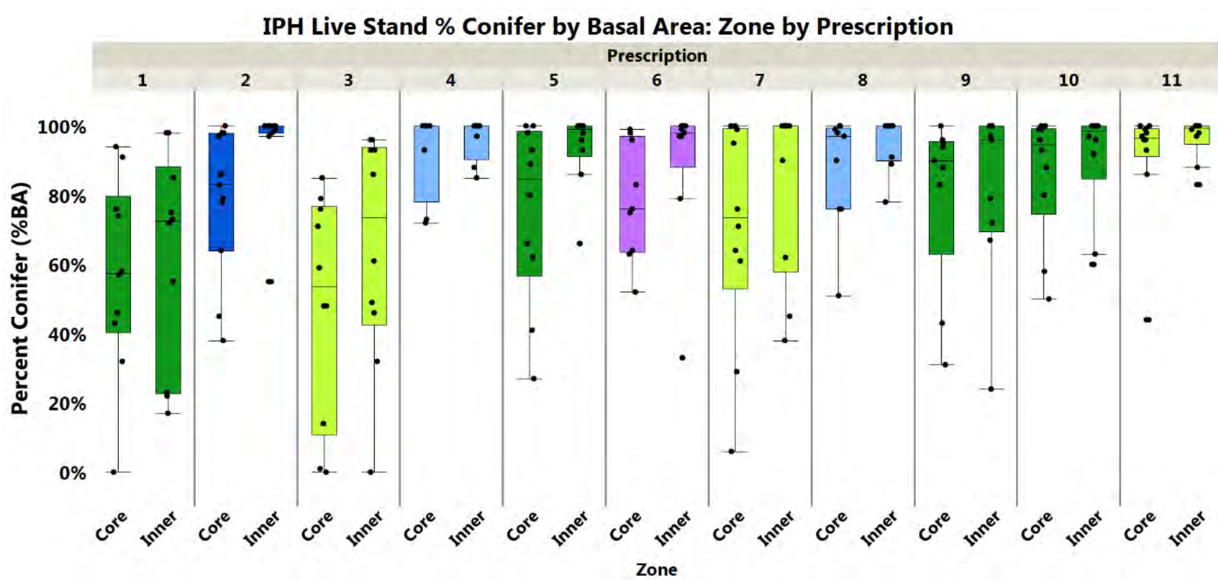


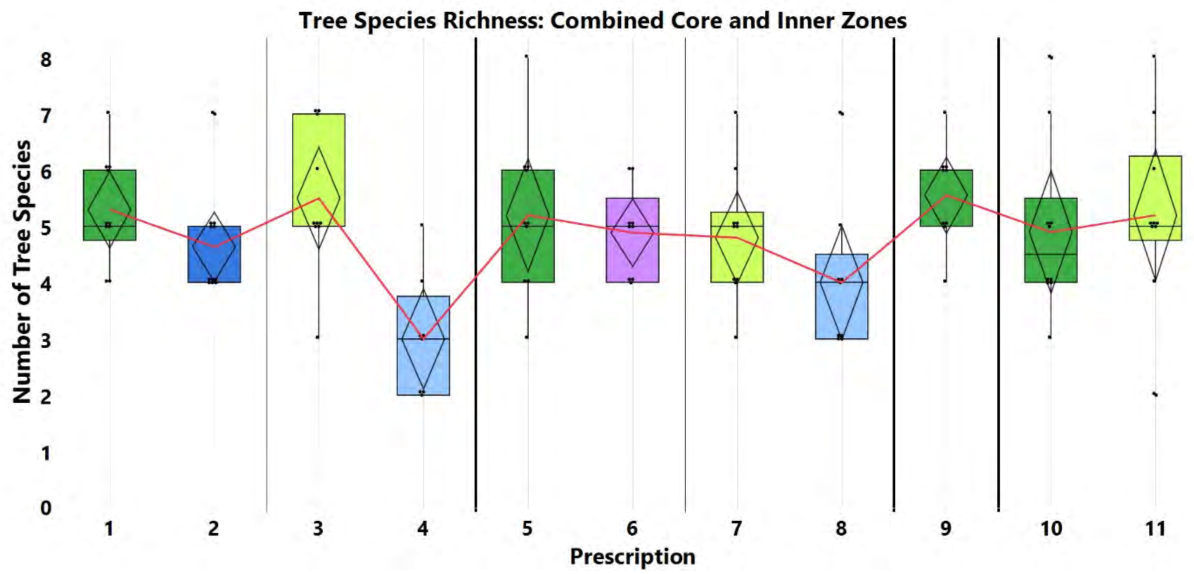
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



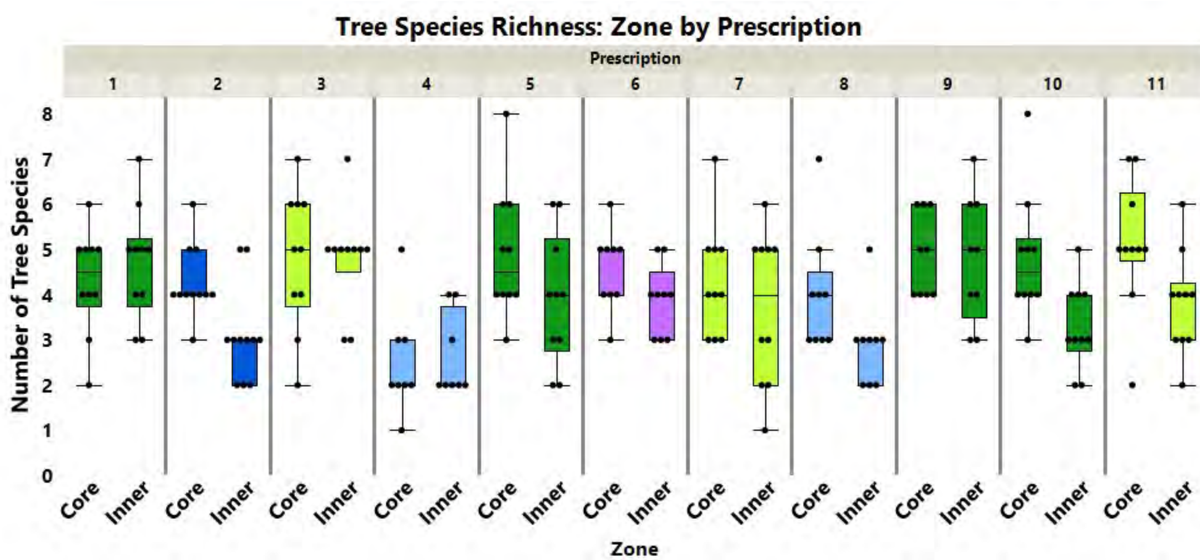


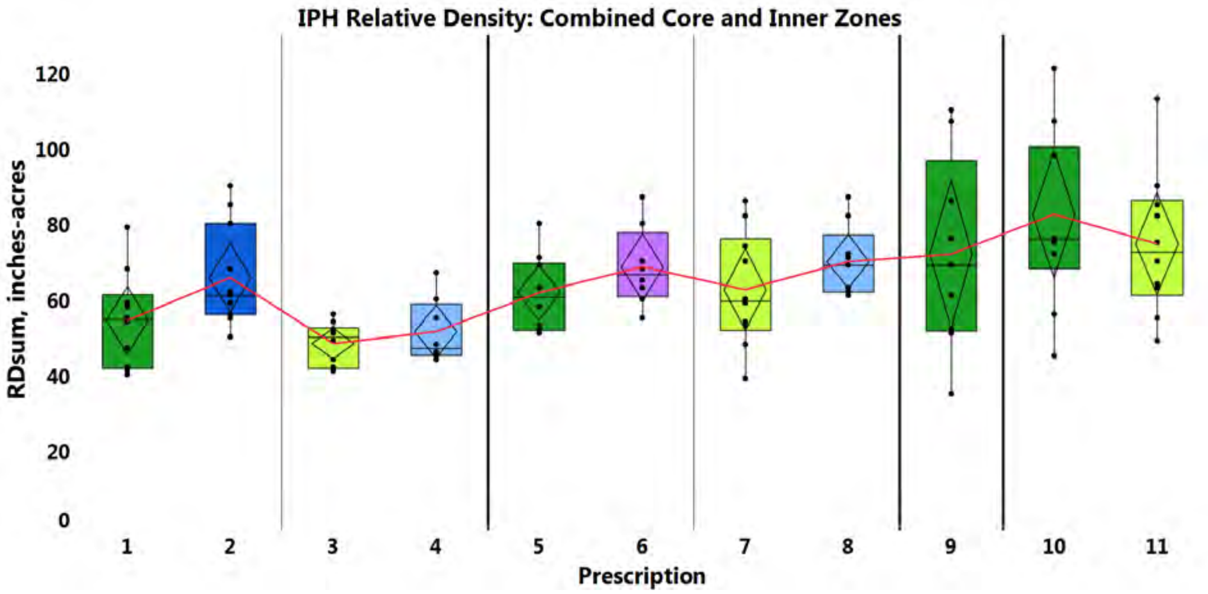
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



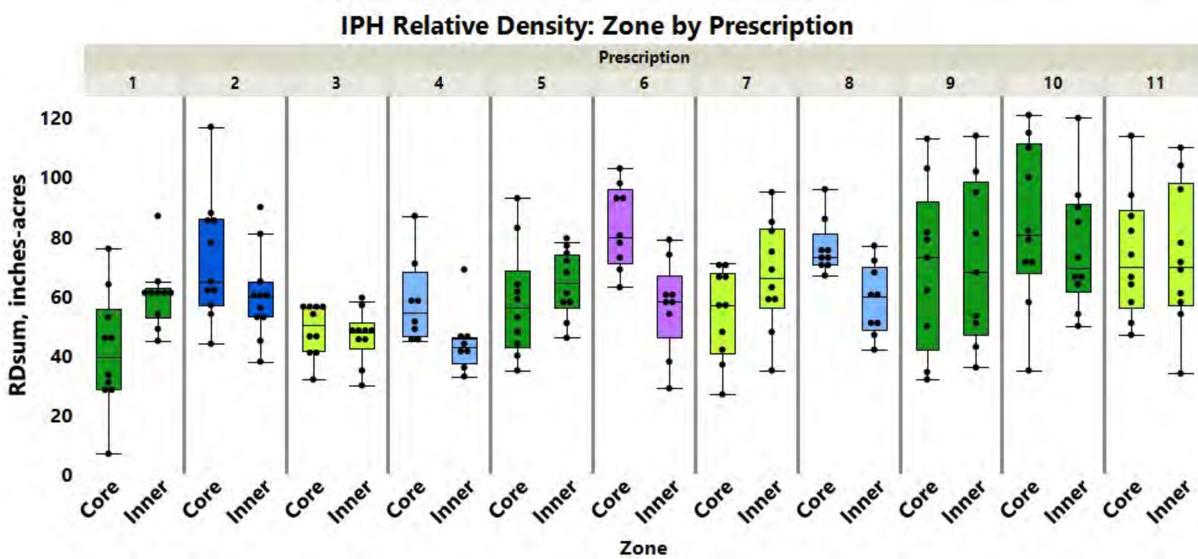


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

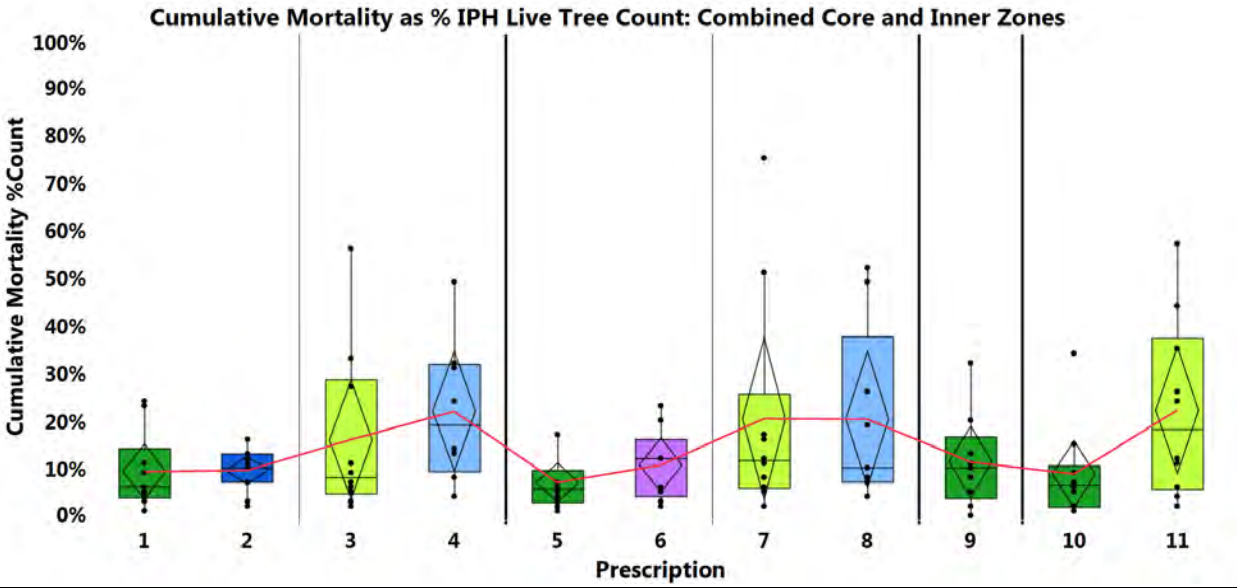




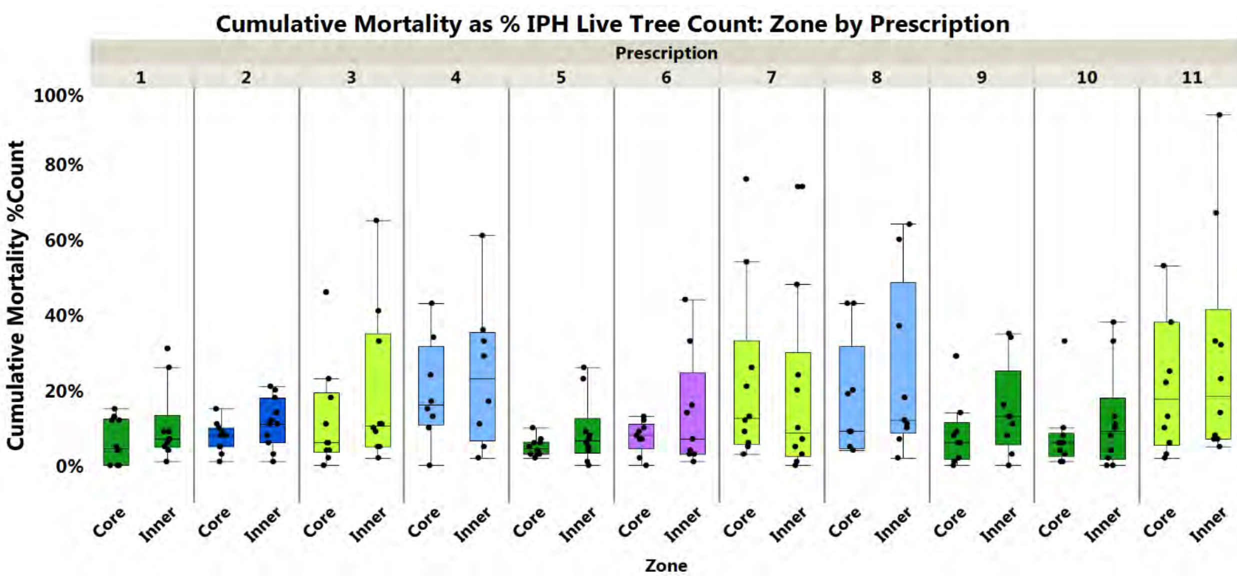
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

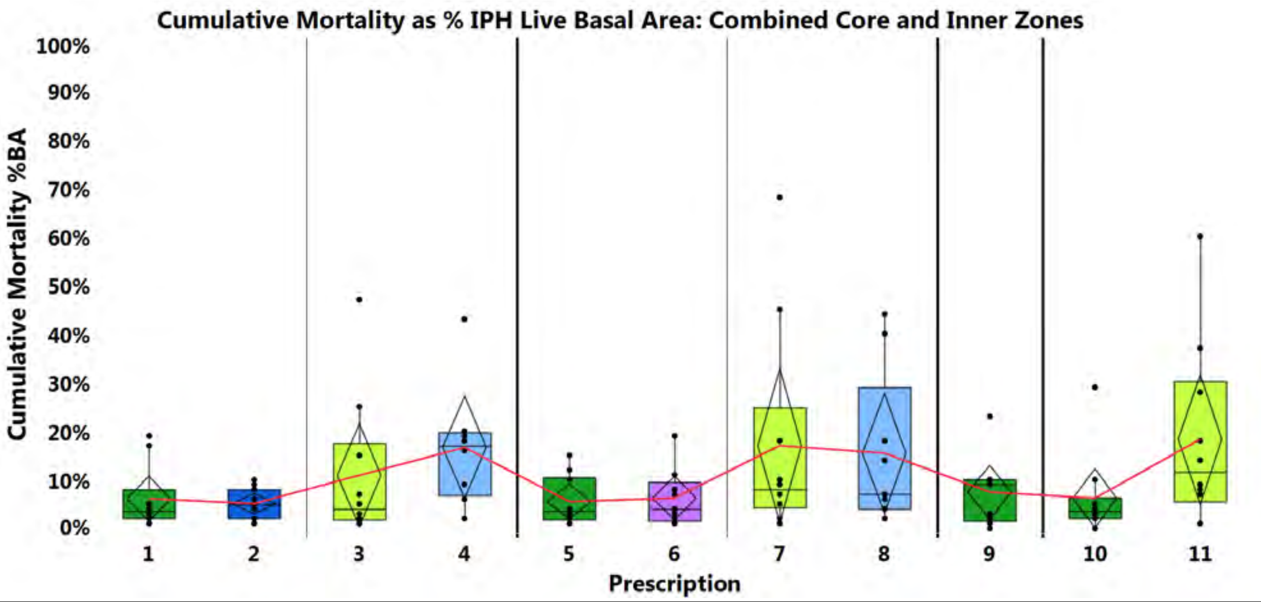


B-3. Mortality Metrics

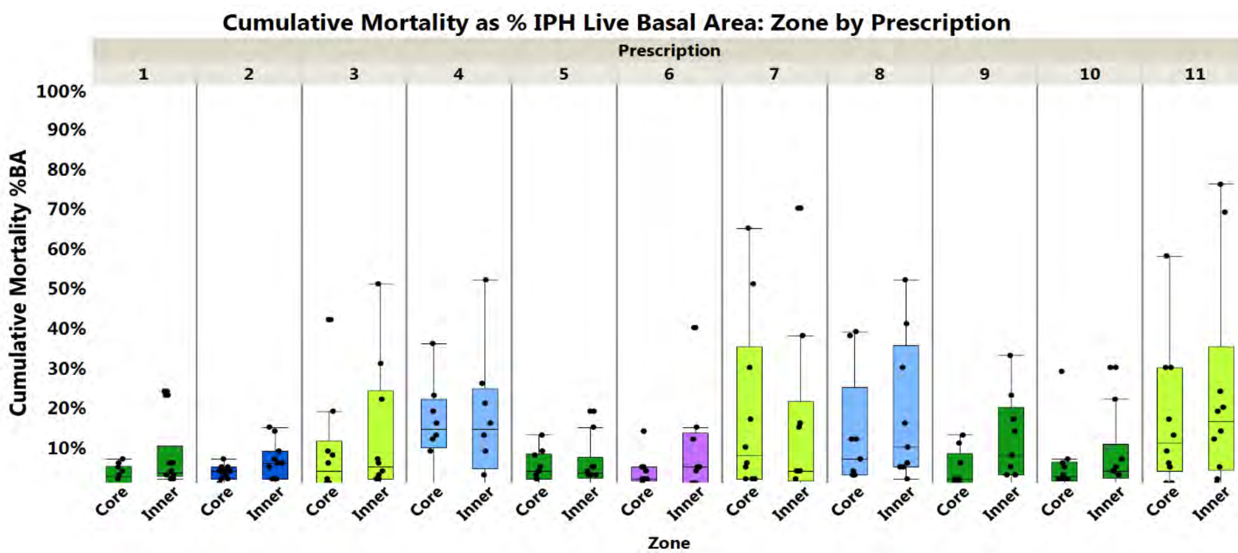


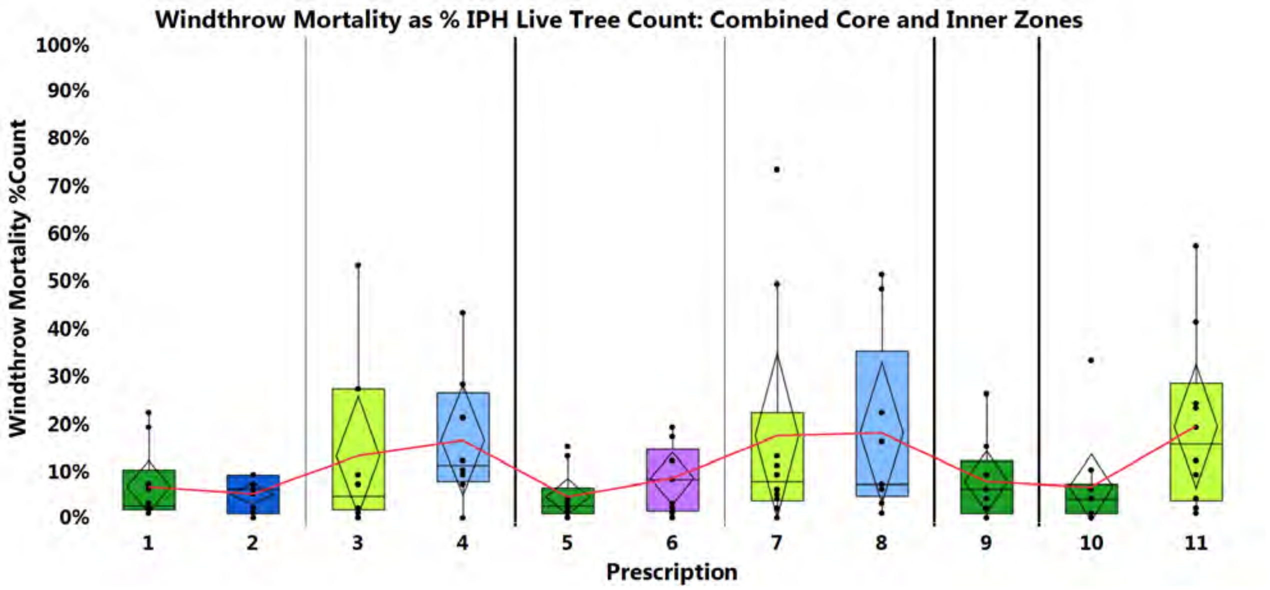
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



