Westside Type F Riparian Management Zone Exploratory Study Draft Report

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Cooperative Monitoring, Evaluation, and Research (CMER) Committee
Forest Practices Adaptive Management Program
Washington State Department of Natural Resources

This study is part of the Westside Type F Riparian Rules Effectiveness Monitoring program.

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Washington State Forest Practices Adaptive Management Program

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

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

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

Report Type and Disclaimer

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

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

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Proprietary Statement

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Abstract:

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Table of Contents

List of Tables

List of Figures

Definition of acronyms used in the Westside Type F Exploratory Study Report

BA – Basal Area

BAPA – Basal Area per Acre

CMER- Cooperative Monitoring, Evaluation and Research Committee. The Cooperative Monitoring, Evaluation, and Research (CMER) Committee is 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 and Fish Report.

DBH – diameter at breast height (4’ 7”)

FPA- Forest Practice Application. A permit required to conduct most forest practices activities on state or private forest land in Washington State.

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.

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 freshwater fish species and some stream associated amphibians). The HCP seeks to provide for the protection and long-term conservation of aquatic designated species, meet Clean Water Act requirements, and support the restoration and conservation of riparian habitat. The FPHCP is also supposed to provide for the restoration of harvestable levels of salmon while maintaining an economically viable timber industry.

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

LTCW-Leave trees closest to the water. An inner zone harvest strategy that involves of harvesting trees furthest from the water and leaving those closest to the water.

LW – Large wood

QMD – quadratic mean diameter. Average tree diameter in a stand = total BA/number of trees

RMZ- Riparian Management Zone. An area protected on each side of a Type F or S Water.

TFB- Thin from below. An inner zone harvest strategy of harvesting smaller diameter trees and leaving the larger trees.

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; also waters containing fish habitat.

YR3 – Year 3. The single field survey was conducted approximately 3 years after harvest.

1 Introduction

The westside Type F and S riparian prescriptions are an important component of the riparian conservation strategy of the Washington Forest Practices Habitat Conservation Plan (FPHCP) (WA DNR 2005). The riparian conservation strategy of the FPHCP focuses on protection of riparian habitat and processes to meet water quality standards and support recovery of aquatic and riparian dependent species such as fish and stream-associated amphibians. Riparian forests covered by the Type F and S prescriptions are adjacent to waters used by fish. Habitat for fish is influenced by the functions, processes, and inputs provided by these forests including litter fall, shade, long-term wood recruitment, stream bank protection, fine-sediment filtering, and coarse sediment supply and attenuation (of large inputs from mass wasting, for example). The Forests and Fish Agreement (1999) and subsequent FPHCP identify functional objectives and performance targets for key aquatic conditions and processes affected by forest practices (WA DNR 2005, Appendix N) and prescribe measures to be taken in the course of forestry activities to reach those objectives. The resulting state forest practices rules for Westside Type F and S stream riparian zones are intended to achieve resource targets for heat/water temperature, large wood/organic inputs, and sediment by providing shade to maintain cool water temperatures, maintaining a source of large wood and organic material to create aquatic habitat, and by preventing input of-sediment related to timber harvest operations.

Although riparian buffers have been required for fish-bearing streams for many years, research and data from the 1980s and 90s indicated that the early rules were not enough to protect and achieve recovery of aquatic habitat conditions for salmonids. In order to reach the agreed-upon resource objectives, the Westside Type F and S riparian prescriptions laid out in the Forests and Fish agreement of 1999, and the resulting forest practices rules, increased the requirements for riparian management zones (RMZs) adjacent to both fish-bearing and non-fish-bearing streams (WA DNR 1999; WA DNR 2000; WA 222-30-021). The Washington State Department of Natural Resources, Forest Practices Adaptive Management program is tasked with assessing the effectiveness of those rules in achieving the functional targets of the revised rules. This exploratory study is part of a set of studies to do that.

1.1 Westside Type F and S Stream Riparian Prescriptions

The Type F/S stream RMZs established in 2000 for Westside Type F and S streams have a total width that varies according to five site class categories. That total RMZ width consists of three zones oriented parallel to the edge of the bankfull channel (Figure 1). Closest to the stream is the 50 ft wide core zone where no harvest is allowed. Beyond the core zone lies the inner zone, which varies in width depending on site class and stream width category and in which some harvest may be allowed. Beyond the inner zone lies an outer zone, which also varies in width and where landowners are required to leave 20 trees/acre (or in some instances fewer). Landowners can choose whether to clump or disperse the leave trees in the outer zone.

Some harvest is allowed within the inner zone if stocking is adequate to meet the desired future condition (DFC) performance target when the stand reaches 140 years old (WA DNR, 1999, WA DNR 2013). Stand inventory data from the core and inner zone are used to run the DFC stand growth and yield model that predicts whether the stand will achieve the DFC target[2]. If basal area is sufficient, the model identifies trees that can be harvested from the inner zone. In cases where inner zone harvest is allowed, landowners can 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 target will not be met, or where inner zone harvest is not economically or operationally feasible or by landowner choice, no inner zone harvest occurs. McConnell (2007) and a review of forest practices applications (FPAs) by the Technical Writing and Implementation Group (TWIG) for this study (Schuett-Hames et al. 2017) indicate that landowners use Option 2 (LTCW) more than 90% of the time when they have both options available to them.

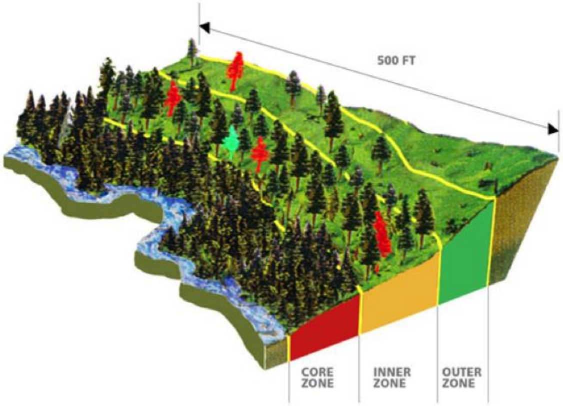

Figure 1. Diagram of the western Washington Type F Riparian Management Zone layout, showing the core, inner and outer zone. Colored trees indicate trees retained for wildlife.

The widths of the riparian buffer zones and overall width depend upon the establish Site Class, which is based on the soil potential for growing trees ("Site Potential Tree Height"). Site Class is counterintuitively inversely related to the soil quality and site potential tree heights. Higher Site Class numbers are assigned to generally poorer quality soils that grow smaller trees. So, Site Class I is the best while Site Class V is poor (Table 1). The rules prescribe wider buffers for site classes capable of growing larger trees because larger trees are capable of providing riparian functions such as shade and wood recruitment at greater distances from the stream channels.

The total prescribed westside Type F and S RMZ width therefore varies according to five site class categories, and the relative widths of the inner zone and outer zones vary by two channel bankfull width categories and three inner zone harvest options (Table 1). Given the possible combinations,

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[2] The DFC models growth for each zone individually. The 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.

there are 25 potential variations of the westside Type F standard rules, hereafter referred to as prescription variants (Table 2).

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[3] equals 100-year site indices for W. Wash. = ¾ site potential Doug fir tree height (WA DNR 2005, based on McArdle et al. 1961)
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 IZ conifers per acre
Option 2	Leave trees closest to water (LTCW)	Must leave at least 20 conifers >12” per acre; No harvest within 50 ft of the Core Zone for large streams and 30 ft for small streams
No-inner zone-harvest	Leave all trees	

1.2 Westside Type F Riparian Prescription Effectiveness Monitoring Project

The CMER Workplan (CMER 2014; CMER 2015) identified the need for research to examine the effectiveness of these Westside Type F RMZ rules, including whether allowing harvest in the inner zone affects the ability of the riparian zones to achieve the resource objectives of the FPHCP. In 2015, CMER established a Technical Writing and Implementation Group (TWIG) to conduct scoping and develop a research approach for assessing Type F riparian prescription effectiveness to fulfill that need (Schuett-Hames et al. 2015).

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[3] Horizontal distance from channel or CMZ edge

The TWIG suggested that an intensive before-after-control-impact (BACI) study was the preferred approach to answer questions about causal linkages between the prescriptions, changes in riparian stand structure and inputs/functions, and the responses of stream habitat, water quality, and aquatic biota (Schuett-Hames et al. 2015). However, due to the large number of different prescription variants and uncertainty about how frequently they were used and how they influenced post-harvest riparian stand structure and functions, the TWIG decided to conduct two preliminary information gathering steps prior to designing the intensive study: 1) an analysis of approved forest practice applications and GIS data to determine the implementation frequency of different prescription variants and the size and spatial distribution of riparian harvest units on the landscape, and 2) an exploratory field study to examine post-harvest stand characteristics and riparian functions associated with various prescription variants. The results of the FPA GIS analysis are presented in Table 2 and more fully in Appendix A of the approved study design (Schuett-Hames et al. 2017). The application frequencies found in that analysis were used to design this exploratory study.

1.3 Goal and Objectives of the Exploratory Field Study

The overall goal of the exploratory field study was to produce information needed to help narrow the focus of and design the experimental BACI effectiveness study. It was intended to reduce uncertainties associated with the relative sensitivity of post-harvest riparian stand conditions and riparian functions to potential disturbances associated with the prescription variants and to provide an estimate of effect size for some metrics. Information on the magnitude of differences between prescription variants will be used to inform and guide the design of the intensive BACI study. In addition, stand structure data and soil disturbance data are used to provide an estimate of the proportion of sites meeting FPHCP performance targets. (Schuett-Hames et al. 2017)

Due to the decision to create a sample balanced among the test prescription variants rather than weighting the sample and that we do not know the stream lengths each represents, our sample set has limited inference to the entire population of Type F buffers on the landscape. However, we can reasonably present the proportions of our sites as valid for the prescription variants tested. Therefore, we modify the original goal to: “In addition, stand structure data and soil disturbance data are used to provide an estimate of the proportion of sites [*within each of the sampled prescription variants*] meeting FPHCP performance targets.” Findings from this study should be considered with the knowledge that the prescription variants included in this study represent over 90% of the submitted FPAs, though we cannot say how much weight each result should carry as a representation of the whole population.