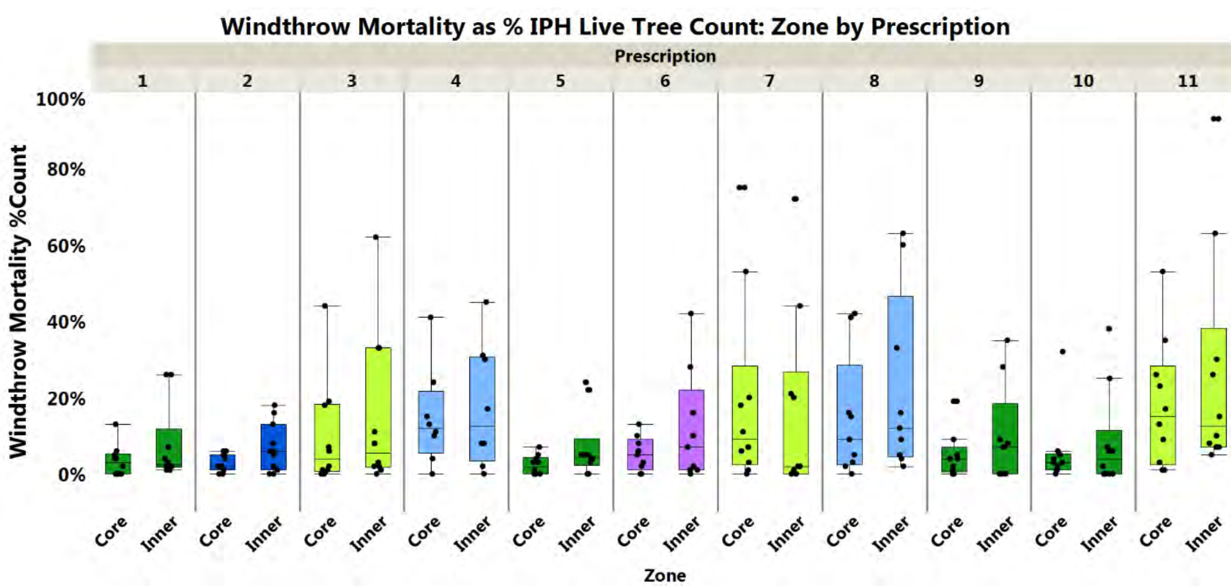


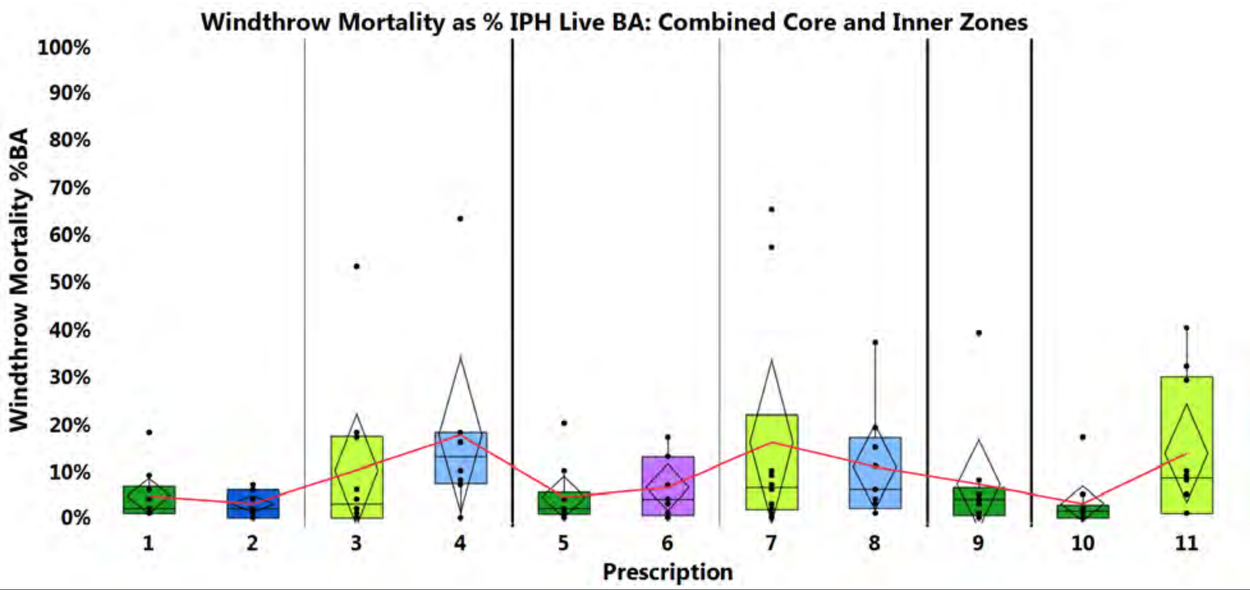
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



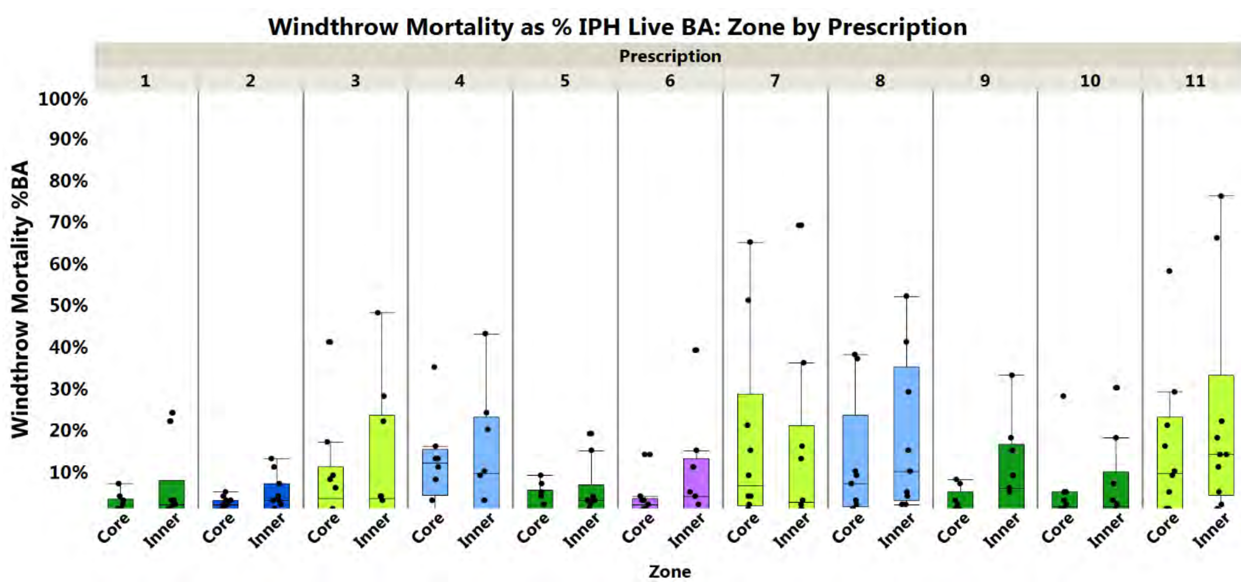


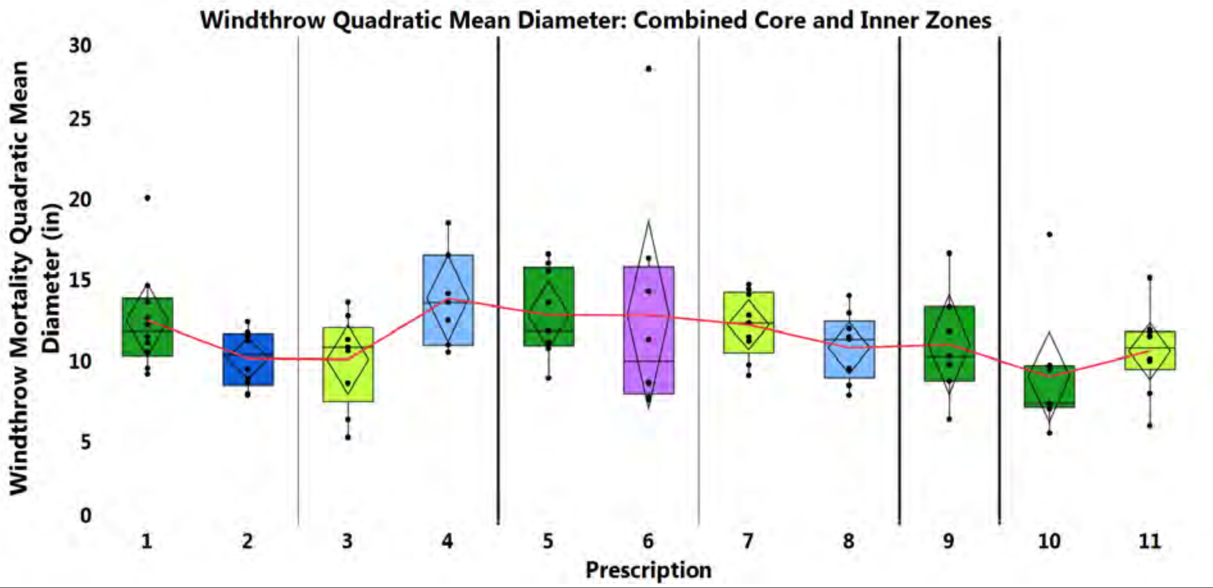
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



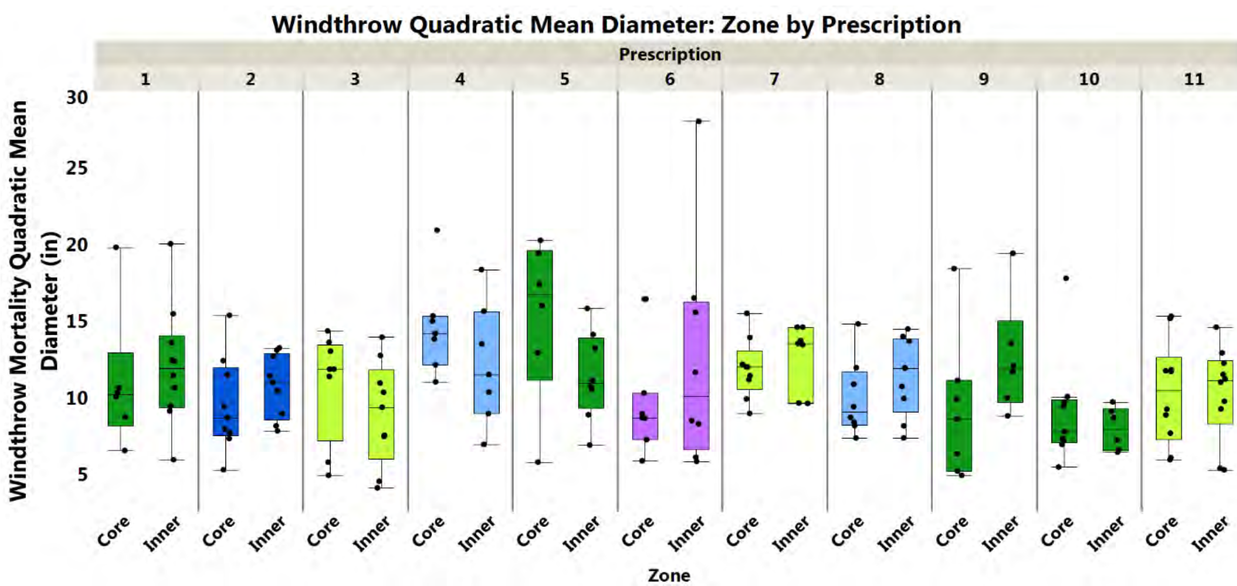


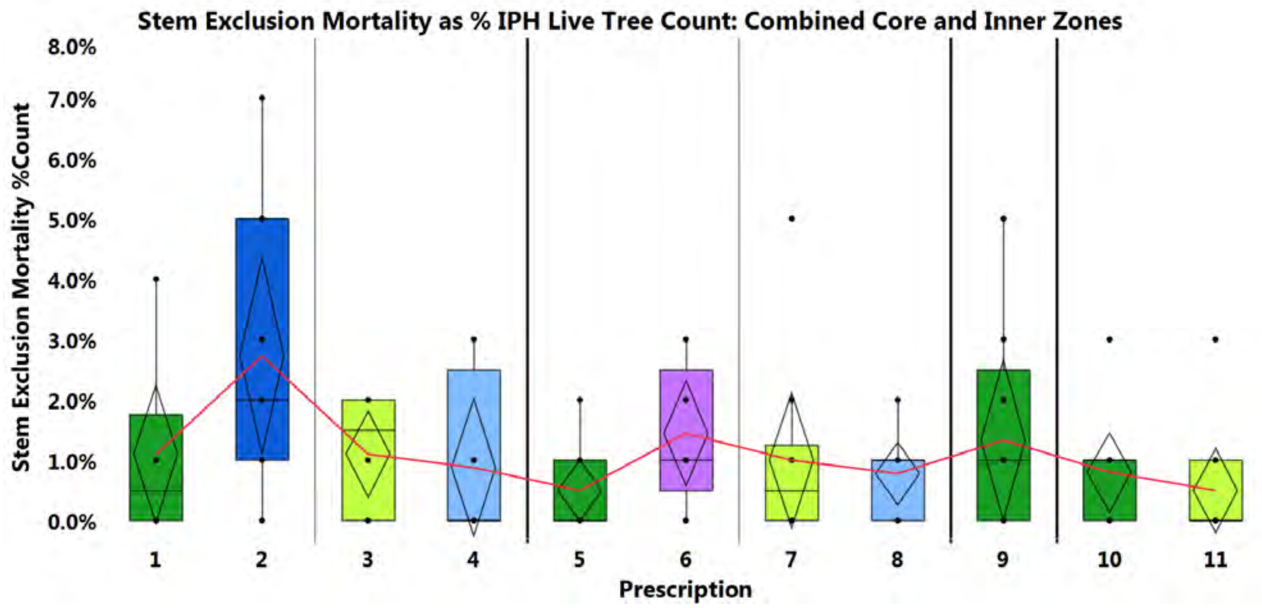
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



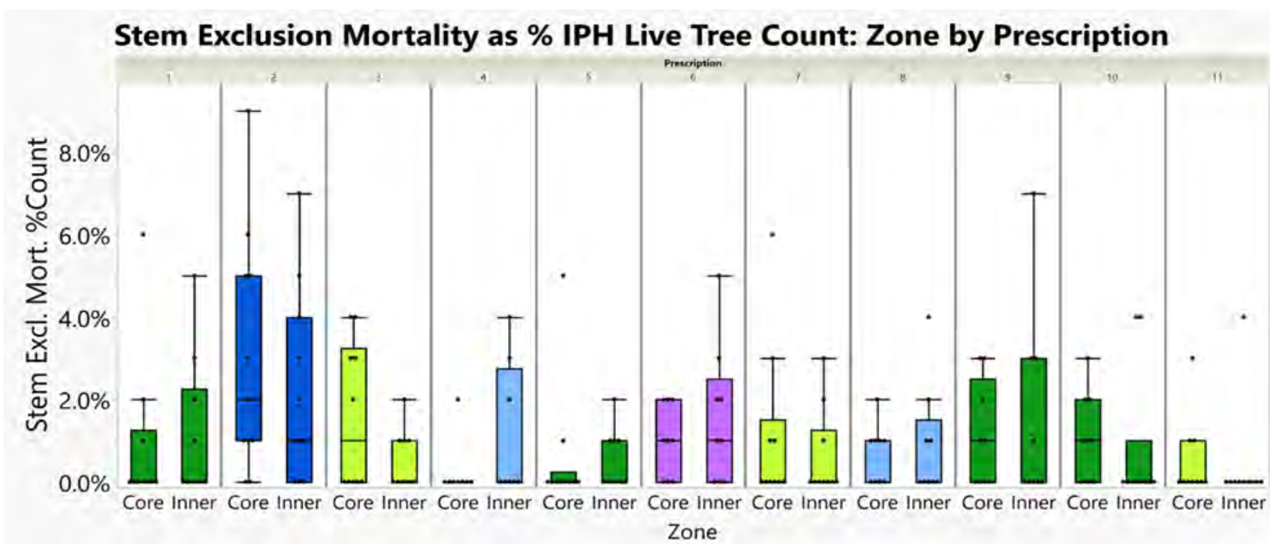


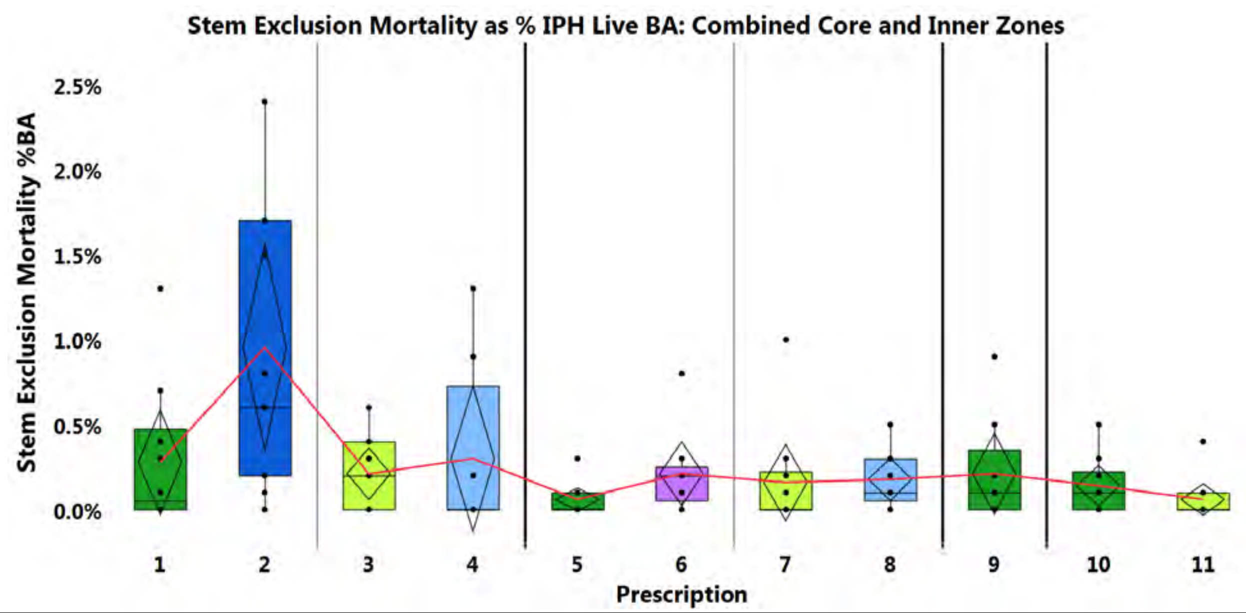
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