Objectives of the exploratory study were:

1. To evaluate post-harvest riparian stand conditions and riparian ecological functions across prescription variants with and without inner zone harvest.
2. To evaluate the extent 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:

- the level of riparian functions associated with the prescriptions, including data on post-harvest large wood recruitment, shade, and sediment delivery;
- riparian stand conditions associated with the prescriptions, including stand mortality, density, basal area, and the proportion of sites currently on trajectory to meet DFC target of 325 ft^2/acre of basal area at a stand age of 140 years;
- the frequency, magnitude, and distribution of windthrow and its effects on stand structure, buffer tree mortality rates and riparian functions; and
- the relative influence of differences in site conditions and geographic location on the above.

1.4 Study Approach

In order to achieve these objectives, we used a retrospective approach, looking at recent timber harvests to provide a coarse-level landscape-scale assessment of post-harvest riparian stand structure and functions and evaluating whether stands are on trajectory to meet DFC targets in a three- to six-year window after harvest. We collected after-impact (AI) post-harvest data on recent stream-adjacent timber harvests that used one of the eleven most commonly applied riparian prescription variants. The data collected allowed us to explore changes in the buffers in the immediate post-harvest years that related to the functional objectives of streamside buffers. The short time period following harvest constraint for this study was in order to reduce the potential for stochastic events that create conditions unrelated to timber harvest and to be able to still discern and assess trees that died and/or fell post-harvest. We considered using an after-control-impact (ACI) approach but rejected it for this phase because it requires a substantial effort to obtain and sample an appropriate reference population. The AI approach enabled us to maximize the number of treatment sites that could be sampled, which improved our ability to detect, distinguish and assess measurable patterns in post-harvest conditions across treated sites.

In order to attribute observed conditions to buffer treatments, control sites and/or pre-treatment data would be necessary. Attributing causation was not the goal of this phase of the Type F Riparian Buffer Effectiveness study. We do have limited pre-harvest information about some of the sites and we can compare aspects of harvested versus unharvested inner zone areas for those site class and stream sizes where we have both, but the lack of consistent pre-harvest comparison data limits the ability to attribute causation. Therefore, it is important to refrain from drawing conclusions about inner zone harvest effects from this exploratory study. For example, we can say that differences exist and may be related to the prescription, but we cannot conclude that differences between one prescription and another are solely the result of the harvest treatments.

Table 2: **Frequency distribution of stream segments with RMZs harvested according to Westside Type F prescription variants (WAC 222-30-021). Based on random sample of 170 FPAs and 590 associated stream segments with Effective Dates between July 2008 and June 2013. Yellow highlighting indicates prescription variants that had no or very low (<2%) occurrence in the sample and were therefore excluded from this exploratory study. Green highlights indicate the variants that were investigated in this study.**

Prescription Variant			Total RMZ Width (ft)	Core Zone No Harvest Width(ft)	Inner Zone Width (ft)	Outer Zone Width (ft)	Target Basal Area at age 140 yrs (ft^2/acre)	Stream Segment Count	Percent of sampled stream segments
Site Class	Stream Width Category	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	325	11	1.9%
I	small*	No IZ harvest	200	50	84	67	NA	6	1.0%
I	small	Option 1- TFB[1]		50			325	0	0.0%
I	small	Option 2- LTCW[2]		50	84	66	325	7	1.2%
II	large	No IZ harvest	170	50	78	42	NA	52	9.0%
II	large	Option 1- TFB[1]		50			325	0	0.0%
II	large	Option 2- LTCW[2]		50	70	50	325	24	4.1%
II	small	No IZ harvest	170	50	63	57	NA	59	10.2%
II	small	Option 1- TFB[1]		50			325	4	0.7%
II	small	Option 2- LTCW[2]		50	64	56	325	13	2.2%
III	large	No IZ harvest	140	50	55	35	NA	86	14.8%
III	large	Option 1- TFB[1]		50			325	31	5.3%
III	small	No IZ harvest	140	50	43	47	NA	107	18.4%
III	small	Option 1- TFB[1]		50			325	8	1.4%
III	small	Option 2- LTCW[2]		50	44	46	325	94	16.2%
IV	large	No IZ harvest	110	50	33	27	NA	15	2.6%
IV	large	Option 1- TFB[1]		50			325	0	0.0%
IV	small	No IZ harvest	110	50	23	37	NA	6	1.0%
IV	small	Option 1- TFB[1]		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) ** Inner zone [1] Thin from below [2] Leave trees closest to the water

1.5 Study Sample Population and Unit

The population of interest was riparian stands in the core and inner zones of RMZs adjacent to fish-bearing streams harvested according to the current Washington State Forest Practices standard riparian prescriptions for western Washington Type F and S streams (lands shown colored in Figure 4). The population of interest excluded stands harvested using 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 be likely to 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.

Because the intent of the effectiveness study, under which this exploratory study is conducted, is to assess the effectiveness of the current riparian timber practices rules (CMER 2015), the population of interest only includes harvest plans approved under the DFC target revision of 2009. As noted above, inner zone harvest is allowed in cases where the conifer trees in the core and inner zone stands are stocked at a level anticipated to exceed the target (conifer) basal area when the riparian stand is 140 years old. That target basal area initially varied by site class and averaged 246.4 sq ft/acre (range = 190-285) (WA DNR 2010). Research performed as part of the adaptive management program (Schuett-Hames et al. 2005; McConnell 2007, 2010) found that the initial basal area per acre target was not representative of values found in unmanaged stands. After extensive investigation, the researchers recommended that 325 sq ft/acre was a more appropriate target value, and this new value was incorporated into rule in 2009 (WA DNR 2009, 2010).

A single FPA can have several harvest units and streams with multiple RMZ segments based on stream type, site class, and stream width category, each with different prescription options. Furthermore, the landowner can choose to break streams into separate segments with different harvest strategies based on stand characteristics and operational considerations. Consequently, we defined the experimental unit to be an RMZ segment on one side of a Type F or S stream with a specific DNR site class (I, II, III, IV or V), stream width category, and harvest option (i.e., prescription variant).

The sample unit was a 300 ft (91.4 m) long segment of riparian buffer within those identified Type F or S RMZ segments, plus 75 feet of unsampled buffer on each end to avoid buffer edge effects, for a total of 450 ft (137 m). Certain features were allowed to be within the sample segment, although their presence caused that portion of the segment to be excluded and a compensating portion to be added to the overall segment length (see Methods for more details on this).

We stratified sampling by prescription variants, which differ in buffer width and leave tree requirements as shown in Table 1. These differences were assumed to influence riparian stands and key riparian functions post-harvest. Given that some prescription variants are relatively rare and others are relatively common, a simple random sample would run the risk of creating too much or too little information about one particular treatment variant. However, a variant with less common application on the landscape may be more susceptible to environmental influence due to substantially narrower riparian buffers (i.e., Site Classes IV and V, compared to Site Classes II and III). Having no information about the total stream length on the landscape (total population) in each variant category prevented us from creating an appropriately weighted sample that would allow inference to the total riparian population, so we therefore determined to sample the same number (n = 10) of RMZ segments in each of the most common prescription variants.

Since the main goal of this exploratory study is to help focus an experimental study on prescription variants where there is evidence of one or more key riparian functions not being met (Schuett-Hames et al 2015), we wanted to survey as many prescription variants as possible. However, due to budget and logistical constraints, we limited sampling to the most common variants across the landscape (Table 3), as found in the GIS FPA analysis results shown above. We eliminated seven variants that did not occur in that sample of 590 stream buffer implementations and another seven which each represented <2% of the total. Together, the excluded variants represented <10% of the population, based on the desktop FPA analysis. This left us with the eleven sampled variants shown in Table 3 and a total sample size of 110 sites. Figure 2 shows how the study sample allocation compares with the FPA evaluation sample results, in terms of percentage of overall sample size.

Table 3: Eleven most common prescription variants (strata) for type F/S RMZs in Western Washington, with sample allocation.

Prescription Variant				Core & Inner Zone Width (ft)	Minimum Basal Area (ft^2/acre)	Sample Allocation
Variant Nomenclature for Our Study	**Site Class**	**Stream Width Category**	**Harvest Treatment**			
Variant 1	**II**	large	No inner zone harvest	128	No Minimum	10
Variant 2	**II**	large	Option 2-LTCW[1]	120	325	10
Variant 3	**II**	small	No inner zone harvest	113	No Minimum	10
Variant 4	**II**	small	Option 2-LTCW[1]	114	325	10
Variant 5	**III**	large	No inner zone harvest	105	No Minimum	10

Variant 6	**III**	large	Option 1- TFB[2]	105	325	10
Variant 7	**III**	small	No inner zone harvest	93	No Minimum	10
Variant 8	**III**	small	Option 2- LTCW[1]	94	325	10
Variant 9	**IV**	large	No inner zone harvest	83	No Minimum	10
Variant 10	**V**	large	No inner zone harvest	68	No Minimum	10
Variant 11	**V**	small	No inner zone harvest	60	No Minimum	10

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

As an exploratory study, using a balanced sample design is reasonable. However, it is important to remember that the ability to make inferences about the entire population from these results is limited as we do not have the same relative sample size for each sampled category on the landscape and several prescription variants were not sampled at all. Therefore, although these results are an indication of the range of conditions we may find on the landscape, inference to the general landscape should be treated with caution.

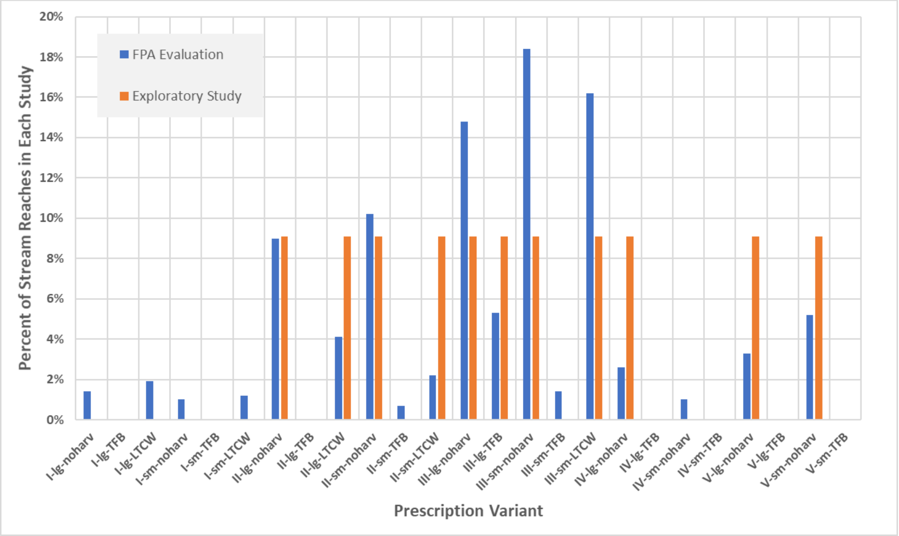

Figure 2. Comparison of percentage distribution of sample buffers in this study versus 590 buffers found in 170 randomly selected FPAs with effective dates from July, 2008 through June, 2013 (Schuett-Hames et al., 2017)

2 Methods

2.1 Site Selection and Office Screening

The sampling frame for each prescription variant in Table 3 was assembled from approved forest practice applications (FPAs) in the WDNR Forest Practices Application Review System (FPARS) GIS geodatabase ("Forest Practices Applications (All)", continuously updated). We began the site selection and screening process by querying the harvest units layer in the FPARS database for harvest units that met our criteria. Harvest unit (a single FPA can contain many harvest units) is the smallest unit area available to search on FPARS, which contains no data on actual RMZ segments themselves. We queried for harvest units from the desired region (western WA); date range; harvest type; presence of an RMZ; and proximity (200 feet) to an F or S stream. As noted previously, we excluded units harvested using alternative riparian prescriptions or because they are regulated under separate provisions of the forest practice rules. Riparian stands with salvage in the inner zone were also excluded. The presence of yarding corridors and the outer zone harvest strategy were not used to exclude sites. We anticipated that the outer zone leave trees, which are primarily left to provide wildlife habitat and to protect other sensitive sites (WA DNR 2005), would have little effect on the observed response variables of this study due to the small number of trees, current stand age and tree heights, short time from harvest, distance from the stream, and multitude of configuration options. We therefore did not stratify on outer zone configuration or sample that zone.

Yarding corridors consist of strips where trees are cut (and left lying) to allow harvested logs to be transported across the stream; they are considered to be part of the RMZ harvest prescription and were included when they occurred in a study reach.

From this initial harvest unit query (about 7,000 from a starting total of 230,000 in FPARS), we randomly selected a subset of 1000 to screen for evidence of harvest in the desired date range. FPAs contain no information on harvest date and only provide the dates when the application was submitted and accepted/rejected/resubmitted/expired. Originally, we proposed to sample only sites that were exactly three years post-harvest. We queried FPARS for applications that had been approved or renewed between 2012 and 2015 (approval date generally = effective date), because this would capture sites that had been harvested between March and September 2015. (Landowners have up to three years after FPA approval to harvest a unit before the FPA expires. They may renew it once and after that they must resubmit it, so an FPA approved in 2012 might not be harvested until 2018.) Sites that had been harvested between March and September 2015 would be exactly three years post-harvest during our original sampling window of summer 2018. The FPARS query only narrowed our pool to a certain extent; it was then necessary to visually screen sites on aerial photos (using National Agricultural Imagery Program (NAIP) aerial imagery from multiple years) and call landowners to ensure sites were within the very specific harvest window.

We discovered through the site selection process that with a rejection rate of over 99%, it was exceedingly difficult to find enough sites harvested between March-September 2015 that met all the rest of the requirements. In fact, we ended up with almost a complete census of these sites, not a sample, because these sites were so rare. We also discovered that in many cases, pinning down an exact harvest date was impossible, because landowners often do not record this information or it is discarded when a parcel is sold; therefore, it is sometimes possible only to pin down harvest date within an 18-month window. Our sampling timeline was also delayed until summer 2019. We therefore decided to expand the harvest window. We simply included all harvest units from FPAs in the original query approval date range of 2012-2015, visually screened them with NAIP photography to ensure they had been harvested by summer 2016 (to ensure at least three years since harvest based on our plan to sample in summer 2019) and dropped the requirement of calling landowners to pin down exact harvest date. Our expanded harvest window thus encompassed units that ranged from 3-7 years post-harvest. We concluded that this expanded window would not alter the results of the study because we would still be able to capture relatively recent post-harvest conditions.

We sampled within this relatively recent time frame because research shows that post-harvest windthrow in newly harvested buffer strips generally peaks within a few years after logging (Harris 1989; Grizzell and McGowen 1997; Bahuguna et al. 2010; Schuett-Hames et al. 2012). Over time, windthrow mortality generally declines as the surviving trees grow more wind firm (Ruel et al. 2001, Bahuguna et al. 2010, Mitchell 2013). However, buffer strips remain vulnerable to impacts from severe storm events which can also cause high mortality in unharvested stands (Ruel et al. 2001, Schuett-Hames et al. 2012). The post-harvest sampling schedule was designed to allow time for the newly established buffers to be exposed to natural wind disturbances yet was soon enough after harvest to enable differentiation of pre- versus post-harvest tree mortality and recent wood recruitment (see "Fallen trees and large wood recruitment" section of Methods). This short post-harvest time frame limits our assessment of mortality and changes in stand structure that affect stand trajectory to meet the DFC target over longer timeframes and a greater range of natural disturbance. However, it also provides a useful assessment of the initial impacts of post-harvest mortality which can affect long-term trends in riparian functions (Martin and Shelly 2017) and change in the ability of stands to achieve the DFC target by reducing stocking at three to six years post-harvest. On the other hand, mortality creates openings into the buffer that may allow release of suppressed small trees and establishment of new young trees, leading to more diversity within the riparian buffer stands. It would be useful to resample these sites after longer time periods in order to continue to monitor the trajectory toward DFC, but that is outside the scope of this study.

Our sample sites consist of one side of a single RMZ segment that was treated with a single prescription variant and is 300 feet in length (sampled) plus at least 75 feet at each end (450+ feet total). As noted previously, 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. RMZ segments with both one- and two-sided treatments were included in the sample frame, but if a segment with a two-sided treatment was selected, one side was chosen at random by the crew. A detailed rationale for this is included in the Study Design document (Schuett-Hames et al, 2017).

After the visual screen for evidence of harvest, we then examined individual FPA documents for information not present in the FPARS database to select harvest units with stream segments at least 492 feet (150m) long[4], with one of the eleven treatments of interest that did not have a stream adjacent road, CMZ, or other disqualifying feature such as a landslide or large wetland. Because the FPARS GIS database does not contain all the information available from the FPA and is error-prone, we manually reviewed the FPA documents to make sure that none of the disqualifying conditions were present. Following this step, we created a database of individual stream segments with their prescription variants and other covariates available from the inspected FPAs. This process was iterated several times, each time randomly selecting a subset of harvest units from the initially queried pool to screen in more detail. At the end of the process, we had a database of potentially viable stream segments to be further screened using GIS, aerial imagery, and field validation.

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[4] We screened for stream segments longer than 300 feet because we required 75 feet at either end of the test reach (300 + 75 + 75 = 450 feet) to prevent edge effects from confounding our data. The GIS databases were set up in meters, and 150 meters (493 feet) was a round number to use for the GIS screening that included all this length.

To minimize the potential for spatial autocorrelation, final selections of potential candidate RMZ segments had to be spaced at least 2 km apart. Because of the comparative rarity of RMZ segments that met all of our criteria, the majority of the candidate segments we identified were further than 2 km apart; when planning for field screening, we were able to manually spot any segments that were too close using GIS and randomly select which one would be field-screened and/or surveyed.

The disqualifying riparian segment criteria noted above were used to eliminate RMZ segments from the study due to their potential to confound our ability to detect conditions related to the timber harvest. Factors that only affect a portion of an RMZ segment, such as the presence of road crossings or unharvested areas with mass wasting or wetlands buffers, were not used to exclude entire segments, only to exclude affected portions of the RMZ. In these cases, the affected portion of the RMZ segment would not be surveyed, but the remainder would be included in the study, as long as the total remainder met the minimum stream length criterion. Using the DNR stream layer in GIS and aerial photography, we manually created linework representing each potential qualifying pre-screened F and S segment. In the linework creation, we referred to FPA maps and visual evidence from aerial photography to exclude anomalous areas such as areas with extra buffering due to unstable slopes or a wetland. This resulted in a layer of line features with accompanying attribute information such as harvest prescription and other covariates.

Because RMZ segments have varying lengths and our sample reach has a fixed length of 450 feet (137 m) for each site (300 sampled plus 75 foot (22.9 m) buffers at the ends), we needed to randomly select a portion of the RMZ segment—hereafter a 'study reach'—to sample within a given RMZ segment. The study design (Schuett-Hames et al. 2017) and field methods manual (Davis 2019) describe the process used to further screen and lay out the study sites for the field crews.

2.2 Field Screening and Layout of Potential Study Reaches

CMER staff provided information and spatial data with pre-screened potential study reaches to West Fork Environmental (WFE) crews. WFE crews began field screening potential study reaches and laying them out in preparation for future data collection in October 2018. DNR project management staff called all landowners in advance of site visits to ensure access permits were in place. WFE then visited the potential RMZ segments and, if a potential segment met study qualifications, measured and marked out the 300-foot study reach and inner/core zone boundaries with flagging tape and points on the GIS application Collector, in accordance with the study Methods manual (Davis 2019). If a potential segment candidate had both sides of its RMZ adjoining the relevant harvest unit, then it had two separate sets of line work with two separate randomly selected start points, one per side. Because the sampling unit is just one side of an RMZ, crews selected which side of a two-sided RMZ to lay out and survey by flipping a coin.