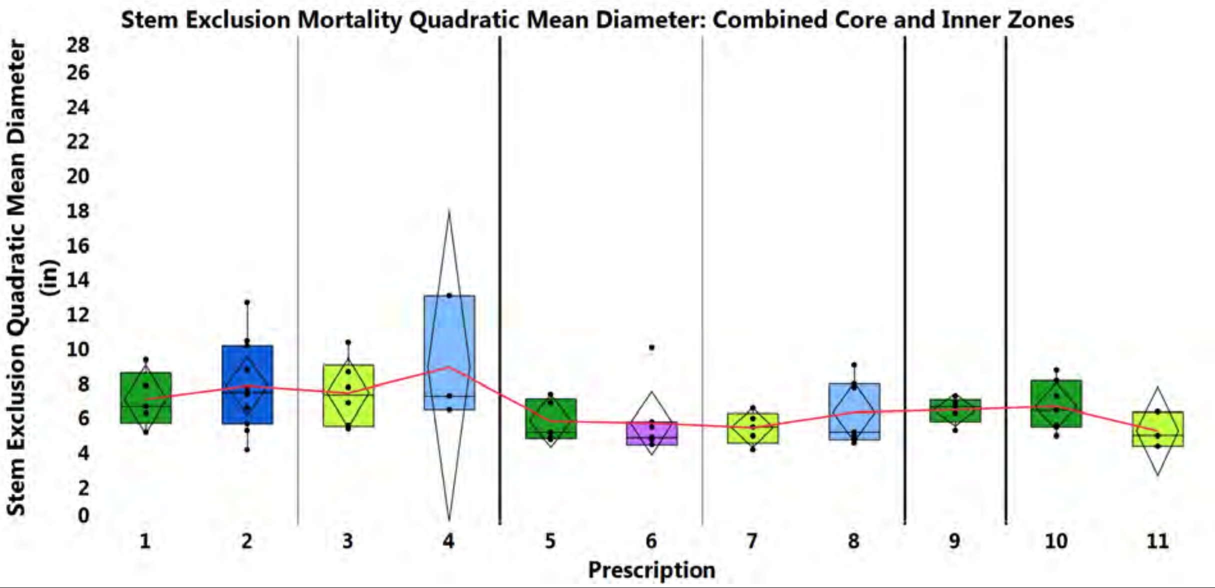


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



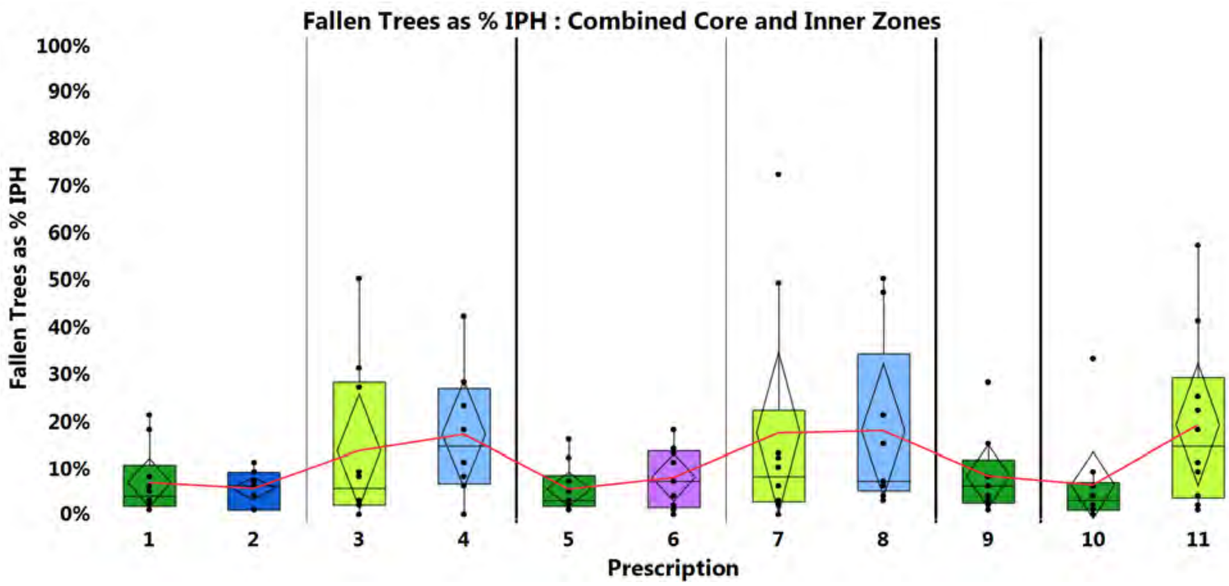


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

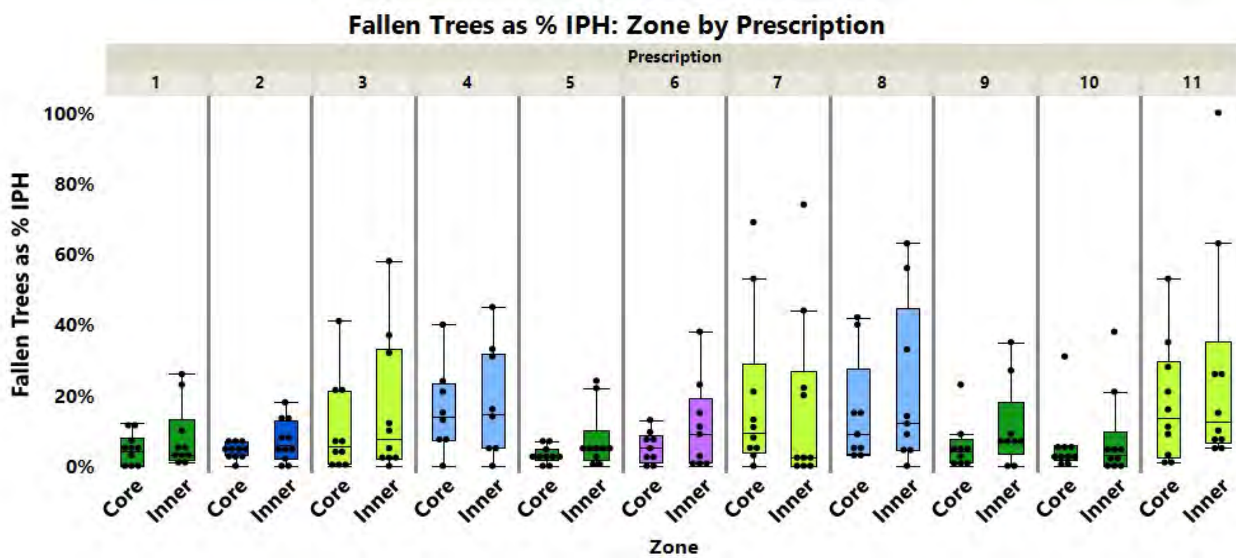


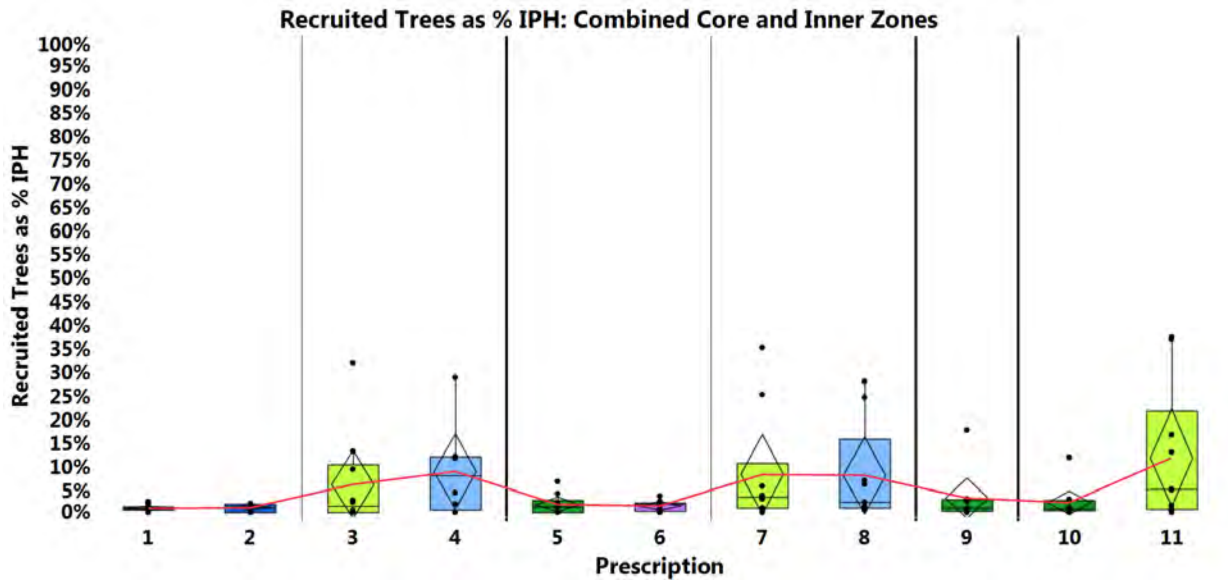
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

B-4. Recruitment Metrics

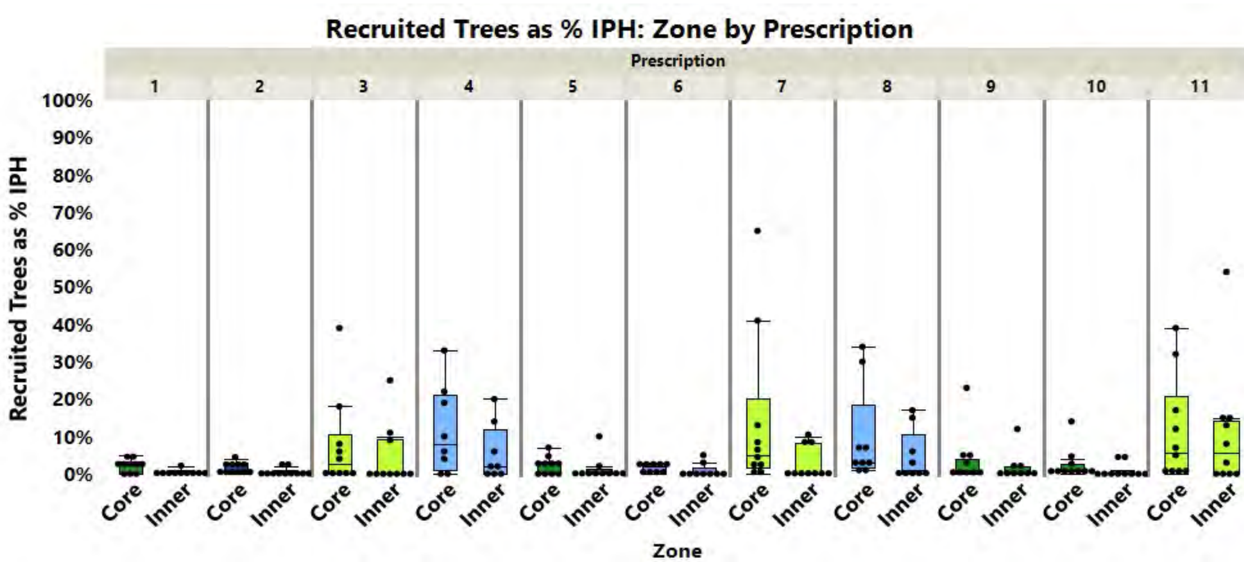


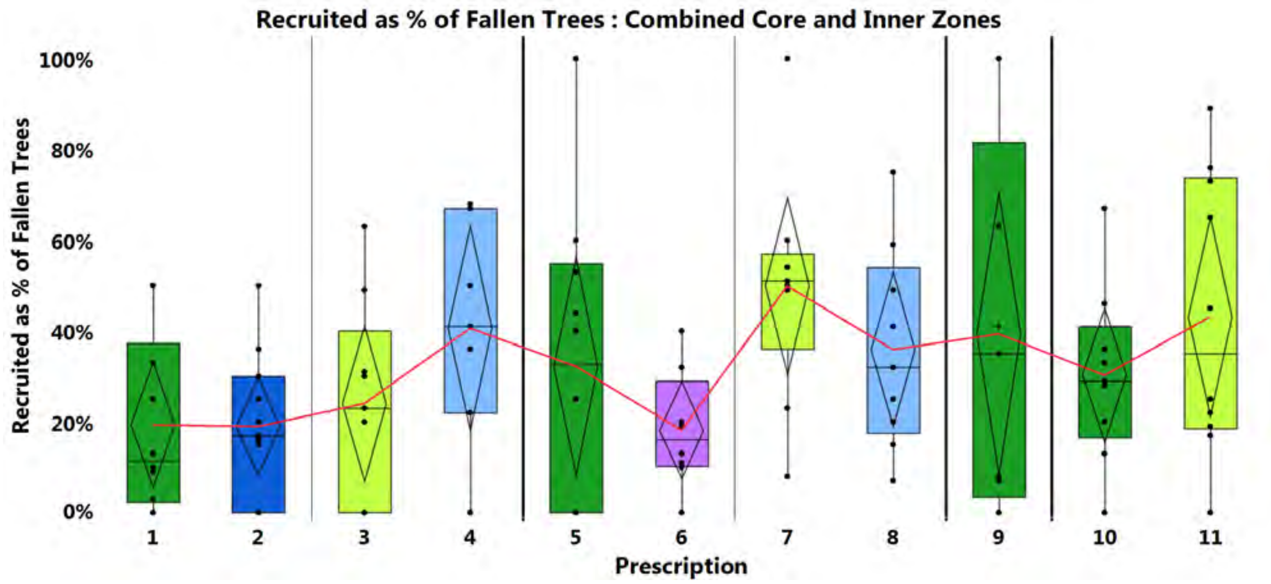
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



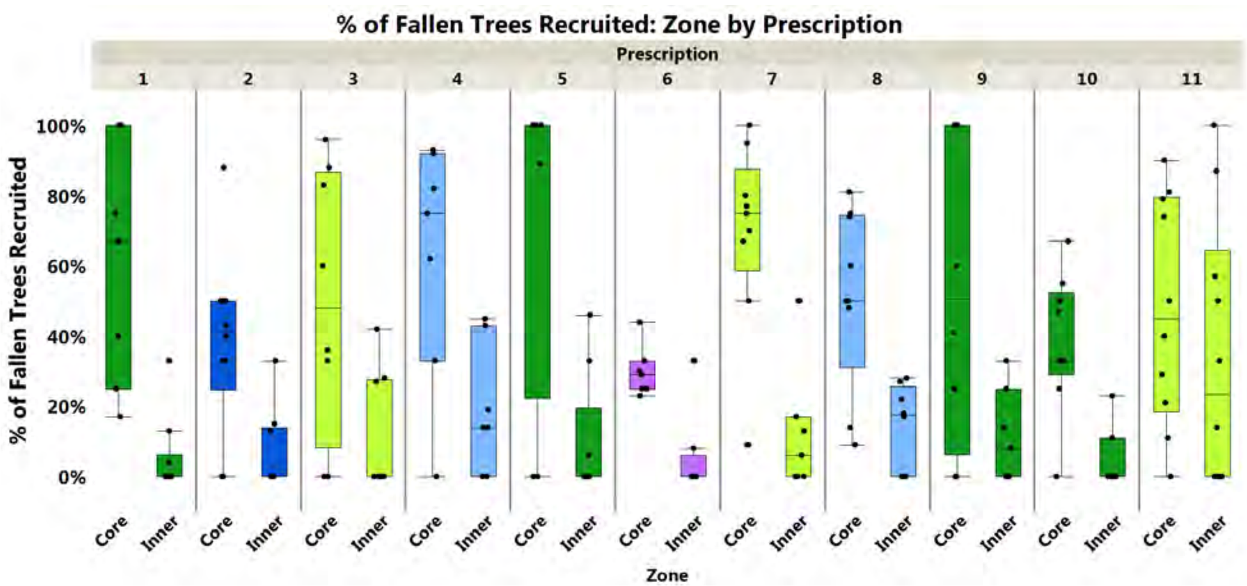


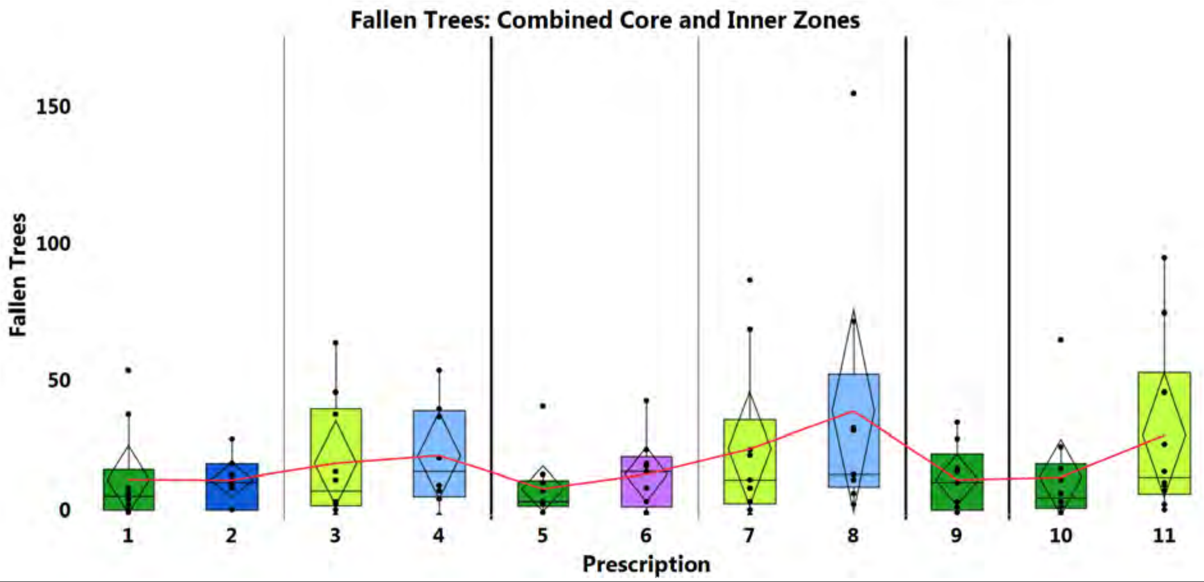
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



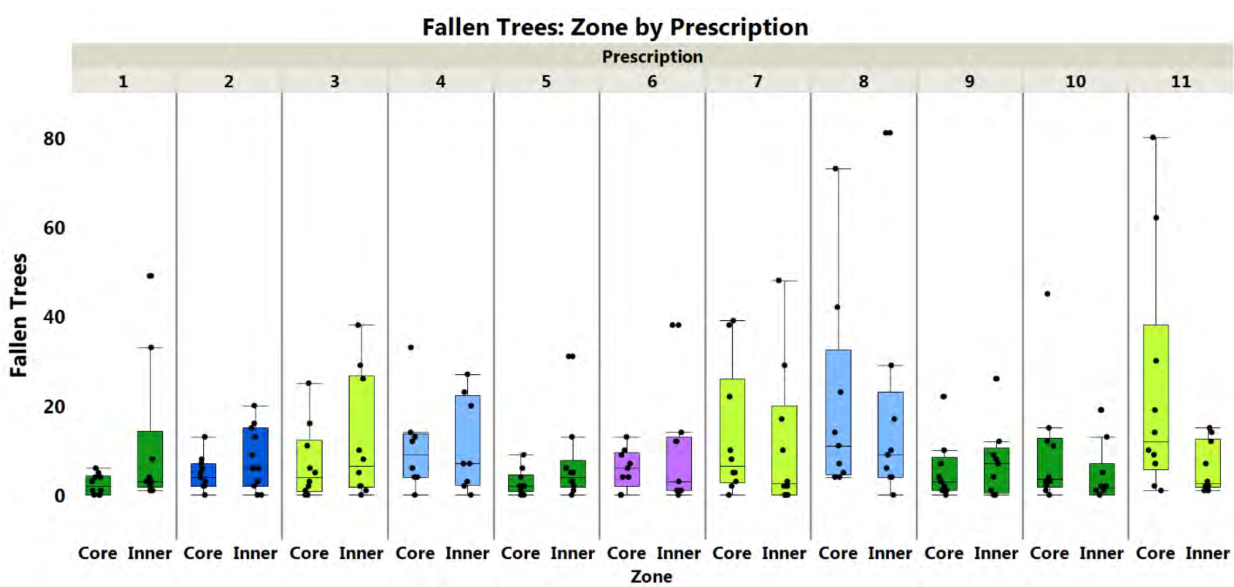


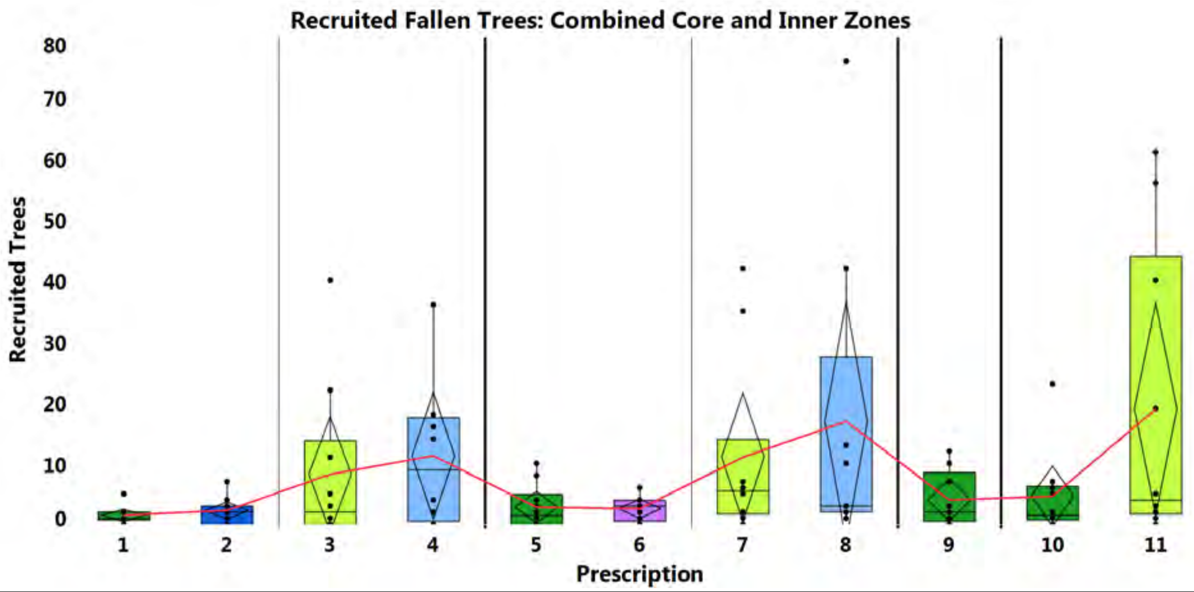
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



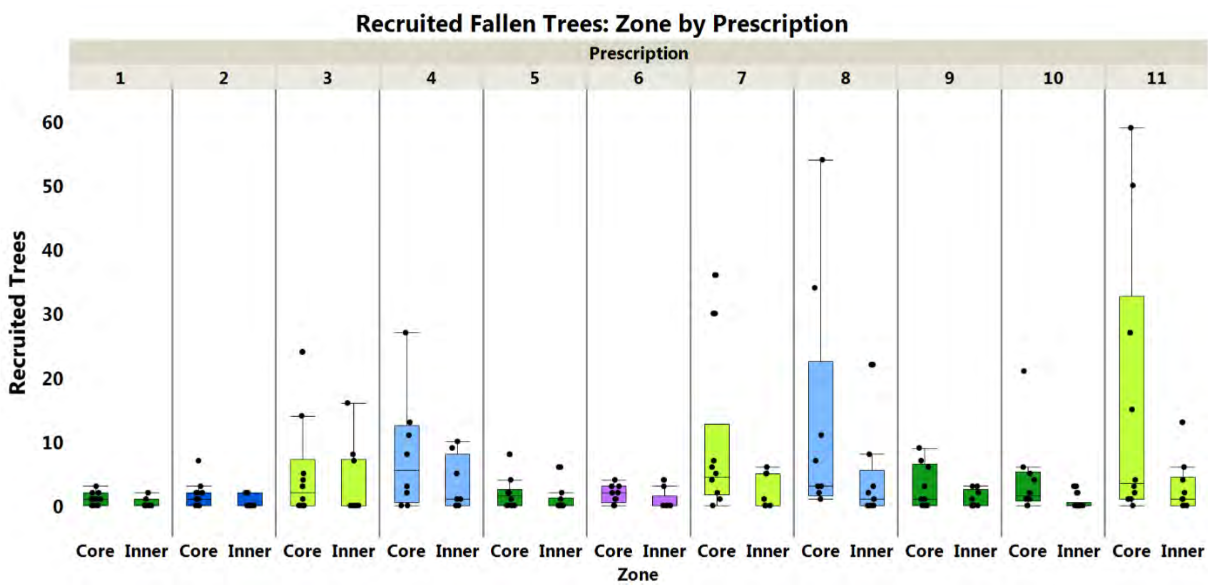


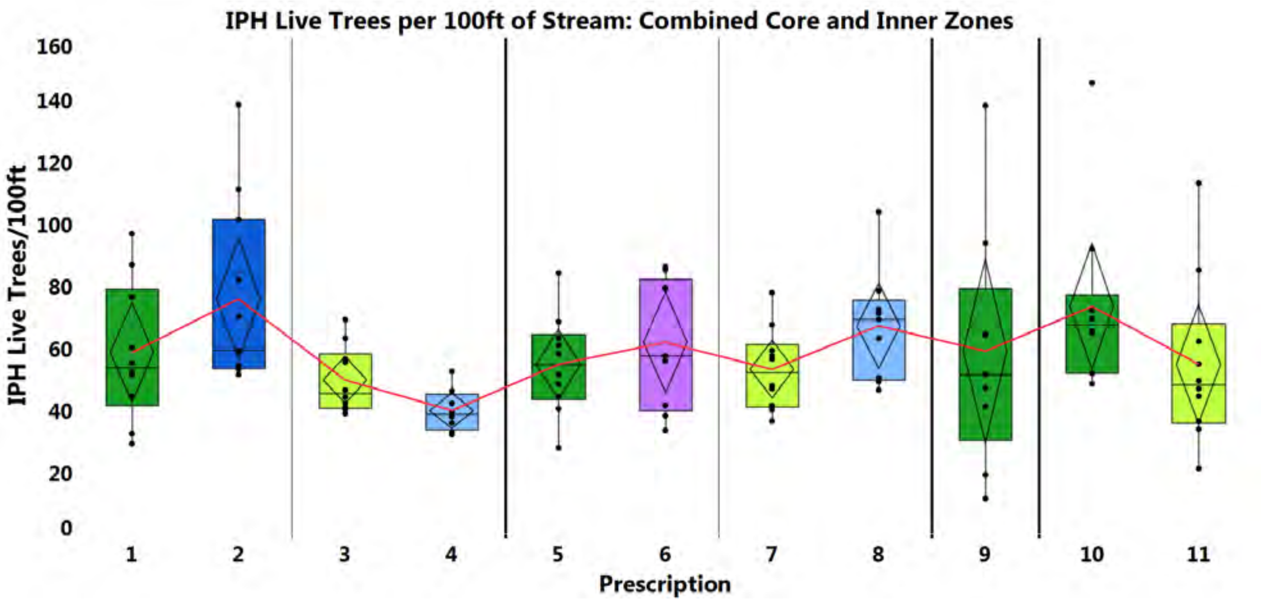
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



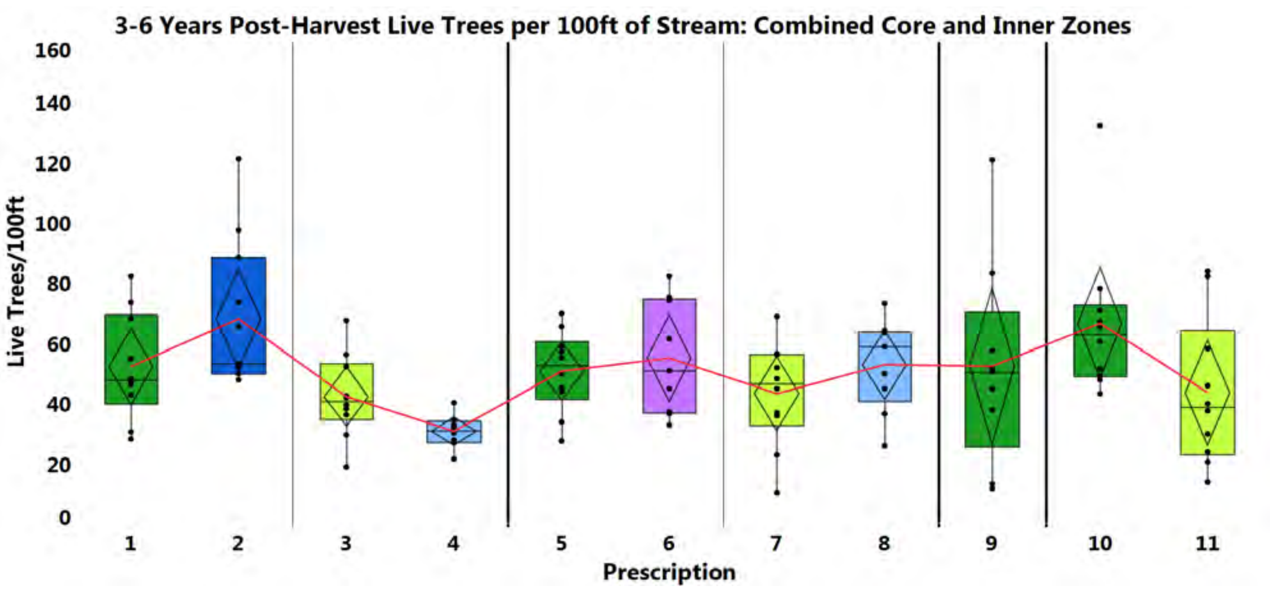


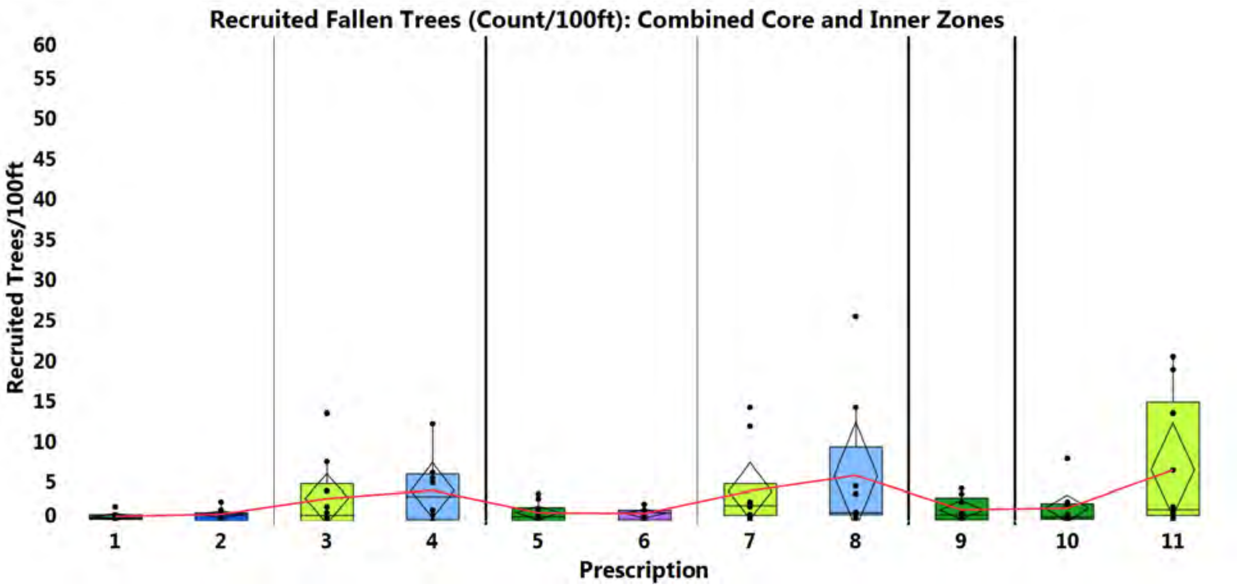
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



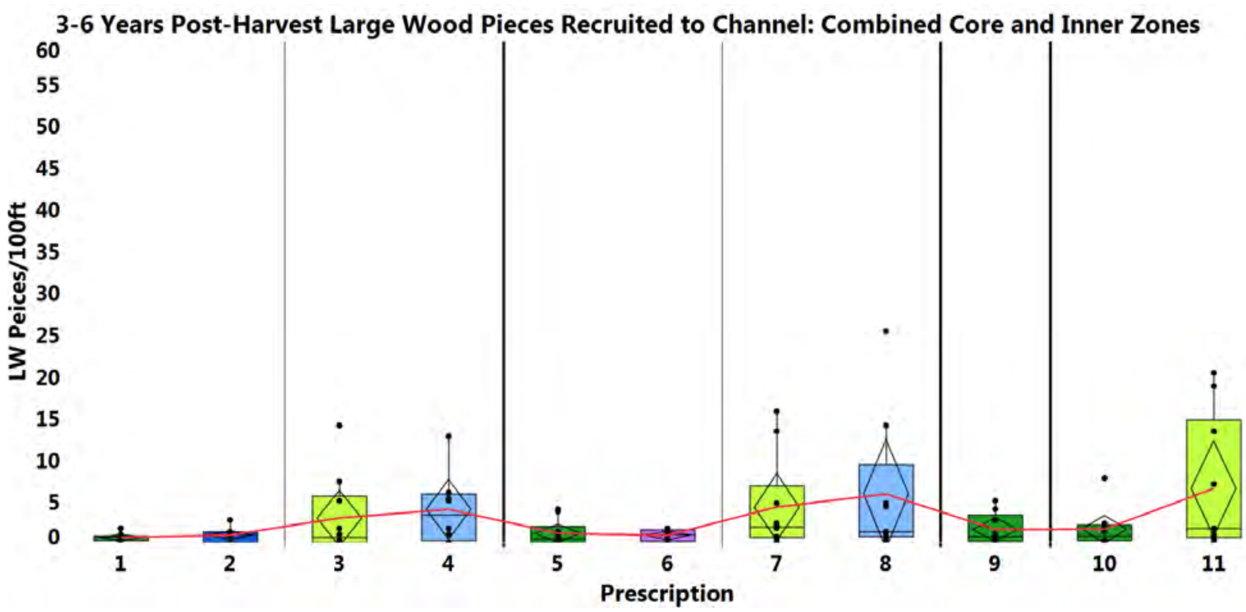


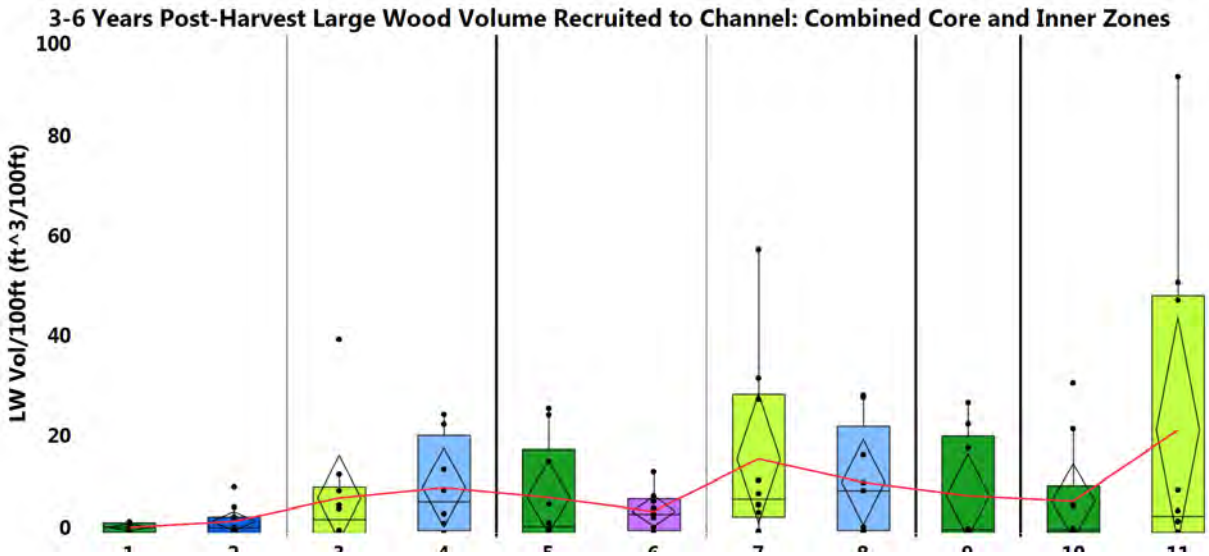
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+-	83	68	60



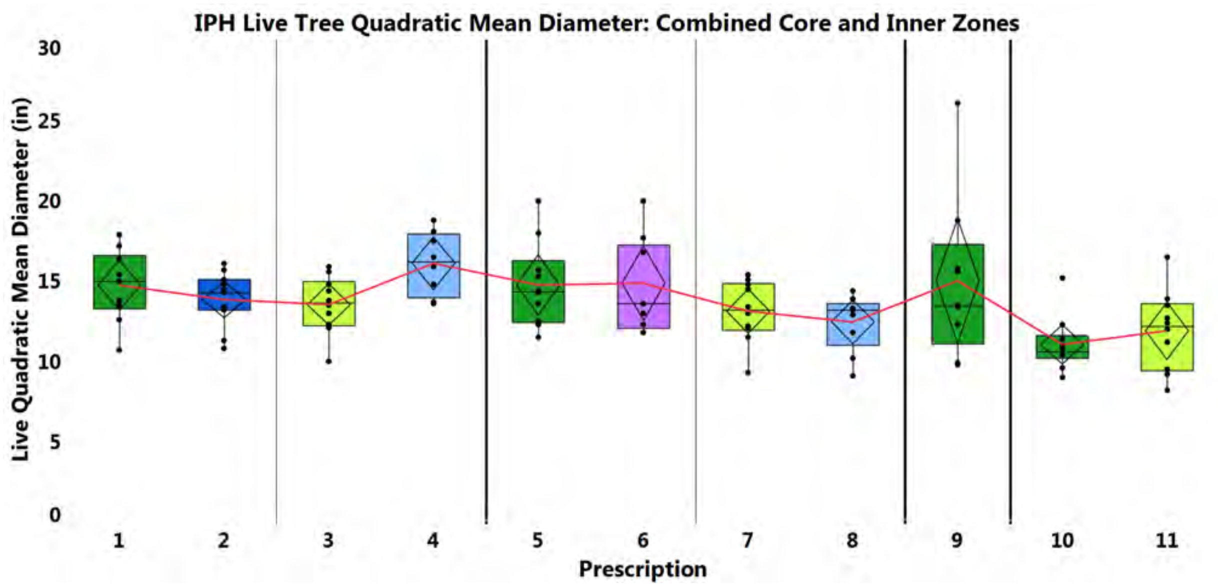


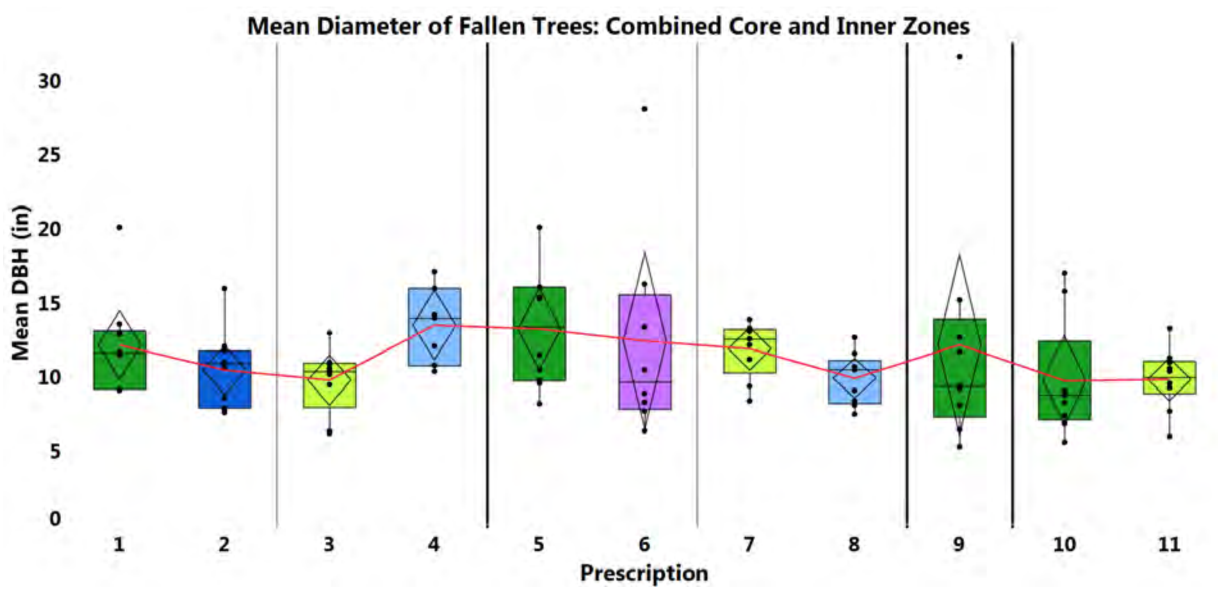
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

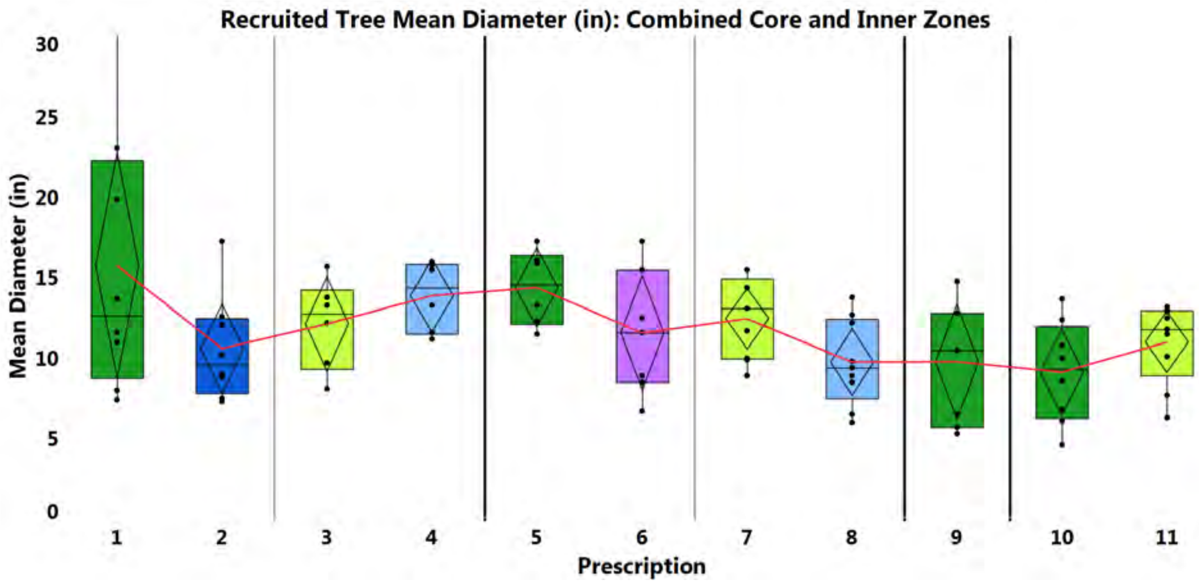




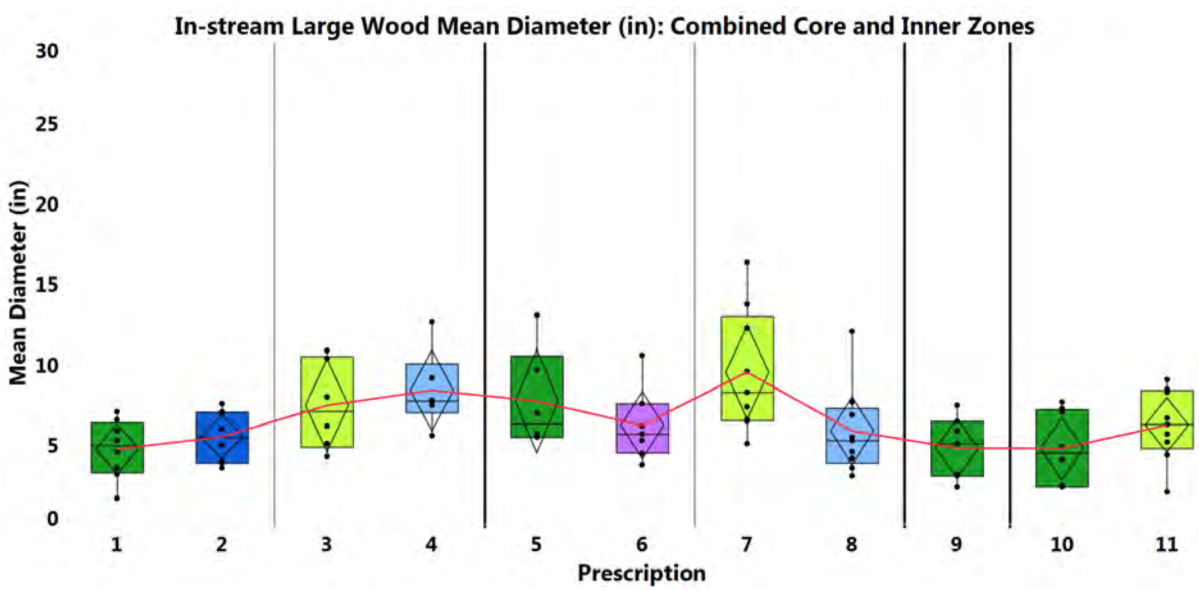
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60


IPH Live Tree Quadratic Mean Diameter: Combined Core and Inner Zones
Live Quadratic Mean Diameter (in)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
Prescription


Mean Diameter of Fallen Trees: Combined Core and Inner Zones
Mean DBH (in)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
Prescription