Crews then proceeded with the site layout according to the field methods manual (see manual for details). Site class was not verified in the field; sites were laid out according to the FPA site class data and the designated RMZ treatment the FPA declared for the harvest. If after laying out the stream channel edge of the site, the crew determined the reach still qualified for the study, they completed the rest of the buffer zone boundary layout. Crews delineated the core and inner zone boundaries based on their measurements and the buffer requirements of Table 2; they did not try to copy how the original layout was done by the forester or second guess zones based on apparent harvest. They simply measured out the prescribed widths for the zones using the azimuth as measured and a distance interval judged to be useful (60 ft or another width). This provides standard study reach sizes across the board but some flexibility in layout to capture unique site-scale characteristics.

The RMZ width was measured from the bankfull channel edge and extended upslope to the distances specified in Table 1. Core and inner zone boundaries were delineated in horizontal distance. Besides flagging the boundaries, crews took points using ArcGIS Collector at the upstream and downstream endpoints of the core zone and inner zone boundaries. Crews took photos at the start point, one in each of the 4 cardinal directions, plus one facing upstream and one facing downstream, to visually capture site conditions.

2.3 Field Data Collection

Data collection began after leaf-on in May 2019 and continued through early September 2019. 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 collected. For the specific procedures used for each type of data collected, please refer to the Methods Manual (Davis 2019).

2.3.1 Stand Structure Data Collection

2.3.1.1 Standing Trees

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 to be within the RMZ when at least 50% of the DBH of the tree lies inside the study reach boundary. Live and dead trees under 4.5 ft tall were not counted at all, regardless of diameter; cut stumps were ignored entirely and were not included as dead trees[5], even if they were over 4.5 ft tall. For all qualifying standing trees, condition (live/dead), regulatory zone (core/inner), species, and diameter at breast height (DBH) to the nearest tenth of an inch were recorded using methods in WA DNR (1996).

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[5] 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 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 is a massive effort and when done 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 that is part of the FPAs for sites that had Inner Zone harvest, the measurement of stumps component was not included in the study implementation.

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 a special key and decay criteria. For more information on how the key was developed and how to use it, refer to the Methods Manual (Davis 2019). Standing dead trees (both pre- and post-harvest mortality) were also assigned a mortality agent (cause of death). If several potential agents appeared to have played a part, the primary agent that played the bigger role was selected.

2.3.1.2 Post-harvest Fallen Trees and Large Wood Recruitment

Surveyors collected data 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.

Surveyors first assessed whether a tree met the qualifications for a post-harvest fallen tree, using the key described above. 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. 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 all linked with the identification number of the parent tree in order to analyze attributes of the tree from whence it came and not count 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 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.

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 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 (**Error! Reference source not found.**). A single piece of LW 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).

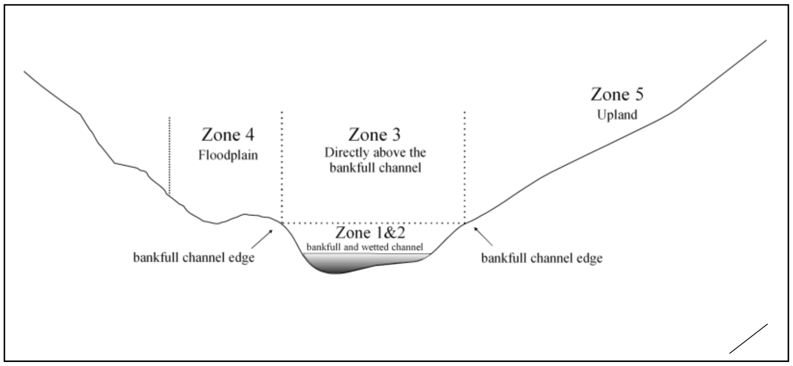

Figure 3. Criteria for channel zone identification (adapted from Schuett-Hames et al., 1999). Zone 1&2 corresponds to the in-channel zone, zone 3 corresponds with the over-channel zone, Zone 4 corresponds with the out of channel floodplain zone, and Zone 5 corresponds to upland areas outside the floodplain.

If the tree or broken piece had a recruitment class of 'Upland' or 'Floodplain,' no additional data were recorded. 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 large wood within the channel (at least 4 inches in diameter and 1 foot long), then it was considered recruited large wood (LW) for the purposes of data collection and 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.

One exception to the 'no measurement of pre-harvest mortality trees' rule was trees that had died previous to the most recent harvest but had subsequently (after the most recent harvest) recruited to the stream channel. The rationale for including these trees is that post-harvest windthrow could impact the number of old snags newly recruiting to the channel, which could potentially be an effect of the harvest treatment on riparian function that would otherwise not be measured. Surveyors simply tallied the number of "pre-harvest-mort/post-harvest-recruit" trees in the channel and did not collect additional information on volume, etc., in order to get a general idea of how common this phenomenon might be.

2.3.2 Canopy Closure/Shade Data Collection

The purpose of canopy closure surveys was to provide estimates for cover that provides shade to the stream channel. Although they are not directly equal, canopy closure is a surrogate for shade and the terms are used interchangeably in this report. Two methods of canopy closure data collection were used: one based on Lemmon (1957) and described in the Forest Practices Board Manual (WA DNR 2000) that captures a coarser level of shade conditions in the study reach and one following Platts et al. (1987) that more specifically captures the shade conditions produced by the one-sided RMZ treatment we measured. The Platt method improves assessment of the shade provided by the study RMZ by eliminating the confounding cover data provided by the trees on the other side of the stream and by taking measurements at a consistent distance from the RMZ regardless of stream width. Canopy closure data were collected at systematic intervals along the study reach. Stations were spaced evenly throughout the reach at 60-foot intervals if possible, with a minimum of 30 feet from the upstream and downstream edges; this was done in the interest of avoiding the edges of blocks to avoid capturing spurious shade effects. Where spacing every 60 feet would result in measuring at an edge or was otherwise impractical, surveyors adjusted spacing to avoid edges but still dispersed measurements as evenly as possible throughout the reach. Each study reach had five canopy stations. At each canopy station, surveyors collected data using both the Board Manual method (Surveyor reads the densiometer four times in four different directions, counting number of obstructed within-square dots per 96 dots as they go), and the Platts method (Surveyor reads the densiometer one time, facing in one direction, counting number of obstructed dots-at-intersections per 17 in the wedge-shaped subset). GPS coordinates and photos were taken at each station using the Collector app.

2.3.3 Soil Disturbance and Sediment Delivery Data Collection

Surveyors looked for stream-bank disturbance or soil disturbance features caused by harvest or yarding activity that had a surface area of > / = 10 sq ft (1 m^2). Surveyors were to measure and record data only on the areas of a disturbance feature that fell within the core and inner zones of the study reach and disregard 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. No soil disturbance or erosion that met minimum criteria was observed.

2.3.4 Stand Age Data Collection

Running the DNR DFC Model Worksheet, version 3.0 (https://fortress.wa.gov/dnr/protection/dfc/DfcRun.aspx) entails knowing the age of a stand at harvest. For stands with no harvest in the inner zone, this information is not included in the FPA. To obtain a measure of stand age at harvest in the area outside the buffer (which is not publicly available from DNR), crews counted rings from 3-5 stumps of a dominant tree species which had been harvested just along the buffer edge in the most recent harvest, dispersed along the length of the 300 ft study reach, following methods of USDA Forest Service (2018). Crews avoided stumps from large anomalous remnant trees, because those would not be representative of the main stand to be modeled in the DFC calculations. Ring counts were averaged to obtain stand age.

2.4 Additional FPA Data Collection

For sites with harvest in the inner zone, stand age is included in the DFC worksheet results that are submitted by the landowner as part of the FPA. The FPAs for those sites were combed for not only stand age but also for pre-harvest stand information and for actual no-cut buffer widths for the 30 LTCW harvest option 2 sites. Stream type data were pulled from the original FPAs for all sites.

2.5 Data Preparation

A large number of descriptive metrics were calculated and summarized by site and zone (core vs inner) (Table A-1). The calculated metrics are QMD, count, density, basal area (total), and basal area per acre for live, dead, and fallen trees; the number of fallen trees that reached the stream and the volume of wood that ended up in the channel; and dominant species by count and basal area, species richness by count of species present, and percent species for any tree species that was found to be dominant at one or more sites.

The Immediate Post-Harvest (IPH) standing live trees composition was estimated by adding standing dead trees that died post-harvest, fallen broken bottoms of trees, and fallen uprooted trees to the inventory of standing live trees at the time of survey. Those data were also summarized by site and zone.

The tree and basal area densities reported for the inner zones of sites in LTCW prescription variants are not very representative of true conditions with respect to shade and stream wood recruitment potential. In reality, those inner zones look like an extended Core zone out to the no-cut line, and then they look like the Outer zone. Therefore, we also calculated data for “Unharvested zones” by assuming all IPH standing trees were in the unharvested inner zone and the rest of the inner zone was clearcut[6], and the Unharvested zone TPA and BAPA were calculated based on the total no-cut distance specified in the DFC run prescription. For TFB sites, the Unharvested zone is only the Core zone width. For sites that were neither LTCW nor TFB sites, the Unharvested zone is the entire Core + Inner zone width. Although there were often some trees left in the inner zone beyond the no-harvest portion, the numbers were low, and. we feel the results presented here are a reasonable estimate to use for comparison among sites.

In addition to the several stand descriptive variables, we calculated response metrics related to stream conditions: stand mortality and mortality rates, the two densiometer shade measurements, and recruited wood by piece count and volume within the bankfull channel using two methods. We

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[6] The harvested portion of the Inner Zone is not really clearcut; 20 trees/acre must be left, similar to the Outer Zone rule. However, for the purposes of this analysis, the data were prepared as though all trees were in the no-harvest area and the rest was clearcut. Without a stem map, we had no way of knowing which trees were where within the zones.

averaged the shade measurements from each method separately for each site. We calculated annual mortality rates for each site using the formula

$$1 - \left(\frac{Yr3\ standing\ live\ count}{IPH\ standing\ live\ count}\right)^{1/3}$$

Large wood data were collected consistent with the Washington State Timber Fish and Wildlife (TFW) monitoring methods that have been in use since at least 1990 (TFW 1990), as well as with much other referenced research in Washington State (Bilby and Ward, 1989 and 1991). This method counts and collects data on any piece in the riparian zone that exceeds the minimum "large wood" criteria used (4" midpoint diameter by at least 6' long). Recruited large wood (LW) is considered to be the portions, of any size, 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 key piece information can be elucidated from the data.

Other studies and reported volumes use a method that only counts pieces of wood that have a minimum *in-channel* size, most commonly 4" diameter by 6' long (0.1m x 2m). We will refer to this as the "In-channel LW" method. Requiring the piece within the channel width to be this minimum size results in fewer pieces and less volume reported than the other "Riparian LW" method. Studies that use this 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)

A third method for calculating and reporting wood loading uses a variant of the first method but where the piece volume is calculated for the entire piece, not just the portion extending into the bankfull channel width. This method is useful in key piece analysis and on large rivers, which are more likely than smaller streams to entrain a log that is resting primarily up on the bank or floodplain, as long as some portion (>1m) extends into the bankfull channel (Fox and Bolton, 2007; M. Fox, pers. comm., 2020). That method is not used in this study.

Because they collect measurements on the portions of wood pieces that are within each recruitment class, either of the "Riparian LW" data collection methods allow for comparison of results to those of what we will call the "In-channel LWD" method by filtering the data from the former for only those pieces that exceeded the minimum criteria within the channel width zones 1, 2, and 3. In this study, we therefore calculated wood piece and volume loading for both methods. "LW pieces/100 ft" and "LW vol/100'" are calculated using the pieces and volume of wood of any size that extend into zones 1, 2, or 3. "BF-LW pieces/100 ft" and "BF-LW volume/100 ft" are calculated by filtering the large wood data (LW) to only include wood that was at least 6 feet long by 4 inches in diameter within Zones 1-3.

2.6 Resurveys

Habitat resurveys are replicate surveys at a given monitoring site, performed by a different set of crew members than those that performed the original survey. By replicating a subset of surveys, a monitoring study is able to partition sources of error in the data and thus parse true environmental variability (actual differences between sites, between types of treatments, or between other variables of interest) from variability in the data due to human data collectors (aka crew variability). In addition, re-surveys can help determine the relative repeatability of metrics used in the study to help target reliable metrics that will be useful to track change over time or determine true differences between sites or strata. This helps scientists ask the right questions, use the most reliable metrics and protocols, and more directly target areas of interest or concern, thereby helping reduce the high cost of monitoring. Re-surveys are commonly used in large, landscape-scale habitat monitoring studies, such as Oregon Department of Fish and Wildlife's Aquatic Inventory project (Flitcroft et al. 2002, Anlauf-Dunn and Jones 2012), the Environmental Protection Agency's Environmental Monitoring and Assessment Program (Kaufmann et al. 1999), and the United States Forest Service's Forest Inventory Analysis.

A resurvey sample was conducted in this exploratory study to help quantify crew variability due to the rotating cast of surveyors and to set crew variability apart from true environmental variability. Standard practice when implementing large, landscape-level ecological investigations is to resurvey 5-10% of the total sites (Roper et al. 2010). We have 110 sites with 10 sites per each of 11 strata. Eleven sites (one per stratum) were selected randomly for resurveying. Identical procedures were used to collect the same data attributes as in the first survey. The resample crew relied on the initial site layout flagging, which was not part of the resurvey. Although replicate sampling often is, this portion of the study was not meant to be part of a quality control program but rather was only intended to inform the interpretation of study results and to help guide the future experimental effectiveness study design and implementation.

Metrics that were re-measured and that are reported on are shown in Table 4 with the anticipated sources of variability for each and the potential influence each source could have on the calculated metric.

Table 4. Site level metrics collected during the resurvey sampling, potential sources of variability in them, and the possible effect of those variances on the metric. Streambank soil disturbance is not included in the table as none was observed on any of the study sites. Major = errors could have a strong effect on metric estimation; Medium = errors could have a moderate effect on metric estimation.

METRIC GROUP	**VARIABILITY SOURCES**					
Original Stand Characteristics	**Different stumps counted**	**Ring counts**				
Stand age at harvest	Major	Medium				
Stand Structure/ Mortality Metrics	**Missed trees**	**Live vs. dead determination**	**DBH measurement**	**Pre- vs. post-harvest mortality determination**		
Live stem count	Major	Major				
Live basal area	Major	Major	Medium			
Mortality count	Major	Major		Major		
Mortality basal area	Major	Major	Medium	Major		
LW Recruitment Metrics	**Missed pieces**	**In vs. out determination**	**Pre vs. post-mortality**	**Length measurement**	**DBH measurement**	
Piece count	Major	Major	Major			
Piece volume	Major	Major	Major	Medium	Medium	
Canopy Closure/Cover Metrics	**Missing measurements**	**Different measurement location**	**Cover measurement**			
% canopy cover, 4-direction method	Major	Major	Medium			
% canopy cover, towards RMZ method	Major	Major	Medium			

2.7 Quality Assurance and Control

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 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 field data and calculated metrics were created, anomalous data were inspected in detail for accuracy and reasonableness, and any necessary corrections were made before the data were incorporated into analyses.

2.8 Analysis of Post-harvest Riparian Stand Conditions and Ecological Functions

We began the evaluation of post-harvest conditions and functions by performing some exploratory data analyses to look for correlations and patterns among the many measured variables. Then we further investigated the level of specific riparian functions to which this study was oriented - large wood recruitment, stream shade, and sediment delivery to the streams – for sites that did and did not have harvest in the inner zones.

2.8.1 Exploratory Analysis

We used many exploratory methods to identify patterns of potential interest including plotting the data by prescription variant, site class, stream width category, harvest type and species and zone. We also performed exploratory tests using linear, generalized linear, and generalized linear mixed models and sought out confirmatory patterns in the data.

Because the dataset was not balanced with respect to variables of interest (Table 5), we analyzed subsets of these data depending on the question we were trying to explore. In general, we used the entire dataset when looking at correlations between residual stand composition and response variables (shade and wood recruitment).

Table 5: Planned study site distribution. Number of sample sites by site class, stream width category and inner zone treatment type.

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

When looking at differences in species composition between core and inner zone, we use the subset of sites without inner zone harvest (n=70) to avoid the confounding effect of selective species removal from the inner zone. For initial conditions analyses, we use the core zone attributes for each site (n=110) because the core zones had no harvest. Because inner zone harvest only occurred in site class II and III, we restricted the prescription treatment analysis to those site classes.

The exploratory nature of the analysis led to a high probability for identifying patterns that were not generalizable. Given the inter-related nature of many of the variables, we used Principal Components Analysis (PCA) and Non-metric multidimensional scaling (NMDS) to help identify the dominant sources of information in the dataset.

PCA is a statistical procedure that converts a set of observations of possibly correlated metrics into a set of values of linearly uncorrelated variables called principal components. This transformation is defined in such a way that the first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set.

Since we had information on species, and species composition appeared to explain a lot of the variance in our data, we also analyzed the data using Non-metric Multidimensional Scaling (NMDS). NMDS is an indirect gradient analysis approach which produces an ordination based on a dissimilarity matrix of species within sites. The sites are arranged in multiple dimensions so that the sites separate in a way that produces the least “stress.” In this analysis, we used a Bray-Curtis dissimilarity and chose 2 or 3 dimensions (typically 3) in order to ensure that the stress was less than 0.2. Environmental gradients and factors of interest (e.g., site class) were overlaid on the NMDS to see significant correlations in the species composition.

All the analyses were conducted using R statistical software version 3.6.2 (R Core Team, 2019). Data wrangling and plotting was done using the tidyverse (Wickham, 2019) and ggplot (Wickham, 2016) packages. The PCA analysis was conducted using the FactorMineR (Sebastien et al. 2008) and FactoInvestigate (Thuleau and Husson, 2019) packages. The NMDS was conducted using the vegan package (Oksanen et al. 2019). The Bayesian GLMM were conducted using R brms package (Bürkner 2017, 2018) and Stan (Carpenter et al. 2017) with default priors.

2.8.2 Large Wood Recruitment Analysis

We evaluated the extent of mortality of different types among the various sites and prescription variants and the amount of wood that has recruited to the stream channels since harvest. We then explored the residual riparian stands and the potential for future wood recruitment.

2.8.3 Canopy Closure/Shade Analysis

We plotted shade levels in relation to the shade required by Board Manual Section 1 for each site based on its elevation and maximum temperature limitation class (16C or 18C). We inspected the data for patterns in shade levels relative to prescription variant, inner zone harvest, mortality, and to the degree possible, stream size. For stream size, we were limited to a channel width classification of "Small" (<10 ft wide) or "Large" (>10 ft wide) and for Large streams, whether they were Type S, which we presumed to be significantly greater than 10 feet wide.

2.8.4 Soil Disturbance and Sediment Delivery Analysis

Since no soil disturbance or erosion that met minimum criteria were observed, no analyses were performed on this riparian function.

2.9 Desired Future Condition (DFC) Assessment

The second objective of this exploratory study was to evaluate the extent to which post-harvest riparian forest stands that did and did not have inner zone harvest are on trajectory to achieve the DFC target of at least 325 ft^2 of basal area in the riparian buffer by the time the stand is 140 years old. We submitted stand data from all sites to the DFC calculator on the Department of Natural Resources web page (https://fortress.wa.gov/dnr/protection/dfc/DfcRun.aspx) and graphed the percentage by which the projected basal area values (at age 140) exceed or are below the target value of 325 ft^2 for each site. We then investigated conditions at the sites that the DFC model predicts will not meet the desired future condition, with a particular look at those sites that had inner zone harvest to assess whether there were patterns that suggested areas of further investigation in the BACI study.

3 Results

3.1 Study Sites

Site locations are shown in Figure 4, which also shows the distribution of Type F stream channel lengths in the various designated site classes on FFR/CMER lands. Characteristics and values used in calculations for sites in each prescription variant are shown in **Error! Reference source not found.**. Individual site parameters measured and calculated are provided in Appendix A tables.