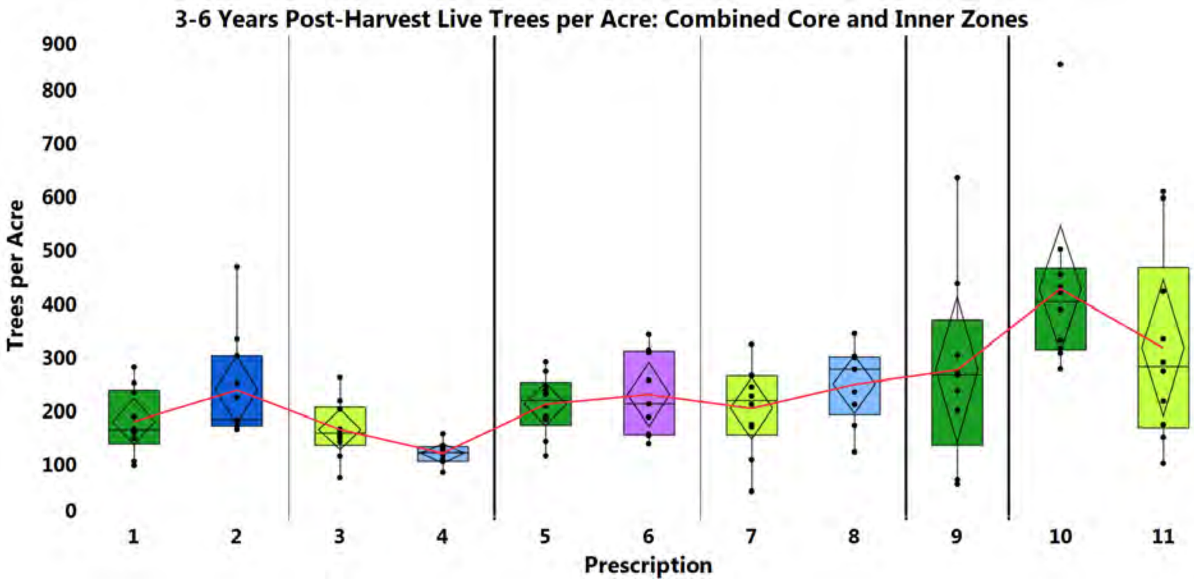


Recruited Tree Mean Diameter (in): Combined Core and Inner Zones
Mean Diameter (in)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
Prescription

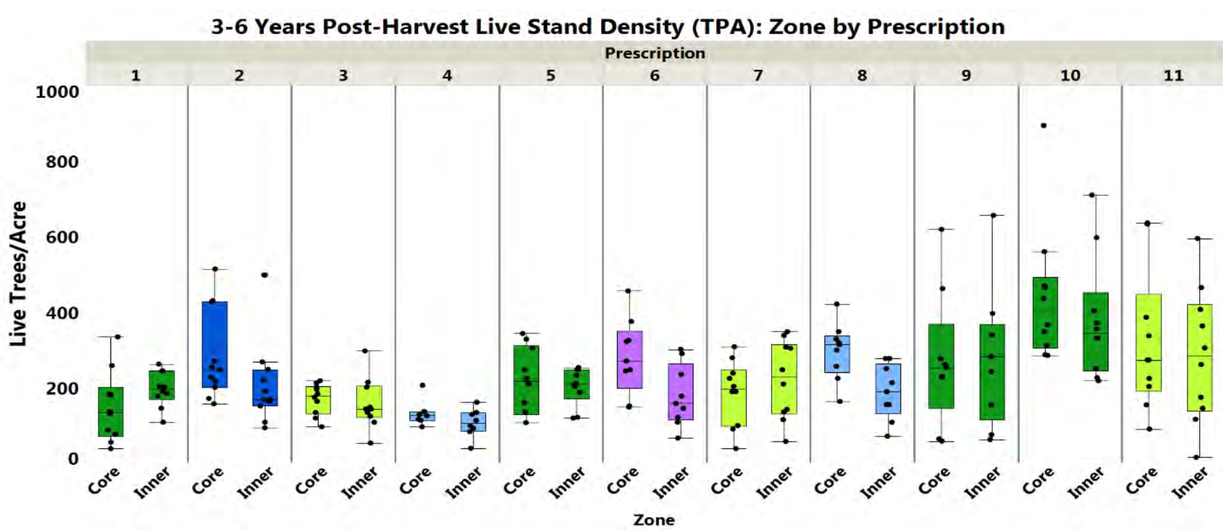


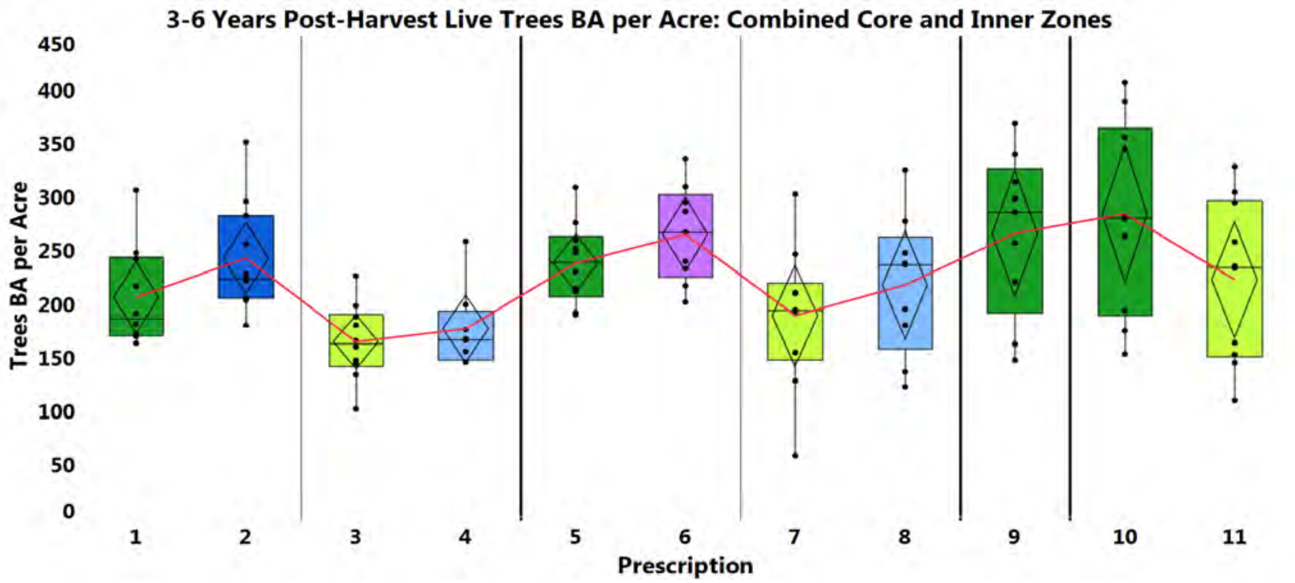
In-stream Large Wood Mean Diameter (in): Combined Core and Inner Zones
Mean Diameter (in)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
Prescription

B-5. 3 to 6 Years Post-Harvest (Yr3-6) Residual Stand Metrics

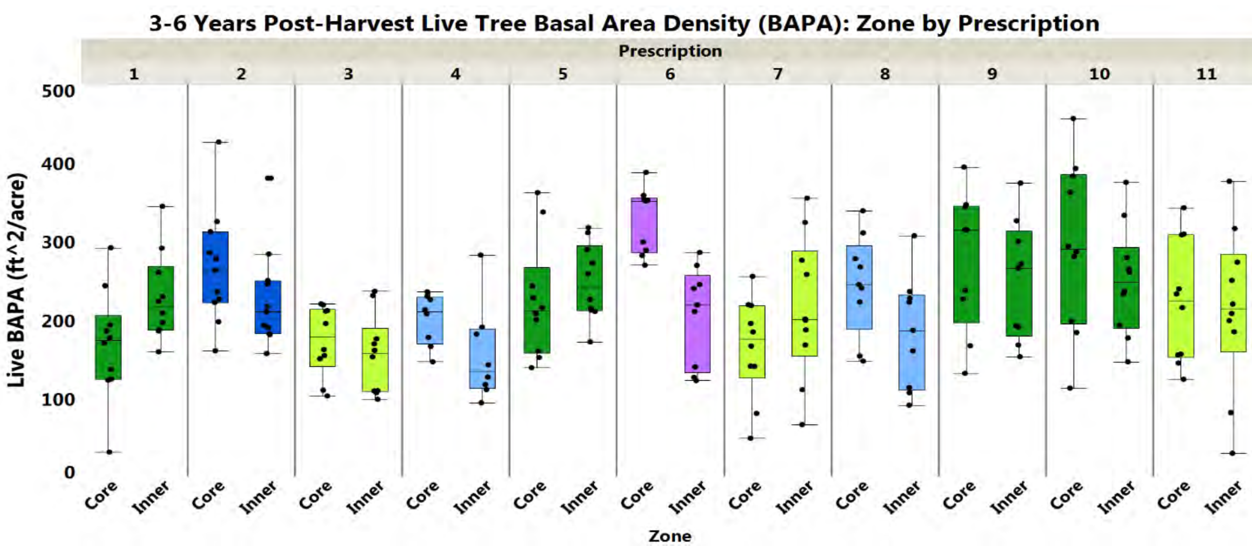


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

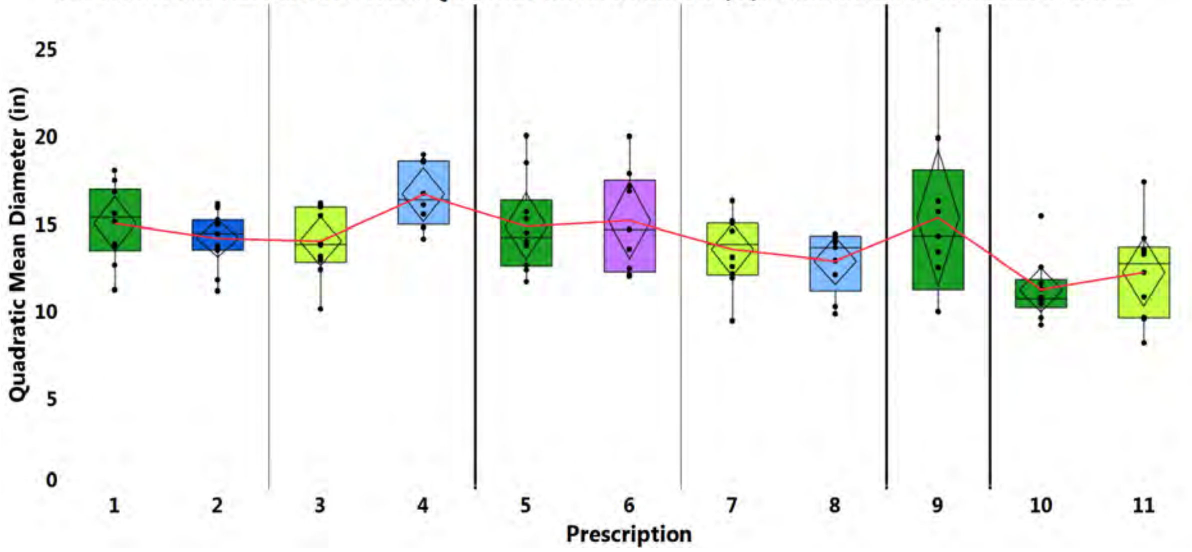




Site Class	II				III				IV	V	
Stream Width	L		S				S		L	L	S
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

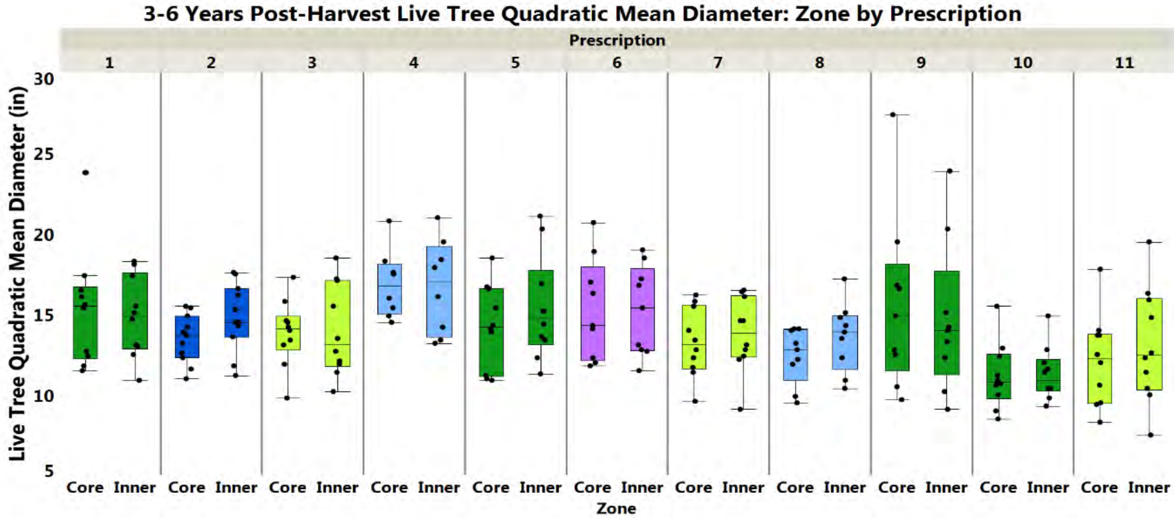


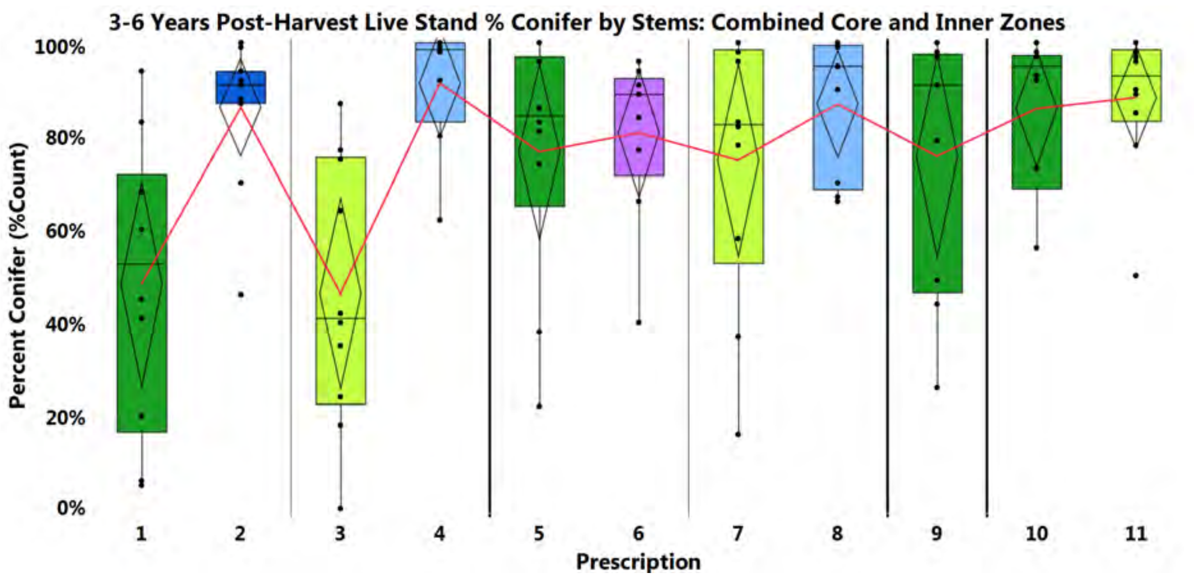
3-6 Years Post-Harvest Live Trees Quadratic Mean Diameter (in): Combined Core and Inner Zones



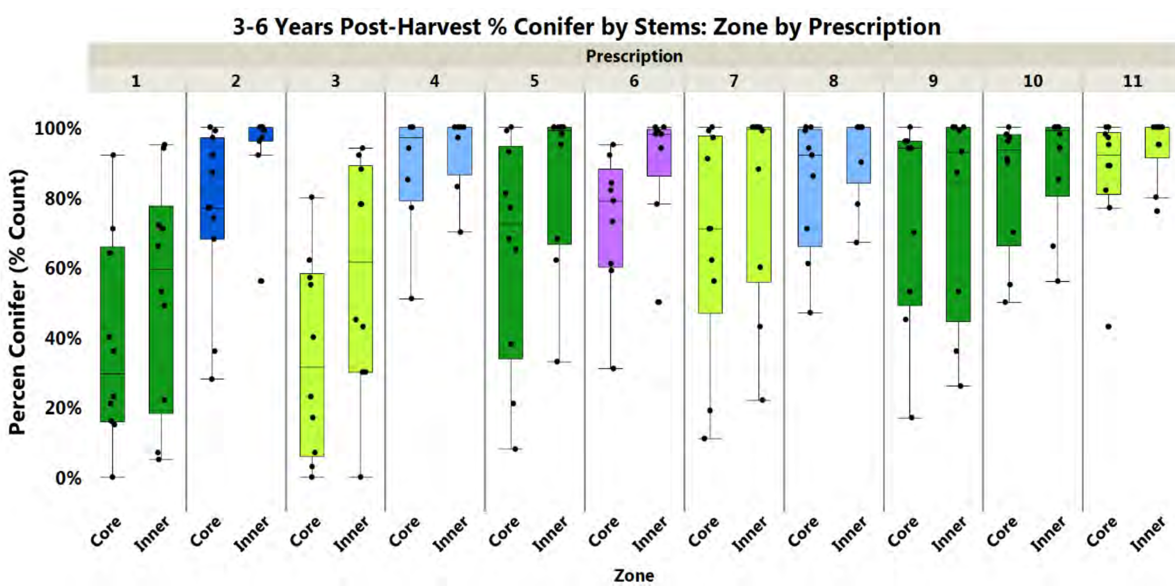
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

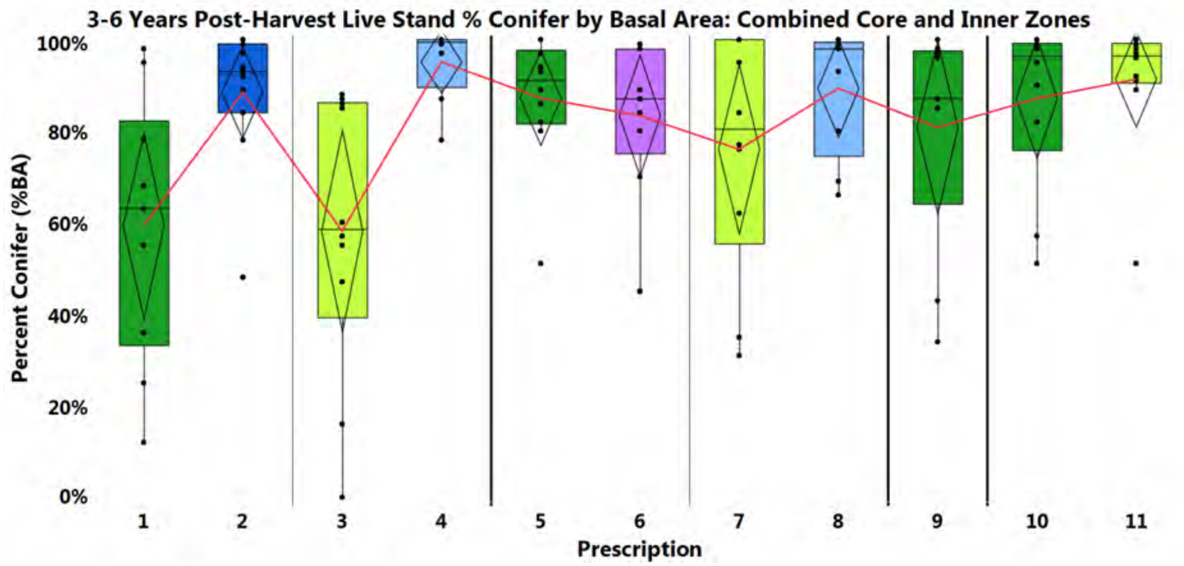
3-6 Years Post-Harvest Live Tree Quadratic Mean Diameter: Zone by Prescription