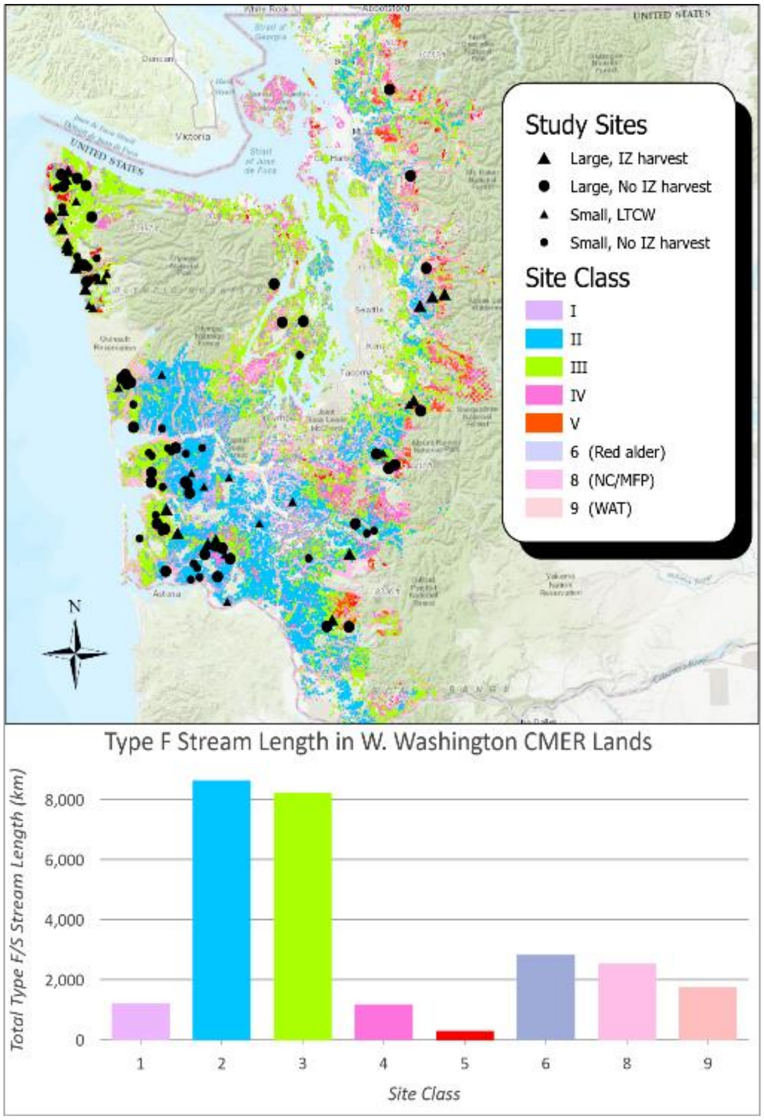

Figure 4. Westside Type F Study Site locations and breakdown of Type F stream length in the study domain (private forest lands in western Washington that are subject to the Forests and Fish forest practices rules), displayed by DNR-designated site class.

Stands in the studied harvest units ranged from 30 to 120 years old at harvest, although nearly all were between 35 and 50 years old (Appendices A and B). These are the stand ages reported by landowners on the associated FPAs and are not specific to the riparian buffers studied. There was a slight tendency for buffers with inner zone harvest to be in older stands. The only notable relationship between stand age and prescription variant was that units in site class V on small streams are closely centered around 40 years old.

Near the end of the analysis, issues were discovered with a few of the sites in this study. Delving back into details of the FPAs revealed that one site in prescription variant 4 (small stream) was actually on a large stream and should have been in variant 2. It was moved for the later analyses, but we did not reconduct the initial exploratory analyses with the new classification. Two sites with inner zone harvest were discovered to have been laid out under the earlier DFC rule, not the post-2009 rule which was the subject of this study. Those sites are included in our reporting for informational purposes but are identified in order to show how the stand conditions differ. One site that was thought to have been a LTCW Type F RMZ was found to in fact be a Type Np buffer on a segment of stream that had a type change at some point but not on the main DNR hydrography and that was not shown on all of the maps in the FPA. Data from this site (4e) were deleted from the later analyses but still exist in the initial exploratory analyses.

Table 6. Site characteristics common to each prescription variant sampled (WA DNR, 2021)**.**

Prescrip Variant	N	Stream Width Class	Site Class	Inner zone harvest trtmt	Plot (Stream) Length [ft]	Core Zone Width [ft]	Core Zone Area [acres]	Inner Zone Width [ft]	Inner Zone Area [acres]	Core + Inner Zone Width
1	**10**	**L**	**II**	**No harvest**	300	50	0.344	78	0.537	128
2	**11**	**L**	**II**	**LTCW**	300	50	0.344	78	0.537	128
3	**10**	**S**	**II**	**No harvest**	300	50	0.344	63	0.434	113
4	**8**	**S**	**II**	**LTCW**	300	50	0.344	63	0.434	113
5	**10**	**L**	**III**	**No harvest**	300	50	0.344	55	0.379	105
6	**9**	**L**	**III**	**TFB**	300	50	0.344	55	0.379	105
7	**10**	**S**	**III**	**No harvest**	300	50	0.344	43	0.296	93
8	**9**	**S**	**III**	**LTCW**	300	50	0.344	43	0.296	93

Prescrip Variant	N	Stream Width Class	Site Class	Inner zone harvest trtmt	Plot (Stream) Length [ft]	Core Zone Width [ft]	Core Zone Area [acres]	Inner Zone Width [ft]	Inner Zone Area [acres]	Core + Inner Zone Width
9	**10**	**L**	**IV**	**No harvest**	300	50	0.344	33	0.227	83
10	**10**	**L**	**V**	**No harvest**	300	50	0.344	18	0.124	68
11	**10**	**S**	**V**	**No harvest**	300	50	0.344	10	0.069	60

3.2 Descriptive Results

Data were collected during a single survey approximately 3 years after harvest. Trees that died and/or fell in the period since harvest (assessed using established methods laid out in the field manual) were added to the year-3 live tree total to get an estimate of the conditions immediately post-harvest (IPH) (see Study Approach). These data were compared with those from the survey year to assess change over the years immediately post-harvest. Distributions of summary results for calculated variables of interest are shown in Appendix B by prescription variant and by Inner/Outer Zone within each prescription variant. When viewing descriptive results by variant, it is important to recognize first, that variants are the *result* of differences in a) site class, b) stream width category, and c) whether the stand met the basal area threshold and the landowner chose to apply an inner zone harvest prescription; and second, that each variant has a different inner zone width. Therefore, there are inherently high correlations among these and other variables and comparing single variables versus another can be misleading. For these reasons, we begin reporting results with the principal components analyses (PCA) and only bring in specific depictions of variable relationships once the PCA has indicated those that appear to be meaningful for specific topics.

3.3 Post-harvest Riparian Stand Conditions

3.3.1 Exploratory Analysis - PCA: Dominant patterns in this dataset - residual stand metrics

Given the exploratory nature of this study and non-independent nature of the variables, we used Principal Components Analysis (PCA) to identify the independent and dominant patterns in the data.

The PCA was conducted using the full set of 110 sites (core and inner zone combined) and 45 descriptive metrics (Appendix A). The PCA indicated there were only four component axes that carried real information, so the analysis described below is restricted to these four dimensions. The three components that make up a prescription variant (site class, stream width category, IZ harvest), the six response variables related to shade and wood recruitment, and dominant species by count were included in the PCA as illustrative variables (see full analysis in Appendix A).

The first two dimensions of the PCA expressed 57.5% of the total dataset inertia, meaning that that 57.5% of the site variable cloud is explained by the plane that includes just the first two axes, which is relatively high. Based on a Wilks test p-value, dominant tree species (Figure 5) was the factor that best separated sites within this plane (Figure 6).

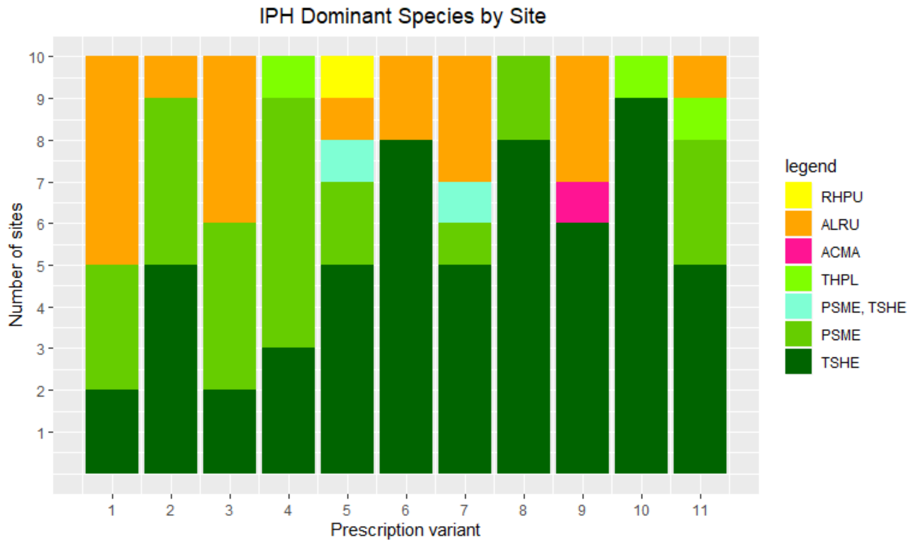

Figure 5: Dominant species by count. RHPU = cascara; ALRU = red alder; ACMA = bigleaf maple; THPL = western redcedar; PSME = Douglas fir; TSHE = western hemlock.

3.3.1.1 PCA Dimension 1 ~ Mortality, Fallen Trees, and Wood Recruitment (Figure 6, X-axis)

Dimension 1 explains 37% of the variance in the dataset and is highly correlated with the descriptive metrics Mortality Basal Area (BA), Percent Mortality, and Percent Mortality BA (respective correlation of 0.97, 0.97, 0.96). Those metrics can be thought of as summarizing this dimension. Dimension 1 is also highly correlated with Fallen BA/100ft (recruiting), Fallen Basal Area Per Acre (all), Fallen TPA (all) (respective correlation of 0.94, 0.94, 0.93) and the response variables Recruited Volume Above Bankfull and Recruited Wood Volume/100ft (respective correlation 0.82, 0.81). In terms of qualitative factors, we find that dimension 1 is correlated with the stream width category (r^2=0.10, p<0.001), and we see that sites dominated by Red Alder are negatively correlated with this axis (p<0.001).

3.3.1.2 Dimension 2 ~ Live Tree Density (Figure 6, Y-axis)

Dimension 2 explains 19.3% of the variation in the dataset and is highly correlated with the descriptive metrics Live TPA IPH, Live TPA at YR3, Live Count/100ft at IPH, and Live Count/100ft at YR3 (respective correlation 0.92, 0.91, 0.91, 0.89). Those metrics can be thought of as summarizing this dimension. Dimension 2 is negatively correlated with Live Quadratic Mean Diameter (QMD) at both IPH and at YR3 (respective correlation -0.71, -0.72). Dimension 2 is also correlated with both sets of densiometer readings, including the four-way reading (Shade 1, correlation 0.2) and the one measurement reading looking into the buffer (Shade 2, correlation 0.35). In terms of qualitative factors, we find that dimension 2 is correlated with both dominant species (r^2=0.31, $p<0.001$)) and site class (r^2=0.16, $p<0.001$).

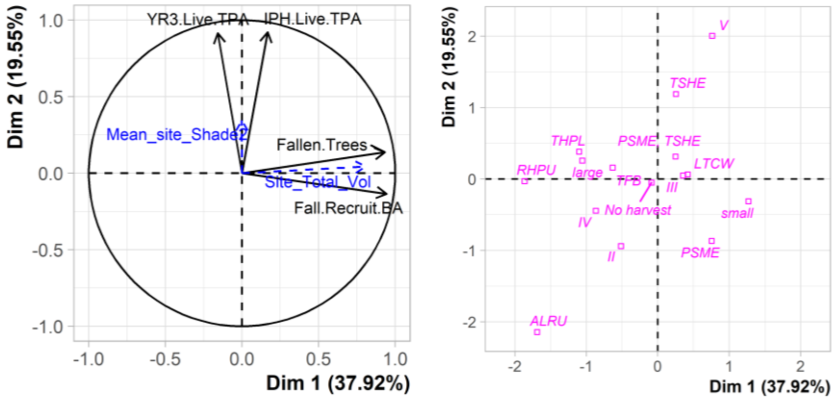

Figure 6: PCA with reduced components showing the relationship between shade, TPA, and site class. PCA Axis 1 & 2 with all data (n=110). Left: Variables factor map. The labeled variables are those with higher contribution to the plane construction. Right: Qualitative factor map. ACMA is not shown because it has PCA coordinates (5,-6) which puts it way down to the right associated with low TPA and high mortality.

3.3.1.3 Dimensions 3 & 4 ~ Tree Size and Species (Appendix C-4)

On similar plots dimensions 3 and 4 account for 10.25% and 5.91% percent of the remaining variation in the dataset, respectively (Appendix C). Dominant Species and Inner Zone harvest treatment were both significant factors in this plane ($p<0.001$). The interpretation of these axes is not clear but dimension 3 is most strongly correlated with Live Basal Area at IPH and YR3 (respective correlation 0.81 and 0.69) and dominant species (r^2=0.14). Dimension 4 is most closely associated with species richness (correlation 0.51), dominant species (r^2=54) and Inner Zone Harvest Treatment (r^2=0.18).

3.3.1.4 Interpretation of the Principal Component Analysis

The PCA suggests that dominant species was the variable in the dataset that best explained differences among sites. After species, site class and stream width category both help separate sites in ways that appear to be largely independent to each other.

PCA axis 1 indicates that the one site dominated by Cascara (RHPU), the 20 sites dominated by Red Alder (ALRU), and the sites on large streams were all were associated with lower mortality than sites on small streams or those dominated by Douglas Fir (PSME). PCA axis 2 indicates that sites dominated by Western Hemlock (TSHE) were significantly more likely to have high live tree density while sites dominated by Big Leaf Maple (ACMA) or Red Alder (ALRU) were less likely to. The PCA also suggests that sites high in dimension 2 (e.g., site class V) are more likely to have higher shade values than sites that plot lower in dimension 2.

In PCA axis 3&4, we see differences in residual stand composition between sites that received inner zone harvest and those that did not. As one would expect from the rules regarding inner zone harvest, sites with Inner Zone harvest (LTCW, TFB) appear to be associated with high percent conifer including Douglas Fir (PSME) and Western Hemlock (TSHE), while sites with no inner zone harvest (‘No harvest’) are more likely to be associated with Western Red Cedar (THPL), Red Alder (ALRU), Cascara (RHPU). We explore species composition in more detail below

Site class is defined as a function of tree height based on soil mapping, with site class II having taller trees at age 50 than site class III, IV or V. With the exception of Site Class IV, which was only sampled on 10 sites, all of which were on large streams, the PCA indicates that tree density increases with site class and that site class V has the highest density, while QMD decreases with density and site class. This can be seen in the figures of Appendix B for live stem density and QMD where site class V, which has the narrowest buffer, tends to be composed of a large number of relatively small trees, and site class II, with the widest buffer, is composed of a lower density of larger trees. These results are consistent with the CMER DFC Validation Study (Schuett-Hames et al. 2005) which found similar results between TPA and Site Class, resulting in the Forest Practices Board making rule changes increasing basal area per acre targets for all Site Classes. Stream shade is also correlated with Dimension 1 which suggests that while site class II might have the largest trees and widest buffers, it still might lag behind site class V in terms of shade. We examine differences in tree density, basal area and size with site class below. Shade is also addressed in a separate section.

Mortality and wood recruitment appear to be strongly correlated with each other and with stream width category. The PCA suggest that the small stream category is associated with higher mortality and wood recruitment than the large stream category ($p<0.001$). This relationship is further explored in a separate section below.

3.3.2 Differences in Species Composition between Core and Inner Zone

This analysis incorporates only those sites that did not receive inner zone harvest (n=70) which allows us to look for differences in species composition between the core and inner zone unbiased by harvest tree removal.[7]

The NMDS separates the five dominant species along three axes and indicates that tree species composition (by basal area) varies with ($p<0.001$) site class ($r^2=0.22$) and buffer zone ($r^2=0.04$). The weak correlation with zone suggests that inner zones are slightly more likely to have a higher percentage of conifer, while core zones are slightly more likely to have a high percentage of red alder (ALRU) and western redcedar (THPL) (Figure 7). The third axis is not shown but it includes Sitka spruce (PISI) as being slightly more likely in the core zone as well. These results from NMDS are consistent with our understanding that wetness and disturbance, which discourage Douglas fir growth but are tolerated by alder, redcedar, and Sitka spruce, are both more likely in the core zone.

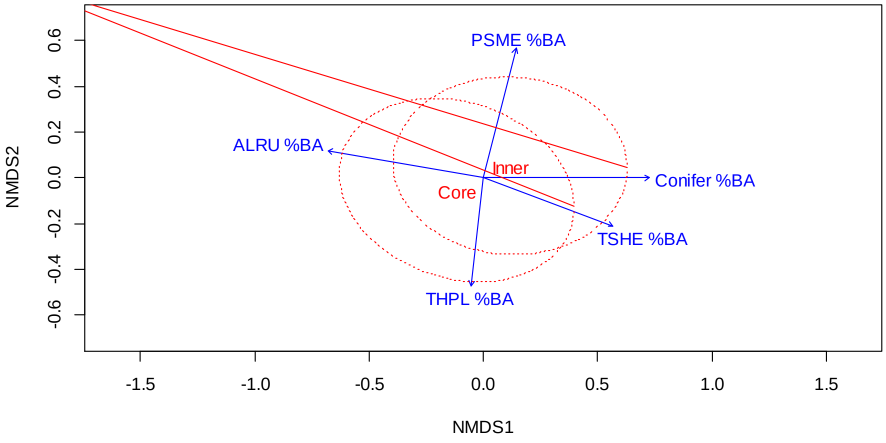

Figure 7: Sites without inner zone harvest (n=70) NMDS axis 1 & 2 separating sites by species basal area with dominant species composition and zone ($r^2=0.04$) overlaid. Axis 3 (not shown) suggests an association between Sitka Spruce and the core zone.

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[7] Note that by excluding sites with inner zone harvest, this analysis is biased against those traits that would lead to inner zone harvest (e.g, high basal area of valuable species in site class II and III).

3.3.3 Differences by site class

We explore the relationship between site class[8] and species composition using the core zone only (n=110) because the core zone should be relatively unaffected by harvest.

The NMDS separates the five dominant species along three axes and indicates that core zone tree species composition (by basal area) varies with ($p<0.001$) site class ($r^2=0.12$) and inner zone treatment ($r^2=0.09$). The smaller coefficient of determination (r^2) in this analysis compared with the one above may indicate that: 1) site class differences may be lower near the stream and increase as you move into the inner zone, or 2) focusing on sites without inner zone harvest accentuated differences between the core and inner zone.

Regardless, in the core zone, we see that western hemlock is associated with high tree density and site class V, while site class II is more likely to be associated with red alder and Douglas fir and a lower overall percentage of conifer species (Figure 8).