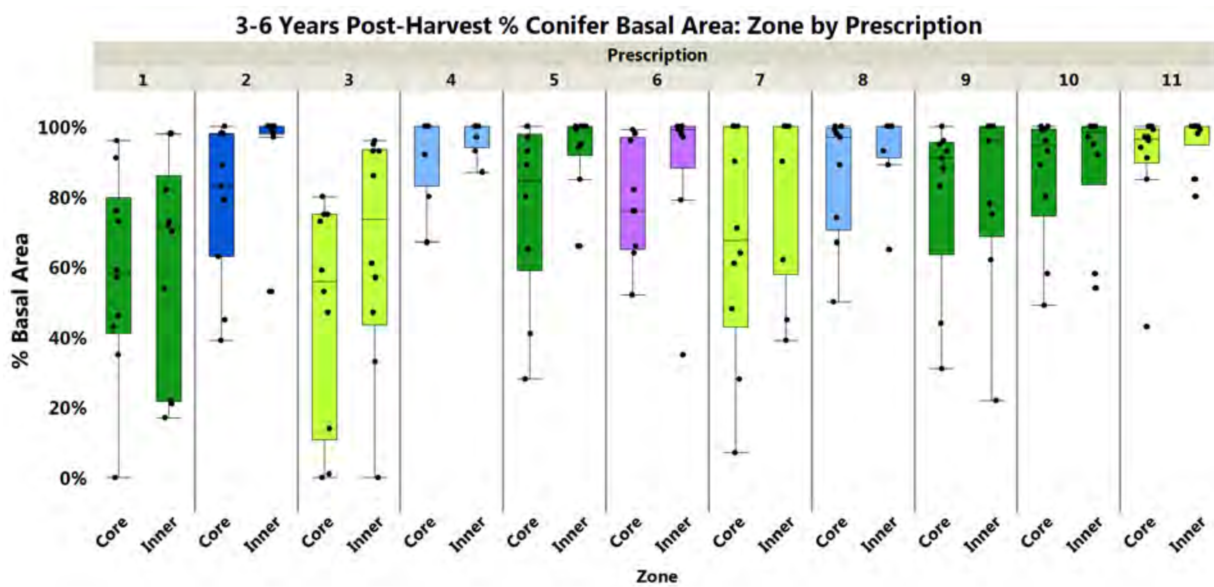


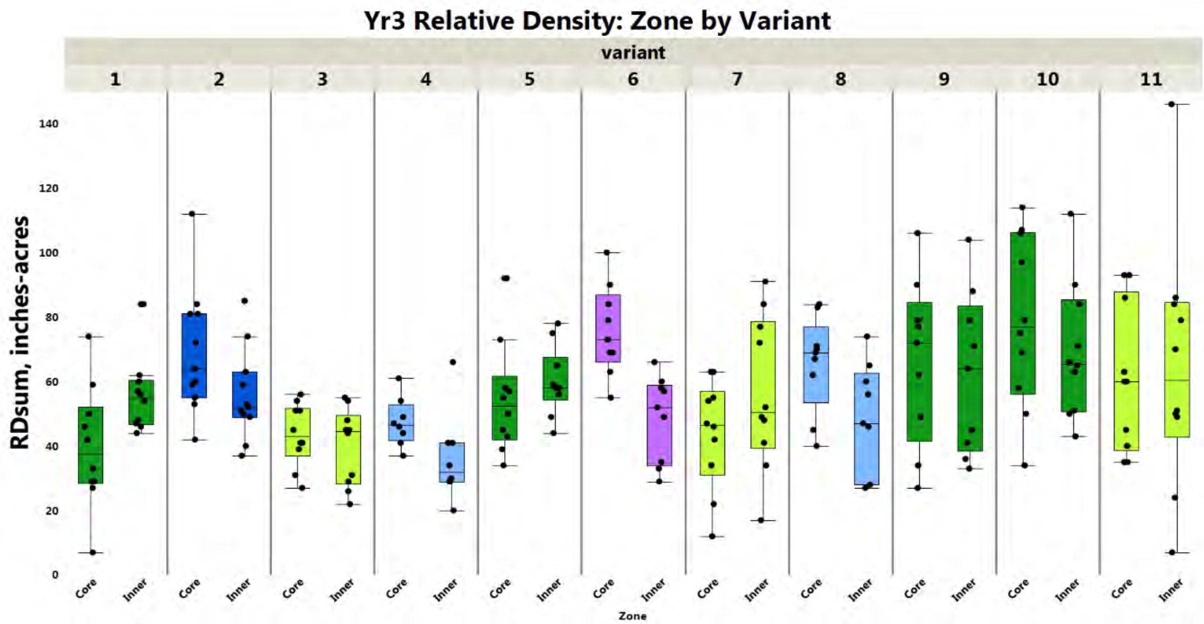


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60

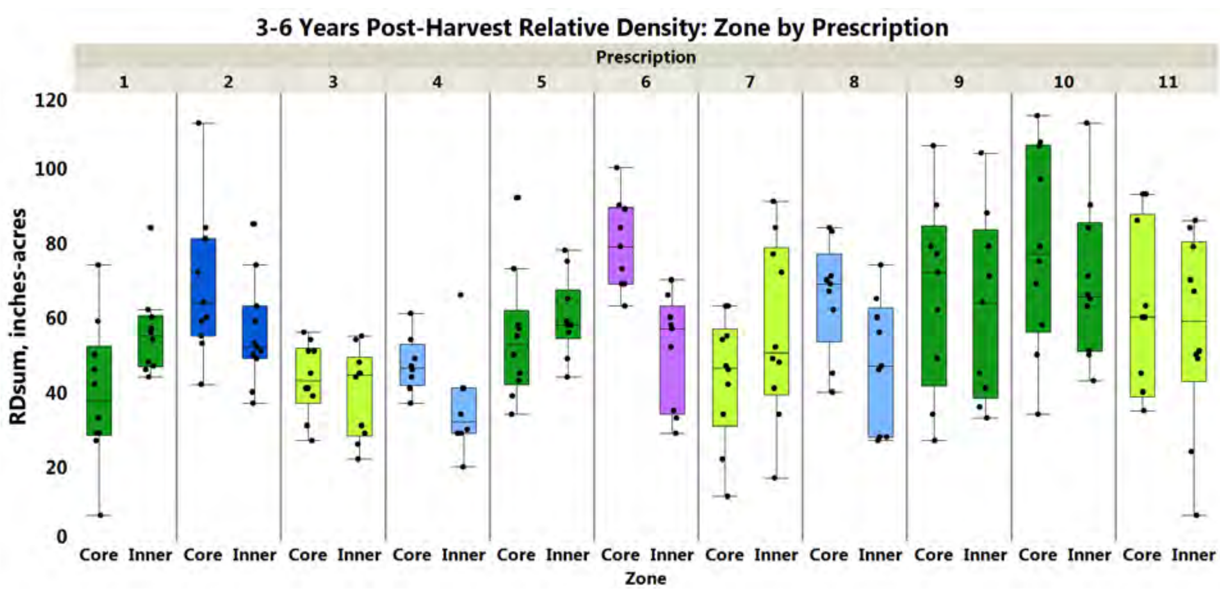



3-6 Years Post-Harvest Live Stand % Conifer by Basal Area: Combined Core and Inner Zones
Percent Conifer (%BA)
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
Prescription

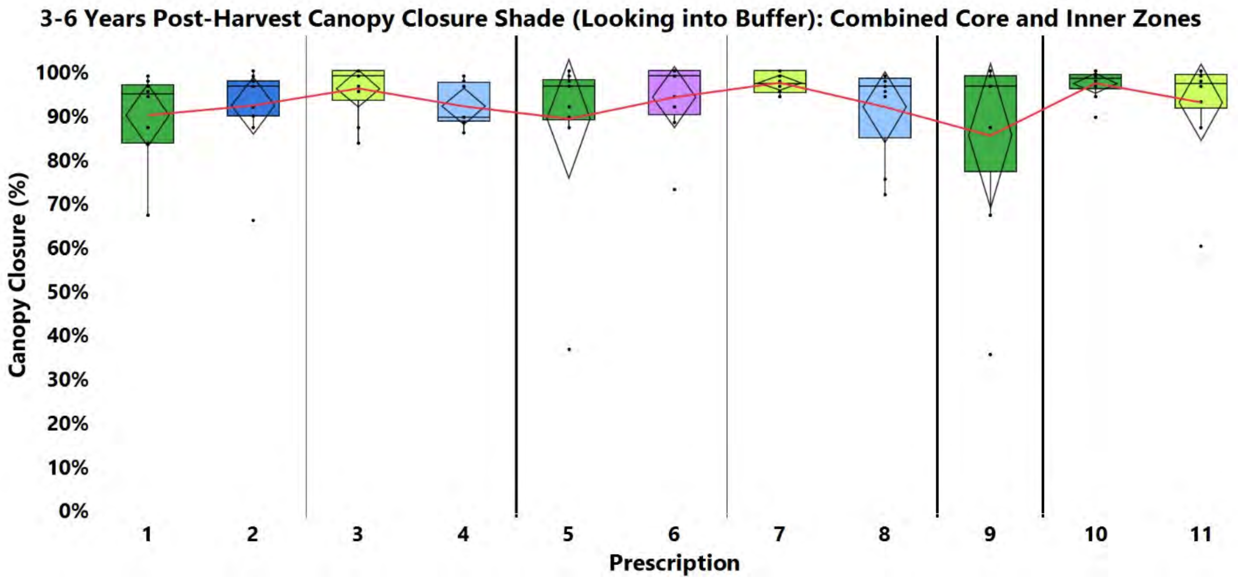

3-6 Years Post-Harvest % Conifer Basal Area: Zone by Prescription
Prescription
1
2
3
4
5
6
7
8
9
10
11
% Basal Area
100%
80%
60%
40%
20%
0%
Core
Inner
Zone



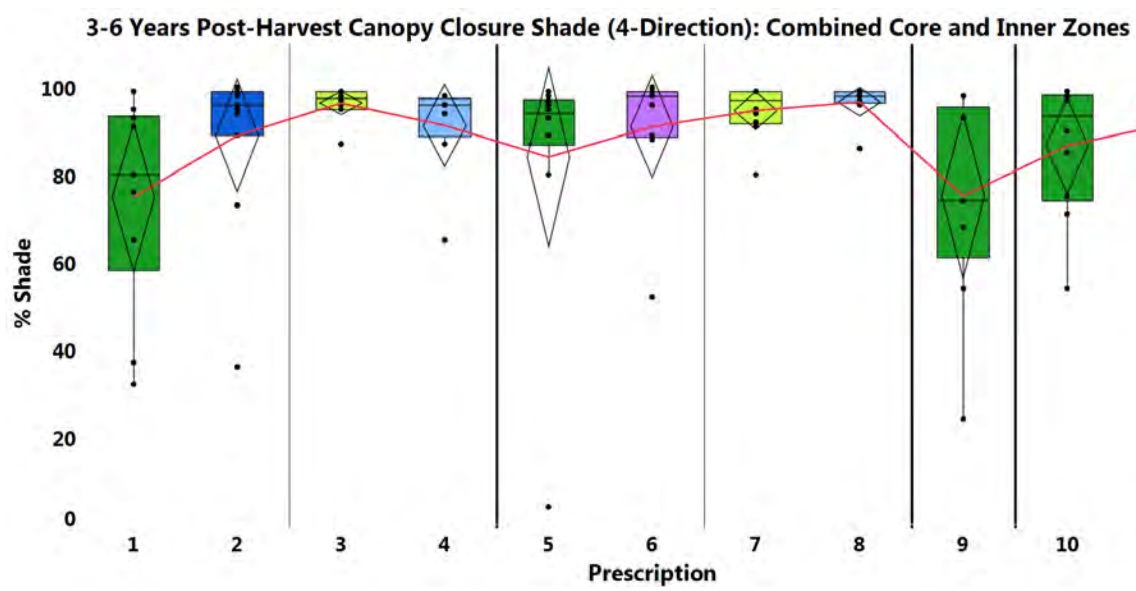
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60



B-6. Canopy Closure/Shade Metrics



Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
N	10	11	10	8	10	9	10	9	9	10	10
Median (%)	94.7	96.4	98.8	89.4	96.4	98.8	97.0	96.4	96.4	98.2	97.0
IQ Rng (%)	13.2	7.9	6.8	8.8	9.1	10.0	5.0	13.5	21.8	3.2	7.6
Mean (%)	89.8	92.1	96.0	91.9	89.0	93.9	97.3	91.7	85.2	97.1	92.8
StdErr (%)	3.1	2.9	1.9	1.7	6.0	3.0	0.7	3.5	7.1	1.0	3.9



B-7. Tables of Metric Means and Std Dev by Prescription

IPH Stand Structure - prescription sample means and (standard deviations)

Site Class	**SC II**				**SC III**				**SC IV**	**SC V**	
Stream Width	**Large**		**Small**		**Large**		**Small**		**Large**	**Large**	**Small**
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ+IZ width (ft)	**128**	**100+**	**113**	**80+**	**105**	**105**	**93**	**80+**	**83**	**68**	**60**
Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
N	**10**	**11**	**10**	**8**	**10**	**9**	**10**	**9**	**9**	**10**	**10**
Live TPA											
Combined	199 (75)	263 (113)	191 (41)	153 (27)	227 (66)	256 (88)	248 (61)	314 (84)	309 (202)	469 (182)	396 (195)
Core	159 (102)	309 (137)	192 (35)	170 (52)	228 (94)	307 (111)	233 (72)	364 (87)	298 (203)	481 (197)	399 (208)
Inner	224 (70)	234 (124)	190 (53)	140 (38)	225 (61)	209 (88)	266 (79)	256 (89)	326 (208)	436 (180)	382 (174)
Live BAPA (ft^2)											
Combined	217 (46)	254 (54)	183 (25)	211 (36)	250 (41)	280 (43)	226 (55)	251 (46)	284 (79)	300 (89)	268 (59)
Core	173 (74)	276 (76)	190 (40)	242 (57)	237 (82)	340 (48)	204 (62)	279 (44)	285 (92)	311 (107)	267 (66)
Inner	246 (50)	241 (66)	177 (41)	187 (49)	263 (50)	227 (62)	251 (70)	220 (54)	282 (83)	269 (67)	272 (95)
Live QMD (in)											
Combined	14.7 (2.2)	13.8 (1.7)	13.4 (1.8)	16.0 (2.0)	14.7 (2.6)	14.8 (3.0)	13.0 (1.9)	12.4 (1.8)	14.9 (5.0)	11.0 (1.7)	11.8 (2.5)
Core	15.0 (3.7)	13.2 (1.6)	13.6 (2.0)	16.5 (2.3)	14.3 (2.7)	15.0 (3.3)	12.8 (1.9)	12.0 (1.7)	15.2 (5.4)	11.0 (2.0)	11.8 (2.6)
Inner	14.6 (2.5)	14.4 (2.1)	13.3 (2.4)	15.9 (2.7)	15.1 (3.2)	14.8 (3.0)	13.3 (2.2)	12.9 (2.0)	14.4 (4.7)	11.0 (1.8)	11.9 (2.5)
%conifer (cnt)											
Combined	50 (31)	86 (15)	48 (31)	91 (13)	77 (27)	81 (18)	76 (30)	39 (13)	75 (29)	86 (16)	90 (14)
Core	38 (10)	76 (24)	36 (30)	89 (15)	65 (33)	70 (20)	70 (33)	85 (18)	74 (30)	85 (18)	88 (16)
Inner	55 (33)	95 (12)	58 (34)	93 (12)	86 (23)	90 (17)	81 (29)	95 (8.0)	76 (31)	91 (13)	95 (7.0)
%conifer (BA)											
Combined	60 (28)	89 (15)	58 (31)	95 (9.0)	87 (15)	83 (18)	77 (27)	91 (12)	81 (24)	88 (18)	92 (14)
Core	57 (8.0)	79 (22)	48 (32)	92 (12)	76 (26)	72 (17)	70 (32)	87 (17)	80 (25)	86 (18)	91 (17)
Inner	62 (31)	95 (13)	65 (33)	96 (6.0)	94 (11)	89 (22)	84 (25)	95 (8)	82 (25)	91 (16)	97 (6.0)

Yr3-6 Stand Structure - prescription sample means and (standard deviations)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	**Large**		**Small**		**Large**		**Small**		**Large**	**Large**	**Small**
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ+IZ width (ft)	**128**	**100+**	**113**	**80+**	**105**	**105**	**93**	**80+**	**83**	**68**	**60**
Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Live TPA											
Combined	172 (41)	245 (112)	162 (54)	119 (35)	210 (69)	230 (91)	203 (95)	243 (74)	274 (179)	411 (171)	303 (182)
Core	148 (35)	283 (115)	169 (41)	132 (33)	217 (89)	282 (100)	186 (86)	297 (78)	272 (177)	442 (183)	321 (186)
Inner	196 (47)	207 (110)	157 (67)	106 (37)	203 (49)	178 (82)	220 (104)	188 (73)	276 (182)	379 (160)	285 (178)
Live BAPA (ft²)											
Combined	198 (41)	247 (69)	165 (47)	178 (47)	237 (61)	267 (52)	190 (77)	214 (68)	262 (83)	273 (88)	219 (90)
Core	168 (27)	267 (75)	174 (44)	200 (33)	225 (74)	327 (42)	165 (64)	245 (64)	275 (89)	295 (107)	223 (78)
Inner	229 (56)	227 (63)	155 (50)	156 (61)	249 (49)	207 (62)	215 (90)	184 (72)	249 (77)	250 (70)	214 (102)
Live QMD (in)											
Combined	15.1 (2.0)	14.2 (1.8)	13.9 (2.5)	16.8 (2.5)	14.8 (2.9)	15.2 (3.0)	13.5 (2.2)	13.0 (1.9)	15.2 (5.1)	11.2 (1.8)	12.6 (3.2)
Core	15.3 (1.4)	13.5 (1.4)	13.9 (2.0)	16.9 (2.1)	14.3 (2.6)	15.3 (3.2)	13.3 (2.1)	12.4 (1.7)	15.6 (5.4)	11.2 (2.0)	12.2 (2.8)
Inner	14.9 (2.5)	14.8 (2.1)	14.0 (2.9)	16.7 (2.9)	15.4 (3.2)	15.2 (2.8)	13.8 (2.3)	13.6 (2.1)	14.7 (4.7)	11.3 (1.6)	13.1 (3.6)

Recruitment Potential (IPH and Yr3-6) - prescription sample means and (standard deviations)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	**Large**		**Small**		**Large**		**Small**		**Large**	**Large**	**Small**
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ+IZ width (ft)	**128**	**100+**	**113**	**80+**	**105**	**105**	**93**	**80+**	**83**	**68**	**60**
Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
IPH Trees/100ft)											
Combined	29 (8.4)	38 (16.1)	25 (5.8)	20 (5.7)	27 (9.2)	31 (12)	26 (8.0)	34 (9.3)	29 (20)	37 (15)	27 (14)
Core	18 (4.4)	35 (15)	22 (4.0)	19 (5.9)	26 (11)	35 (13)	27 (8.2)	42 (10)	34 (23)	55 (23)	46 (24)
Inner	40 (13)	40 (18)	28 (7.6)	20 (5.4)	28 (7.7)	26 (11)	26 (7.8)	25 (8.7)	25 (16)	18 (7.4)	9 (4.0)
IPH BA/100ft (ft²)											
Combined	32 (6.1)	37 (8.9)	24 (5.3)	27 (6.9)	30 (7.8)	34 (6.6)	24 (7.1)	27 (5.2)	27 (8.4)	23 (7.5)	18 (4.9)
Core	20 (3.2)	32 (9.0)	22 (4.5)	28 (6.6)	27 (9.4)	39 (5.5)	23 (7.2)	32 (5.1)	33 (11)	33 (11)	31 (7.5)
Inner	44 (9.0)	42 (8.8)	26 (6.0)	27 (7.1)	33 (6.3)	29 (7.8)	25 (6.9)	22 (5.3)	21 (6.3)	11 (2.8)	6 (2.2)
Yr3-6 Trees/100ft)											
Combined	26 (6.3)	34 (14)	21 (7.1)	15 (4.6)	25 (8.2)	27 (11)	21 (10)	26 (7.8)	26 (17)	33 (14)	22 (13)
Core	17 (4.0)	32 (13)	19 (4.6)	15 (3.9)	25 (10)	32 (12)	21 (10)	34 (8.5)	31 (20)	51 (21)	37 (21)
Inner	35 (8.6)	35 (15)	23 (9.6)	15 (5.2)	26 (6.1)	22 (10)	22 (10)	19 (7.1)	21 (14)	16 (6.6)	7 (4.2)
Yr3-6 BA/100ft (ft²)											
Combined	30 (6.6)	35 (8.5)	21 (6.2)	23 (6.3)	29 (7.3)	32 (6.3)	20 (8.1)	23 (7.2)	25 (8.0)	22 (7.6)	15 (5.6)
Core	19 (3.1)	31 (8.5)	20 (5.1)	23 (3.8)	38 (1.6)	38 (4.8)	19 (7.4)	28 (7.4)	32 (10)	34 (12)	26 (8.9)
Inner	41 (10)	39 (8.4)	22 (7.3)	23 (8.9)	26 (6.1)	26 (7.8)	21 (8.9)	18 (7.1)	19 (5.8)	10 (2.9)	5 (2.4)

Recruitment (IPH-YR3) - prescription sample means and (standard deviations)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	Large		Small		Large		Small		Large	Large	Small
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ+IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Variant	1	2	3	4	5	6	7	8	9	10	11
Recruiting Tree Count/100ft											
Combined	0.5 (0.5)	0.8 (0.7)	2.7 (4.4)	3.8 (4.1)	0.9 (1.2)	0.8 (0.7)	3.7 (4.9)	56 (8.5)	1.3 (1.5)	1.5 (2.3)	6.3 (8.1)
Core	0.4 (0.1)	0.5 (0.1)	1.8 (0.9)	2.6 (0.9)	0.7 (0.3)	1.0 (0.4)	3.4 (1.5)	4.0 (1.9)	1.0 (0.4)	1.4 (0.7)	5.5 (2.3)
Inner	0.2 (0.1)	0.2 (0.1)	1.1 (0.6)	0.9 (0.4)	0.4 (0.3)	0.6 (0.4)	0.6 (0.3)	1.3 (0.7)	0.4 (0.2)	0.2 (0.1)	0.9 (0.4)
Large Wood Pieces/100ft											
Combined	0.3 (0.4)	0.6 (0.5)	1.0 (1.7)	0.7 (0.9)	0.7 (0.1)	0.6 (0.5)	1.6 (1.7)	1.5 (1.6)	0.1 (1.3)	0.8 (1.3)	3.8 (5.3)
Large Wood Volume/100ft (ft^3)											
Combined	1.0 (0.1)	2.2 (2.9)	4.8 (11)	4.3 (7.0)	7.0 (10)	4.2 (4.0)	9.3 (12)	6.2 (6.0)	7.1 (11)	6.2 (11)	18 (28)

Mortality During the First 3 to 6 Years Post-Harvest - prescription sample means and (std dev)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	**Large**		**Small**		**Large**		**Small**		**Large**	**Large**	**Small**
IZ Harvest	**No**	**LTCW**	**No**	**LTCW**	**No**	**TFB**	**No**	**LTCW**	**No**	**No**	**No**
CZ+IZ width (ft)	**128**	**100+**	**113**	**80+**	**105**	**105**	**93**	**80+**	**83**	**68**	**60**
Variant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Percent count	**(IPH)**										
Combined	9.20 (8.0)	9.45 (4.3)	15.9 (17)	20.1 (15)	6.90 (5.7)	10.6 (7.4)	20.3 (24)	20.2 (19)	11.2 (9.8)	8.70 (9.8)	22.1 (19)
Core	6.10 (2.2)	7.55 (3.1)	12.0 (14)	19.5 (14)	4.90 (2.4)	7.56 (4.3)	22.5 (24)	17.3 (16)	8.33 (8.9)	7.80 (9.3)	21.0 (17)
Inner	10.5 (9.9)	11.4 (6.7)	19.2 (21)	24.3 (20)	8.90 (8.7)	13.9 (15)	19.2 (24)	24.5 (23)	14.8 (12)	11.9 (13)	28.9 (29)
Percent BA											
Combined	6.1 (6.4)	5.0 (3.0)	11 (15)	17 (13)	5.5 (5.0)	6.2 (5.9)	17 (22)	15 (16)	7.4 (7.1)	6.2 (8.5)	18 (19)
Core	2.7 (1.0)	3.6 (1.8)	8.9 (13)	16 (11)	5.0 (3.9)	3.9 (4.2)	19 (23)	13 (15)	4.0 (4.9)	5.6 (8.6)	17 (18)
Inner	7.6 (8.5)	6.2 (4.9)	13 (17)	18 (16)	5.7 (6.3)	9.2 (13)	15 (23)	19 (18)	12 (11)	7.8 (10)	24 (27)
TPA											
Combined	22 (25)	27 (19)	29 (29)	36 (27)	17 (17)	28 (23)	47 (45)	67 (77)	35 (31)	44 (47)	82 (80)
Core	12 (5.2)	26 (16)	23 (35)	37 (33)	12 (7.6)	25 (14)	47 (43)	67 (71)	26 (31)	39 (43)	78 (80)
Inner	28 (34)	28 (19)	34 (34)	34 (26)	22 (26)	31 (38)	46 (53)	67 (85)	49 (45)	57 (62)	97 (87)
BAPA											
Combined	13 (12)	13 (8.7)	20 (28)	36 (34)	14 (13)	18 (15)	38 (47)	36 (34)	20 (17)	19 (22)	48 (49)
Core	5.3 (2.0)	10 (6.4)	17 (23)	42 (39)	13 (14)	14 (17)	39 (49)	35 (35)	11 (13)	18 (22)	45 (52)
Inner	18 (20)	15 (12)	23 (32)	31 (31)	15 (19)	21 (28)	37 (52)	37 (34)	34 (31)	59 (24)	57 (20)

Percent Canopy Closure (YR3-6) - prescription sample means and (standard deviations)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	Large		Small		Large		Small		Large	Large	Small
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ+IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Variant	1	2	3	4	5	6	7	8	9	10	11
4-Direction											
Combined	75 (24)	89 (19)	96 (4.0)	91 (11)	84 (29)	91 (15)	95 (6.0)	97 (4.0)	75 (24)	87 (15)	92 (13)
Toward Buffer											
Combined	90 (10)	92 (10)	96 (6.0)	92 (5.0)	89 (19)	94 (9.0)	97 (2.0)	92 (11)	85 (21)	97 (3.0)	93 (12)

Soil Disturbance and Streambank Erosion (YR3-6) - prescription sample means and (std devs)

Site Class	SC II				SC III				SC IV	SC V	
Stream Width	Large		Small		Large		Small		Large	Large	Small
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ+IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Variant	1	2	3	4	5	6	7	8	9	10	11
Soil Disturbance Area (ft^2)											
Combined	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Streambank Erosion {ft}											
Combined	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix C. Westside Type F Riparian, Phase 1 Study - Forest Practice Application-Geographic Information System (FPA-GIS) Analysis

Copied from study design appendix (Schuett-Hames et al. 2017)

C-1. Purpose

This document describes an office review and analysis of forest practice applications (FPAs) to supply information to inform the design of the Western Washington Type F Prescription Monitoring Project pilot study. The purpose of this analysis is to determine how frequently different variations of the western Washington prescriptions for Type F (fish-bearing) and Type S (shorelines of the state) riparian management zones (RMZs) are being implemented, regional distribution patterns, and provide information on the characteristics of sites where the prescriptions are being applied.

C-2. Methods

Data were collected on Type F and S stream segments in harvest units contained in a random sample of Forest Practices Applications (FPAs) selected from the Washington Department of Natural Resources (WDNR) Forest Practices Application Review System (FPARS) database. The information used in this process came from:

1. archived PDFs in the DNRs Forest Practice Application Review System (FPARS) https://fortress.wa.gov/dnr/protection/fparssearch/, and
2. DNRs FPARs Geographic Information System (GIS) database http://www.dnr.wa.gov/GIS

To be included in the survey, each FPA had to meet the following criteria:

- timber harvest along a Type F water within the area of the proposed FPA (this criterion excludes FPAs where harvest is restricted to salvage or road rights-of-way)
- harvest under the "standard" westside Type F forest practices rules (this criterion excludes Alternate Plans, Habitat Conservation Plans, conversions to other land uses, 20 acre exempt parcels, and hardwood conversions)
- an effective date between 2008 and 2013
- within the Northwest, Olympic, Pacific Cascade, or South Puget Sound DNR regions

C-2.1 Sample selection and data collection procedures

The process used to screen FPAs included four steps:

Step 1. Select potential FPARS data for analysis

Download the FPARs data (GIS unit boundary shapefile and associated attribute table) and select those FPA/units with the desired characteristics.

EFFECTIVE_DT (Effective date): select for dates between July 1, 2008 and June 30, 2013 (dates likely to have been harvested within our harvest window (June 2011-July 2013).

REGION_NM (DNR region): select for Northwest, Olympic, Pacific-Cascade or South Puget Sound (excludes eastside regions).

DECISION (Status of Application): select for APPROVED or RENEWAL (excludes applications that are not approved for harvest).

ALTERNATE_PLAN_FLG (Alternative Plan Submitted): exclude Y (excludes activities conducted under an alternative plan).

HABITAT_CONSERVATION_FLG (Application covered by Habitat Conservation Plan): select for blanks- (excludes activities conducted under a Habitat Conservation Plan).

CUTTING_OR_REMOVING_TIMBER_FLG (Involves cutting or removing timber): select for Y (excludes FPAs without timber harvest, e.g. road construction, chemical application).

EXEMPT_20_ACRE_RMZ_FLG (Application qualifies for less than 20 acre parcel RMZ prescription): exclude Y (excludes FPAs with RMZ harvest under special 20 acre parcel exemption).

HARDWOOD_CONVERSION_FLG (Hardwood conversion applications): exclude Y (excludes hardwood conversion applications).

TIMHARV_FP_TY_LABEL_NM (harvest type): select for EVEN AGE, UNEVEN AGE, EVEN/SALVAGE, UN/SALVAGE, EVEN R/W, UNEVEN R/W (excludes FPAs limited to right-of-way, salvage, or no harvest).

CMZ_PRESENT_FLG (channel migration zone): exclude Y (excludes RMZs with channel migration zone buffer present)

Step 2. Identify FPAs within 200 ft of a Type F or S stream.

Using WDNR statewide hydrography (downloaded 16 January 2016 from www.dnr.wa.gov/GIS), restrict the hydro layer to F and S segments and use the ArcGIS Near function to identify those FPAs from Step 1 that are within 200 ft of a Type F or S stream.

Step 3. Put list of selected potential FPARs units in random order.

Use an ArcGIS script to assign a random integer between 1 and 1000000 to each FPA, sort on the random number, and work systematically through the sorted list.

Step 4. Screen the FPAs in assigned order to verify there is a Type F or S stream in or adjacent to the harvest unit.

Working thru the randomized list of FPA numbers from the top, ArcGIS was used to overlay the FPARs unit boundary polygon on the 2013 NAIP imagery and the WDNR hydrography to verify that there was a Type S or F stream in the unit and to determine if the unit was harvested prior to 2013. If no type F or S stream was present in the unit the FPA was rejected. The data were manually screened to remove duplicate records, or FPAs with HCPs or Alternative Plans that were missed in Step 1.

Step 5. Collect data on attributes of interest for each of the selected FPAs.

Using the FPARs database, the pdf file for each FPA, the FPARs unit boundary polygons, and other GIS information (hydrolayer, NAIP imagery, DEM, SSHIAP) extract and record the data on each Type F or S stream segments identified in each FPA. Table 1 (next page) shows the data attributes and provides a brief description of the procedures to obtain the information.

Table C-1. FPA-GIS analysis data attributes and procedures.

Field	**Description**	**Source**	Procedures
FPA Number	FP_ID, unique identifier for each FPA.	FPARs database	Copy data field in FPARs database
DNR region	REGION_NM, DNR region	FPARs database	Copy data field in FPARs database
Landowner Name	Name of legal landowner	FPA pdf	Manually extract from FPA pdf and type in spreadsheet
Project name	Landowner name of project/unit	FPA pdf	Manually extract from FPA pdf and type in spreadsheet
County	County FPA is located in	FPA pdf	Manually extract from FPA pdf and type in spreadsheet
WAU	WAU FPA is located in	FPA pdf	Manually extract from FPA pdf and type in spreadsheet
WRIA	WRIA FPA is located in	FPA pdf	Manually extract from FPA pdf and type in spreadsheet
Harvest Type	Type of harvest (even, uneven age, salvage)	FPA pdf	Copy data field in FPARs database
Effective Date	EFFECTIVE_DT, month/day/yr activities may begin.	FPARs database	Copy data field in FPARs database
Harvested by 2013?	Unit harvested on 2013 NAIP photography	2013 NAIP imagery	Overlay FPAR harvest unit polygon with 2013 NAIP imagery
Stream segment	Individual Type F segment identifier	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
Water type	Water Type classification	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
site class	DNR site class	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
stream width	Average stream width	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
stream width cat	Greater than or less than 10 ft	Table 21 in FPA pdf file	Calculate based on stream width in FPA table
Inner zone harvest	Yes or No, If yes, record code for inner zone harvest	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
Outer zone harvest	Yes or No, If yes, record code for outer zone harvest	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
CMZ present	Channel migration zone present	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
Total RMZ width	Width of total RMZ (core+inner+outer)	Table 21 in FPA pdf file	Manually extract from FPA pdf and type in spreadsheet
DFC worksheet?	Yes if DFC worksheet included in FPA	DFC worksheets in FPA pdf.	Look for DFC worksheet in FPA (RMZ harvest codes D ore E)
Usable FPA map	Yes if activity map in FPA is legible and identifies location of stream segments in table	map in FPA pdf.	Examine FPA map provides useful information
RMZ length	Length of stream segment	DFC worksheet or NAIP	In DFC worksheet when present, otherwise GIS stream layer
1 or 2 sided RMZ	Harvest proposed on 1 or both sides of Type F stream?	FPA map, NAIP imagery	Examine FPA map and NAIP imagery
Stream Adjacent Road	Stream adjacent road present in RMZ	FPA Table 21, map, NAIP	Examine FPA map, NAIP imagery, RMZ harvest code G
Road stream crossing	Road stream crossing present in RMZ	FPA Table 21, map, NAIP	Examine FPA map, NAIP imagery, RMZ harvest code H
Yarding corridors	Yarding corridors present in RMZ	FPA Table 21, map, NAIP	Examine FPA map, NAIP imagery, RMZ harvest code J
Elevation	elevation of stream segment (lower, mid, upper)?	GIS-DEM	Extract from DEM
Gradient	channel gradient	GIS- SSHIAP	Extract from SSHIAP
Confinement	channel confinement	GIS- SSHIAP	Extract from SSHIAP
Basin Area	drainage area above segment	GIS-DEM	Calculate from DEM
Aspect	Stream aspect thru segment in downstream direction	GIS-NAIP imagery	Snap line from upper to lower segment boundary

C-3. Results

A total of 170 FPAs with harvest adjacent Type F and S streams were included in the analysis. These FPAs included 590 unique stream segments (an average of 3.5 per FPA) which varied in their classification by site class, stream width category, and the harvest option applied. The following results are based on analysis at the stream segment scale.

C-3.1 Geographic distribution

The western Washington Type F prescriptions are applied in four WDNR administrative regions. Half of the segments were located in the Pacific Cascade Region, which includes the Willapa Hills and the southwest slopes of the Cascade Range. Another 35% were in the Olympic Region, which includes the Olympic Peninsula outside of Olympic National Park. The remaining 15% occurred in the South Puget Sound and Northwest Regions (Table 2).

Table C-2. Distribution of Type F and S stream segments by WDNR administrative region.

WDNR region	Count	Percent
Northwest	28	4.7%
Olympic	205	34.7%
Pacific-Cascade	295	50.0%
South Puget Sound	62	10.5%

Eighteen western Washington counties were represented in the sample (Table 3). Three counties, Grays Harbor, Pacific and Jefferson, accounted for 60% of the stream segments.

Table C-3. Distribution of Type F and S stream segments by WDNR administrative region.

County	Count	Percent
Clallam	42	7.1%
Clark	2	0.3%
Cowlitz	31	5.3%
Grays Harbor	137	23.2%
Jefferson	105	17.8%
King	25	4.2%
Kitsap	2	0.3%
Lewis	30	5.1%
Mason	8	1.4%
Pacific	108	18.3%
Pierce	17	2.9%
San Juan	4	0.7%
Skagit	1	0.2%
Skamania	18	3.1%
Snohomish	14	2.4%
Thurston	21	3.6%
Wahkiakum	18	3.1%
Whatcom	7	1.2%

C-3.2 RMZ harvest options

The vast majority of the stream segments (92.9%) were on streams classified as Type F waters (fish-bearing). The remaining 7% were classified as Type S (shorelines of the state, also fish bearing). The same RMZ requirements apply to both classifications.

C-3.3 Prescription variants

The combination of site class and stream width determines the leave tree and RMZ width requirements in the Type F and S riparian prescriptions, so we examined the distribution of stream segments by both factors. Site class is typically determined from maps provided by WDNR, while stream width is determined from field measurements as described in the Forest Practices Board Manual.

Site class

Site class III (57%) and Site Class II (26%) together accounted for over 80% of the stream segments (Table 4). Site Classes I, IV and V each accounted for <10% of the segments, and only 17% when combined.

Table C-4. Distribution of stream segments by site class.

Site class	Count	Percent
I	32	5.4%
II	152	25.8%
III	336	56.9%
IV	21	3.6%
V	49	8.3%

Stream width

Both the greater than 10 ft (large stream) and less than 10 ft (small stream) width categories were well represented in the sample, with a higher proportion classified as small streams (58%).

Table C-5. Distribution of stream segments by stream width category.

Stream width category	Count	Percent
Greater than 10 ft	248	42.0%
Less than 10 ft	342	58.0%

Since site classes II and III comprised such a large proportion of the stream segments, it is not surprising that the site class III small and large stream categories had the greatest number of stream segments (37% and 20%, respectively), followed by the site class II large and small stream categories (both 13%). The remaining categories had ≤5% of the stream segments (Table 6).

Table C-6. Distribution of stream segments by combined site class/stream width category.

Combined site class and stream width category	Count	Percent
Site Class I- large stream >10 ft	19	3.2%
Site Class I- small stream <10 ft	13	2.2%
Site Class II- large stream >10 ft	76	12.9%
Site Class II- small stream <10 ft	76	12.9%
Site Class III- large stream >10 ft	119	20.2%

Site Class III- small stream <10 ft	217	36.8%
Site Class IV- large stream >10 ft	15	2.5%
Site Class IV- small stream <10 ft	6	1.0%
Site Class V- large stream >10 ft	19	3.2%
Site Class V- small stream <10 ft	30	5.1%

The western Washington Type F and S riparian prescriptions regulate harvest in RMZs. If stocking is not adequate to meet the DFC performance target, no harvest is allowed in the inner zone. When stocking is adequate, landowners can use harvest Option 1 (thin from below) in any site class/stream width category. Option 2 (leave trees closest to the water) is allowed in Site Class I or II and the small stream category of Site Class III. Two thirds of stream segments had no inner zone harvest (Table 7). Option 2 was done in 25% of the segments and Option 1 occurred less than 7% of the time, although it is the only option for removing timber in 5 of 10 site class/stream width categories. DFC worksheets are required for segments where inner zone harvest is proposed, so this information was available for about 30% of the stream segments.

Table C-7. Distribution of stream segments by harvest option.

Harvest option	Count	Percent
No inner zone harvest	399	67.6%
Option 1- Thin from below	39	6.6%
Option 2- Leave Trees Closest to the Water (LTCW)	150	25.4%
Yarding corridor only	2	0.3%

Since the harvest characteristics (buffer width, leave tree requirements, and harvest configuration) will vary by site class, stream width category and harvest option, the distribution of stream segments in this framework of 25 potential categories (prescription variants) provides an indication of the likely distribution of the population of stream segments that could be sampled in the pilot study (Table 8).

Table C-8. Distribution of stream segments by prescription variant.

Site class	Stream width category	Harvest option	Count**	Percent
I	large stream	No harvest	8	1.4%
I	large stream	Option 1	0	0.0%
I	large stream	Option 2	11	1.9%
I	small stream	No harvest	6	1.0%
I	small stream	Option 1	0	0.0%
I	small stream	Option 2	7	1.2%
II	large stream	No harvest	52	8.9%
II	large stream	Option 1	0	0.0%
II	large stream	Option 2	24	4.1%
II	small stream	No harvest	63	10.7%
II	small stream	Option 1	0	0.0%
II	small stream	Option 2	13	2.2%
III	large stream	No harvest	85	14.5%
III	large stream	Option 1	31	5.3%
III	small stream	No harvest	115	19.6%
III	small stream	Option 1	8	1.4%
III	small stream	Option 2	94	16.0%
IV	large stream	No harvest	15	2.6%

IV	large stream	Option 1	0	0.0%
IV	small stream	No harvest	6	1.0%
IV	small stream	Option 1	0	0.0%
V	large stream	No harvest	19	3.2%
V	large stream	Option 1	0	0.0%
V	small stream	No harvest	30	5.1%
V	small stream	Option 1	0	0.0%

* Opt 2 not allowed in SCIV, SCV, or SCIII>10ft

**1 segment listing an option 2 harvest on a SCIII >10 ft segment was not included, nor were 2 segments with yarding corridors only.

Together, five of the 25 prescription variants contained over 70% of the stream segments. Not surprisingly, three were from SC III and the other two were from SC II. The three SCIII variants included the small stream, no harvest option (20%), small stream, Option 2 (16%) and the large stream, no harvest option (14.5%). The two SCII categories included the small stream, no harvest option (11%) and the large stream, no harvest option (9%). Twelve other prescription variants had from 1 to 5 % of the stream segments each, and together comprised about 30% of the segments. The remaining eight prescription variants each had no stream segments in the sample. All eight were harvest option 1, thin from below, indicating that thin from below was not typically used, even when it is the only harvest method available to remove timber from the inner zone. These findings are also consistent with the CMER Desktop Analysis Report (McConnell 2007) results indicating that when given the choice, landowners choose Option 2 the vast majority of the time or choose not to harvest under Option 1 based on leave tree and other stand requirements.

C-3.4 Other factors affecting RMZ harvest

Several other factors affect RMZ layout and stand conditions.

Road crossings

Perpendicular road crossings occurred in about 2% of the stream segments. In these cases, the RMZs were divided by a road right-of-way and crossing structure.

Stream-adjacent roads

In other cases, roads run parallel to the stream (stream-adjacent roads), occupy portions of the RMZ along the length of the stream. In these cases, special prescriptions are applied to compensate for trees harvested during construction of the road right-of-way. Stream-adjacent roads occurred in about 2% of the stream segments sampled, indicating that they are not widespread.

Channel migration zones

A special situation occurs when there is a channel migration zone (CMZ) between the stream and the RMZ. No harvest is allowed within the CMZ boundary, so in effect the width of no-harvest buffer is increased by the width of the CMZ, which can vary greatly. CMZs occurred in only 2% of the stream segments sampled.

Yarding corridors

Yarding corridors are cleared strips running through the RMZ that allow logs to be transported across the RMZ. Yarding corridors were proposed for 2% of the stream segments sampled.

One- and two-sided harvest

In some cases, larger Type F streams are used as the boundary between units, so the harvest (and buffer) is applied to only one side of the stream, while in other cases harvest (with a buffer) occurs on both sides of the stream. The FPA does not explicitly identify whether harvest (and hence the buffer) is applied on one or both sides of the stream, so we examined the harvest unit maps for a subset of stream segments (346) to determine the proportion of one- and two-sided harvests.

In total, about 30% of the stream segment had two-sided harvest. The proportion of segments with two sided harvest ranged from 8-50% among site class-stream width groupings. Two-sided harvest occurred somewhat more frequently in small streams than for large streams in the same site class category.

Table C-9. Proportion of stream segments with one- and two-sided harvest by site class and stream width.

Stream width category	Site class	Segment count	1 sided harvest count	2 sided harvest count	% of two-sided harvest
large	I	12	11	1	8.3%
large	II	52	37	15	28.8%
large	III	72	60	12	16.7%
large	IV	6	5	1	16.7%
large	V	9	6	3	33.3%
small	I	9	8	1	11.1%
small	II	40	25	15	37.5%
small	III	132	84	48	36.4%
small	IV	4	3	1	25.0%
small	V	10	5	5	50.0%
All combined		346	244	102	29.5%

C-3.5 Outer zone harvest

In the outer zone, the outermost portion of the RMZ, landowners have the option of clumping or dispersing required leave trees. The dispersal option was most common, selected in 65% of the stream segments, followed by clumping (17%) and mixed dispersal/clumping (16%).

C-3.6 Physical site characteristics.

A limited amount of information was collected on the physical stream characteristics and the setting in which they occurred, using available GIS data.

Channel gradient and confinement

Information on channel gradient and confinement was obtained from the Salmon and Steelhead Inventory and Assessment (SSHIAP) database at the Northwest Indian Fisheries Commission for a subset of sites (210) located within the SSHIAP project area (Water Resource Inventory Areas (WRIAs) 1-23.

Channel gradient varied greatly, with stream segments occurring in all channel gradient categories (Table 10). The greatest proportion of stream segments occurred in the 4-8% category (26%), followed by the <1% category (22%) and the 8-20% category (19%).

Table C-10. Distribution of stream segment by channel gradient category.

Channel gradient category	Count	Percent
<1%	46	21.9%
1-2%	16	7.6%
2-4%	27	12.9%
4-8%	55	26.2%
8-20%	40	19.0%
>20%	26	12.4%

The majority of stream segments were classified as confined (69%), followed by unconfined (19%), and moderately confined (12%) (Table 11).

Table C-11. Distribution of stream segment by channel gradient category.

Channel confinement category	Count	Percent
Confined	144	68.6%
Moderately Confined	26	12.4%
Unconfined	40	19.0%

The overall distribution of stream segments according to the gradient/confinement categories used in Washington's Watershed Analysis Process (Table 12) indicates that segments with confined channels occurred most frequently in higher gradient reaches (>2%), while Unconfined and moderately confined segments occurred more frequently in lower gradient reaches (<2%).

Table C-12. Distribution of stream segments by channel gradient/confinement category.

Channel gradient-confinement category	Count	Percent
<1%, Confined	3	1.4%
<1%, Moderately Confined	10	4.8%
<1%, Unconfined	33	15.7%
1-2%, Confined	4	1.9%
1-2%, Moderately Confined	6	2.9%
1-2%, Unconfined	6	2.9%
2-4%, Confined	18	8.6%
2-4%, Moderately Confined	8	3.8%
2-4%, Unconfined	1	0.5%
4-8%, Confined	53	25.2%
4-8%, Moderately Confined	2	1.0%
4-8%, Unconfined	0	0.0%
8-20%, Confined	40	19.0%
8-20%, Moderately Confined	0	0.0%

8-20%, Unconfined	0	0.0%
>20%, Confined	26	12.4%
>20%, Moderately Confined	0	0.0%
>20%, Unconfined	0	0.0%

Basin area

Basin area upstream of the upper end of the segment was calculated using a routed digital elevation model (DEM). Basin area varied by 5 orders of magnitude (Table 13), however the majority of stream segments (83%) were between 1 and 100 acres in size.

Table C-13. Distribution of stream segments by basin area.

Basin area	Count	Percent
< 1 acre	44	9.8%
1-10 acres	138	30.7%
10-100 acres	193	42.9%
100-1,000 acres	62	13.8%
1,000-10,000 acres	12	2.7%
> 10,000 acres	1	0.2%

Stream aspect

Distribution of stream segments by aspect category (measured on a line from the upstream to downstream unit boundary) was somewhat uniform among the eight categories, ranging from 9%-17%, with the highest proportions in the south, southwest and west categories.

Table C-14. Distribution of stream segments by stream aspect.

Aspect Category	Count	Percent
N	53	11.4%
NE	47	10.1%
E	42	9.1%
SE	52	11.2%
S	80	17.2%
SW	71	15.3%
W	70	15.1%
NW	49	10.6%

Appendix D. Tree Diameter-Height Relationships

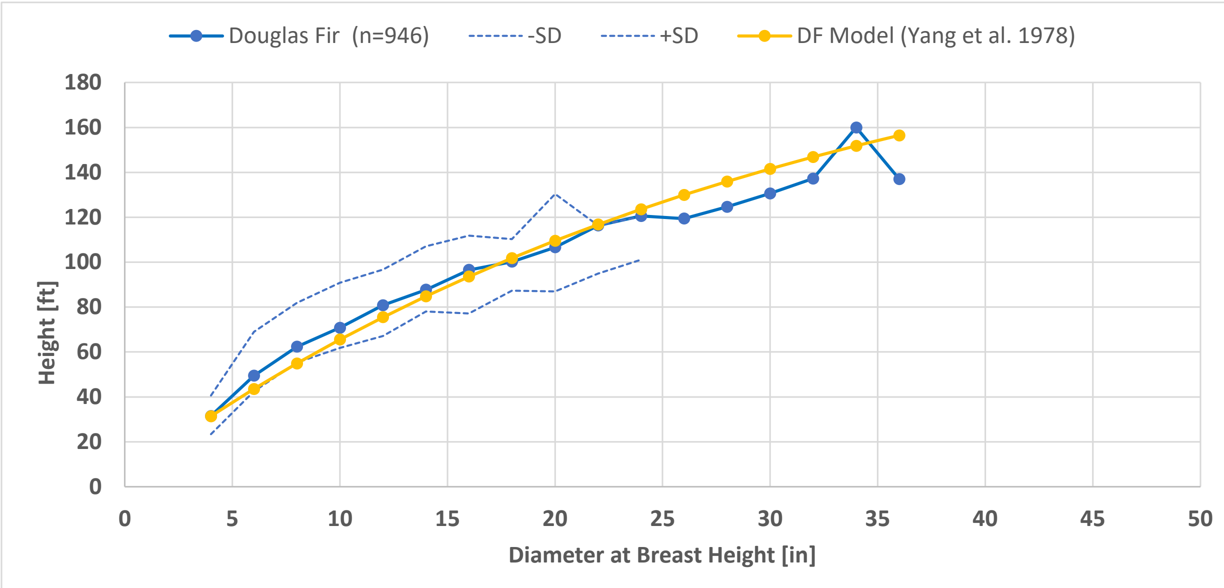


Figure D- 1. Douglas fir height and diameter data from Olympic Peninsula timber cruise data, overlaid with heights modeled using the Yang et al. (1978) equation and parameters from Staudhammer and LeMay (2000). Data summarized and provided by Joseph Murray, JMurray Forestry (2023) with the permission of multiple landowners.

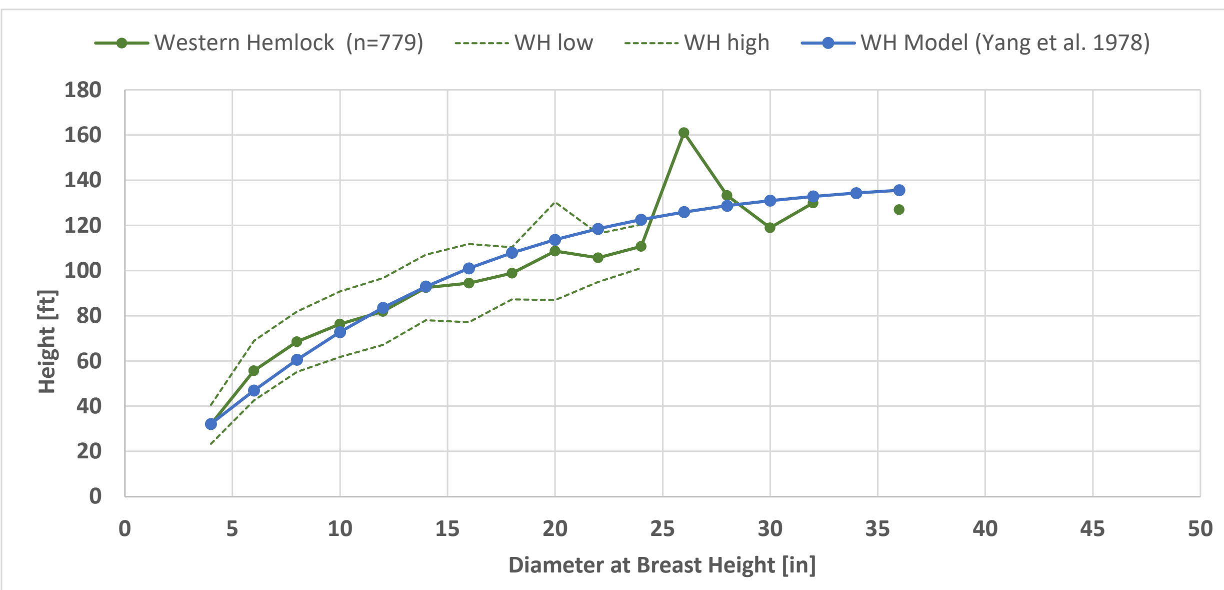


Figure D- 2. Western hemlock height and diameter data from Olympic Peninsula timber cruise data, overlaid with heights modeled using the Yang et al. (1978) equation and parameters from Staudhammer and LeMay (2000). Data summarized and provided by Joseph Murray, JMurray Forestry (2023) with the permission of multiple landowners.

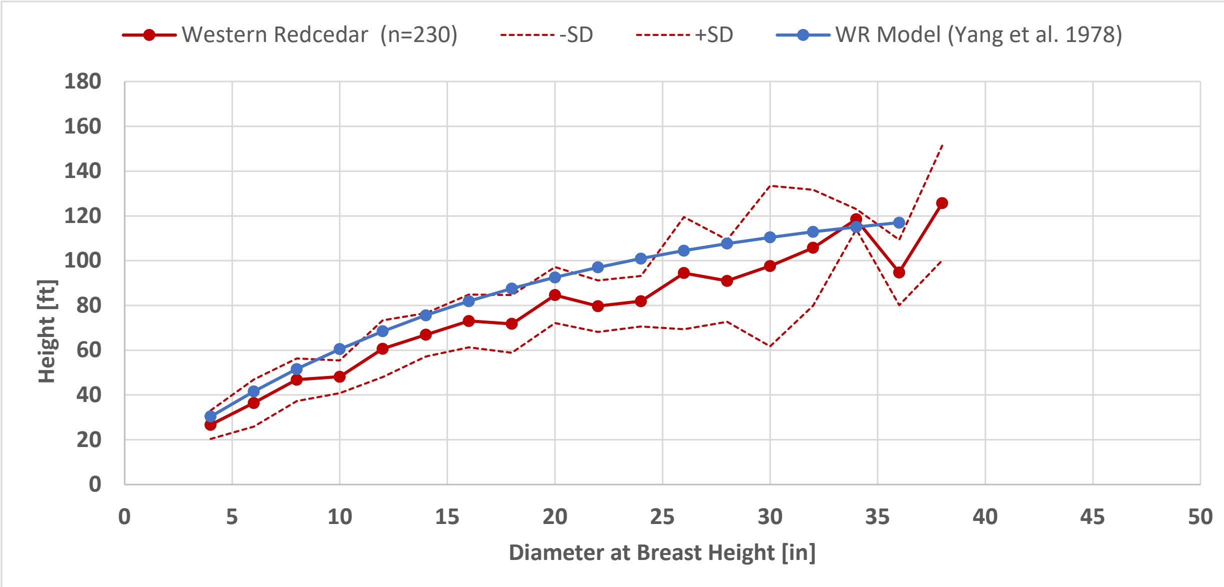


Figure D- 3. Western redcedar height and diameter data from Olympic Peninsula timber cruise data, overlaid with heights modeled using the Yang et al. (1978) equation and parameters from Staudhammer and LeMay (2000). Data summarized and provided by Joseph Murray, JMurray Forestry (2023) with the permission of multiple landowners.

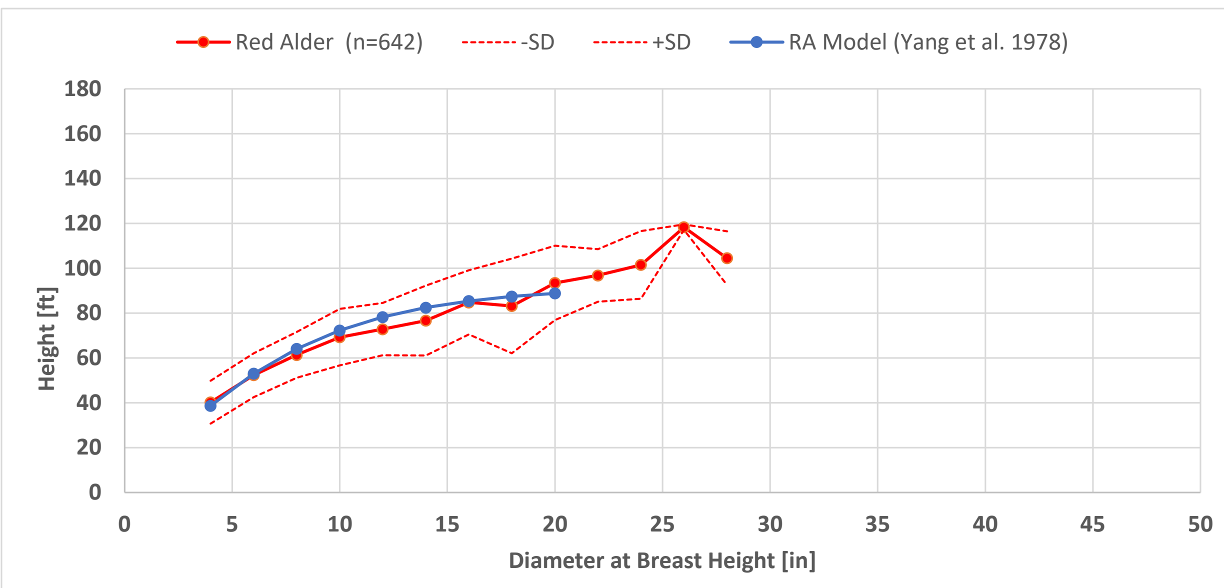


Figure D- 4. Red alder height and diameter data from Olympic Peninsula timber cruise data, overlaid with heights modeled using the Yang et al. (1978) equation and parameters from Staudhammer and LeMay (2000). Data summarized and provided by Joseph Murray, JMurray Forestry (2023) with the permission of multiple landowners.

Appendix E. Windthrow Models

We used boosted regression trees to investigate the relationships between total post-harvest windthrow as a percentage of the standing stems immediately post harvest and several site and RMZ forest stand factors that we hypothesized might be related. We investigated the response variables of both percent windthrow and the binary variable of "Greater than 30% windthrow" versus seven continuous factors:

- Elevation,
- Stand age,
- IPH live tree densities for the stand and that of just the Inner Zone,
- IPH live tree basal area densities for stand and IZ, and
- Relative Density of the IZ;

and seven categorical factors:

- Stream direction,
- RMZ cutface exposure direction,
- Channel width category,
- Site class,
- Inner Zone dominant species (by stem count),
- Inner Zone treatment, and
- A combined Inner/Outer Zone treatment category we developed for this analysis that was thought to categorize the type of face presented to an oncoming wind.

These factors were chosen based on findings in previous studies and their potential relationship to wind forces experienced by standing trees. The various stand density factors were included because stand density has been found in other studies to relate to windthrow (Ruel et al. 2001; Scott and Mitchell 2005; Beese et al. 2019). Dense stands with thick canopies and a bluff face can present a solid face to the wind that could create high forces on newly-exposed trees (Gardiner and Stacey 1996; Mitchell et al. 2001; Beese et al. 2019). On the other hand, trees that are widely spaced might be more susceptible to windthrow due to a lack of support from neighbors (McClintock 1954; Gardiner et al. 1997; Ruel et al. 2001). Also, the stand density can suggest that stands are undergoing heavy stem exclusion, which could make them more susceptible to windthrow. Other factors found to be related to windthrow response are stem height/diameter ratios and canopy characteristics. Our lack of data on actual tree heights and canopy data prevented us from including any of those factors in these models.

The factors that appeared to have the greatest influence on the amount of windthrow and whether a site was likely to experience high windthrow were the direction of the RMZ cutface (by far the most influential), stream direction, elevation, and channel width category (Table E-1). Stand age was very important in predicting the fraction of windthrow but not as important in predicting high windthrow. The basal area and relative density (RD) of the Inner Zone were more influential than those of the total RMZ, and the BAPA was more important than the RD. Site Class was important as a predictor of sites likely to experience high windthrow but not of the percentage of windthrow. The dominant species of the Inner Zone was found to be relatively unimportant in all the analyses. The Inner Zone treatment and a factor derived by combining the Inner and Outer Zone treatments into categories presenting similar faces to an oncoming wind were not found to be significant predictors of either the % of windthrow or whether a site would experience high windthrow. These patterns held true when the analysis was restricted to only sites with southerly to westerly buffer cutfaces (Table E-2), with the exception that the cutface direction fell out (since all cutfaces were toward similar directions).

Table E-1: Boosted regression tree model parameters and output for % Windthrow Total and >30% Windthrow with all possible predictor variables. BRT models were fit using the "gbm.step" function in the R package "gbm" (Greenwell et al. 2022; R Core Team 2022).

Windthrow response	Predictor variable	Relative influence	Model input / output	Value
% Windthrow total	RMZcutfaceDir_8pt	24.5	Tree complexity	5
	StrmDir_8pt	12.5	Learning rate	0.001
	Stand_Age	9.7	Bag fraction	0.5
	Elevation_ft	9.1	Model family	Gaussian
	Channel_Width_Category	8.5	Total deviance	0.02
	IPH_Inner_BAPA	8.2	Residual deviance	0.003
	IPH_InnerRDsum_InAc	6.9	CV deviance	0.016
.	IPH_Live_BAPA	5.8	CV deviance SE	0.002
	IPH_Inner_TPA	4.0	Training data corr.	0.94
	IPH_Live_TPA	4.0	CV corr.	0.49
	InnerDomSpp_byCount	3.4	CV corr. SE	0.06
	Site_Class	2.0		
	Combined_IZ_OZ_trtmt	1.2		
	Inner_Zone_Trtmt	0.4		
> 30% Windthrow	RMZcutfaceDir_8pt	42.1	Tree complexity	5
	StrmDir_8pt	15.5	Learning rate	0.0001
	Elevation_ft	8.1	Bag fraction	0.5
	Channel_Width_Category	7.6	Model family	Gaussian
	IPH_Inner_BAPA	5.1	Total deviance	0.078
	Site_Class	4.5	Residual deviance	0.061
	IPH_InnerRDsum_InAc	3.9	CV deviance	0.079
	Stand_Age	3.9	CV deviance SE	0.025
	IPH_Live_BAPA	2.3	Training data corr.	0.64
	Combined_IZ_OZ_trtmt	2.2	CV corr.	0.14
	InnerDomSpp_byCount	2.0	CV corr. SE	0.059
	IPH_Live_TPA	1.4		
	IPH_Inner_TPA	1.4		
	Inner_Zone_Trtmt	0.1		

Table E-2: Boosted regression tree results for sites with southerly and westerly buffer cutface directions (SE, S, SW, W). Model parameters and output for % Windthrow Total with all possible predictor variables. BRT models for >30% Windthrow unable to be run due to insufficient data points. BRT models were fit using the "gbm.step" function in the R package "gbm" (Greenwell et al. 2022; R Core Team 2022).

Windthrow response	Predictor variable	Relative influence	Model input / output	Value
% Windthrow total	Channel_Width_Category	28.4	Tree complexity	5
	StrmDir_8pt	22.0	Learning rate	0.001
	IPH_Inner_BAPA	11.2	Bag fraction	0.5
	Stand_Age	8.3	Model family	Gaussian
	Elevation_ft	7.9	Total deviance	0.029
	InnerDomSpp_byCount	7.7	Residual deviance	0.027
	IPH_InnerRDsum_InAc	3.7	CV deviance	0.03
.	IPH_Inner_TPA	3.2	CV deviance SE	0.01
	Site_Class	2.6	Training data corr.	0.60
	IPH_Live_TPA	2.4	CV corr.	0.05
	IPH_Live_BAPA	1.8	CV corr. SE	0.11
	RMZcutfaceDir_8pt	0.5		
	Inner_Zone_Trtmt	0.2		
	Combined_IZ_OZ_trtmt	0.0		
> 30% Windthrow	NA	NA	Tree complexity	5
	NA	NA	Learning rate	0.0001
	NA	NA	Bag fraction	0.5
	NA	NA	Model family	Gaussian
	NA	NA	Total deviance	NA
	NA	NA	Residual deviance	NA
	NA	NA	CV deviance	NA
	NA	NA	CV deviance SE	NA
	NA	NA	Training data corr.	NA
	NA	NA	CV corr.	NA
	NA	NA	CV corr. SE	NA
	NA	NA		
	NA	NA		
	NA	NA		

Appendix F. Site Class Background and Discussion

Site Class in this study was always taken from the WA DNR site class raster GIS layer. Information from the metadata for that data layer is included here followed by a discussion of known limitations and implications for using those site class data in this study.

Source: WADNR Forest Practices Site Class GIS layer

https://data-wadnr.opendata.arcgis.com/search?groupIds=04a4947e3b1f4042ac33f1ce97ba42c9

Metadata: https://www.dnr.wa.gov/publications/fp_data_siteclass_meta.htm

Abstract: The siteclass data layer was created for use in implementing new Forest Practices' Riparian Management Rules. (See WAC 222-30-021 and 222-30-022.) The siteclass information was derived from the DNR soils data layer's site index codes and major tree species codes for western and eastern Washington soils contained in the layer's Soils-Main table and Soils-Pflg (private forest land grade) table. Site index ranges in the Soils_PFLG took precedence over site index ranges in the Soils-Main table where data existed. Siteclass codes as derived from the soil survey: For Western Washington, the 50 year site index is used SITECLASS SITE INDEX RANGE I 137+ II 119-136 III 97-118 IV 76-96 V 1-75 For Eastern Washington, the 100 year site index is used SITECLASS SITE INDEX RANGE I 120+ II 101-120 III 81-100 IV 61-80 V 1-60 In addition to the coding scheme above, the following codes were added for rule compliance: SITECLASS DESCRIPTION 6 (Red Alder) The soils major species code indicated Red Alder 7 (ND/GP) No data), NA, or gravel pit 8 (NC/MFP) Non-commercial or marginal commercial forest land 9 (WAT) Water body (Rule note: If the site index does not exist or indicates red alder, noncommercial, or marginally commercial species, the following apply: If the whole RMZ width is within those categories, use site class V. If those categories occupy only a portion of the RMZ width, then use the site index for conifer in the adjacent soil polygon.)

WADNR SOILS LAYER INFORMATION LAYER: SOILS GEN.SOURCE: State soils mapping program CODE DOCUMENT: State soil surveys CONTACT: NA COVER TYPE: Spatial polygon coverage DATA TYPE: Primary data Information for the SOILS data layer was derived from the Private Forest Land Grading system (PFLG) and subsequent soil surveys. PFLG was a five year mapping program completed in 1980 for the purpose of forest land taxation. It was funded by the Washington State Department of Revenue in cooperation with the Department of Natural Resources, Soil Conservation Service (SCS), USDA Forest Service and Washington State University. State and private lands which had the potential of supporting commercial forest stands were surveyed. Some Indian tribal and federal lands were surveyed. Because this was a cooperative soil survey project, agricultural and non-commercial forest lands were also included within some survey areas. After the Department of Natural Resources originally developed its geographic information system, digitized soils delineations and a few soil attributes were transferred to the system. Remaining PFLG soil attributes were added at a later time and are now available through associated lookup tables. SCS soils data on agricultural lands also have subsequently been added to this data layer. Approximately 1100 townships wholly or partially contain digitized soils data (2101 townships would provide complete coverage of the state of Washington). SOILS data are currently stored in the Polygon Attribute Table (.PAT) and INFO expansion files.

COORDINATE SYSTEM: WA State Plane South Zone (5626) (N. zone converted to S. zone)

COORDINATE UNITS: Feet

HORIZONTAL DATUM: NAD27

PROJECTION NAME: Lambert Conformal Conic ****

Site Class Discussion:

The site class data layer has varying degrees of mapping resolution for riparian zones, as can be seen from viewing the map. A previous CMER study (Schuett-Hames et al. 2005) included some data to check the site class (site index) data for riparian areas. They found discrepancies between the site class indicated on maps and site class estimates from field measurements. The map and field site class calls were in agreement less than half of the time, though the discrepancies rarely varied by more than one site class (Table 9 from report). In the majority of the cases where they disagreed, the field estimates indicated higher productivity than the map site classes. Although this study was not designed to evaluate the accuracy of site class maps, it provides an indication of possible inaccuracies that may affect their utility as a framework for riparian management.

Table 9. Comparison of site class estimates derived from maps and field data.

Map Site Class	Field Site Class (BCMF Site Tools equations)				
	I	II	III	IV	V
I	**0**	0	1	0	0
II	2	**15**	8	2	0
III	1	10	**7**	9	1
IV	0	2	14	**6**	6
V	0	0	7	5	**16**

(Shaded cells indicate cases where map and field site class estimates agree).

(Schuett-Hames et al. 2005)