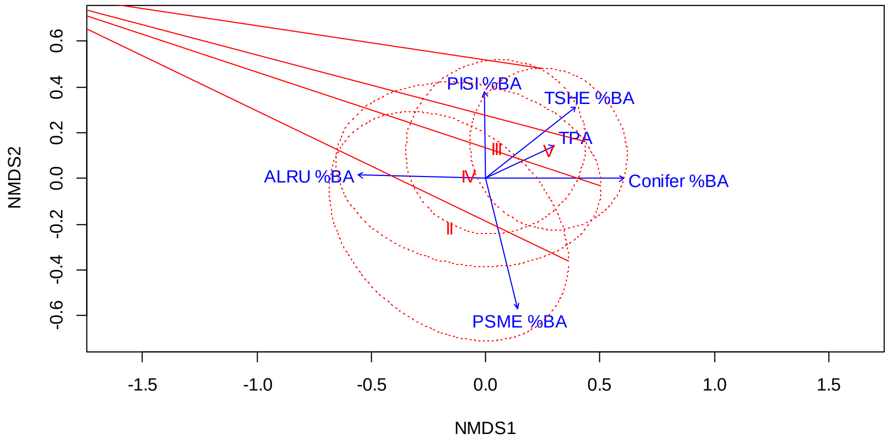

Figure 8: NMDS axis 1 & 2 separating sites by species basal area in the core zone (n=110) with dominant species composition and site class (r^2=0.12) overlaid. Axis 3 is not show because it was not significantly correlated with site class.

We have seen that species composition varies with site class and so does tree density. We also have indications that tree DBH varies inversely with site class. In this section, we ignore the influence of species while looking at differences in tree density, basal area, and size by site class. We use the data from the core zone only to avoid confounding by harvest effects and focus on our IPH estimate, though the patterns observed are very similar in our YR3 sample data.

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[8] Site class as declared on the FPA; did not field-verify

As we saw in the PCA, apart from site class IV, which was only sampled on large streams and contains the only site dominated by Big Leaf Maple, there is an increasing trend in tree density with site class (Figure 9, Figure 10). In contrast, tree diameter (and therefore, tree height) decreases with increasing site class. Basal area, which is a product of both the number of trees and their size, follows the pattern of density and increases with site class. While there are clear patterns of changes in the central tendency with site class there is also a lot of variability, and the variability is of similar or greater magnitude than the mean trend. There are many possible reasons for this variability, and one of them is that site class is not always delineated on DNR maps down to the stream buffer scale on smaller streams and is therefore often based on soils in the adjacent uplands. Schuett-Hames et al (2005) demonstrated the lack of accuracy in, at least, riparian site class designations. Thus, a buffer may have a much different tree height potential than indicated by the site class designation obtained from the Forest Practices site class map.

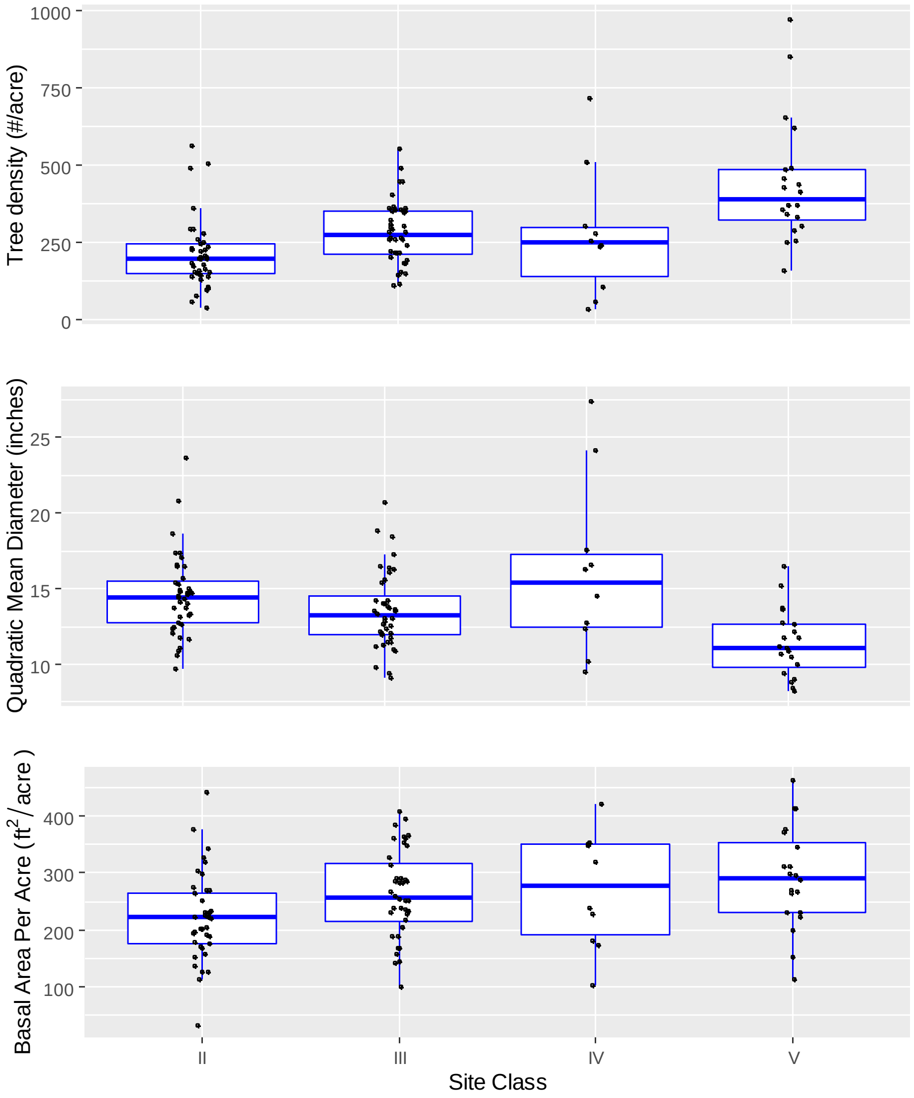

Figure 9: Tree density, mean diameter, and basal area by site class

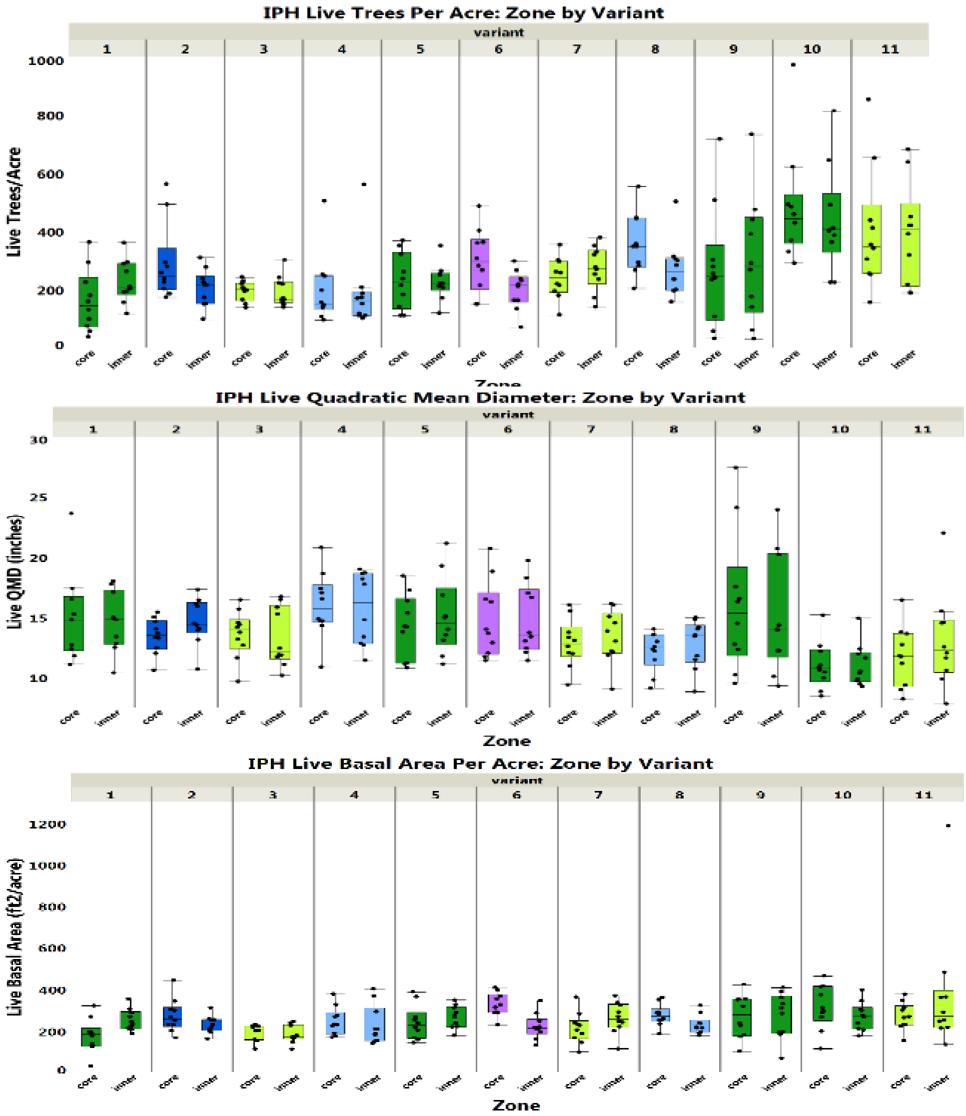

Figure 10. Initial Post Harvest stand characteristics by prescription variant and RMZ zone. Prescription variants are represented by color – Green = No-IZ harvest, Blue = LTCW, and Purple = TFB. Darker shades are for Large stream Rx and lighter shades are Small stream Rx. Site Class II is on the left (1 - 4) and Site Class V is on the right (10, 11). Note that while IPH Inner zone data for the No-harvest (green) prescriptions are representative of pre-harvest stand conditions, only the Core zone data represent pre-harvest conditions for LTCW and TFB prescriptions.

3.3.4 Inner Zone Harvest

One of the stated goals of this exploratory study was to gain insights into inner zone stand conditions following harvest. Inner zone harvest was only observed in site class II and III so this analysis is restricted to those site classes (n=80).

Landowners choose whether to do inner zone harvest for many reasons beyond site and stand qualification under the DFC criteria. When we run a mixed model that incorporates site class and treats site as a random effect (to account for those unknown reasons), and compare basal area in the core zone and inner zone by inner zone treatment, we see that core zone basal area is higher for sites that were harvested (Figure 10, Figure 11).[9] Although we know that core and inner zones are slightly different, they are similar enough that we can infer from these results that in general, sites with and without harvest were inherently different before harvest.

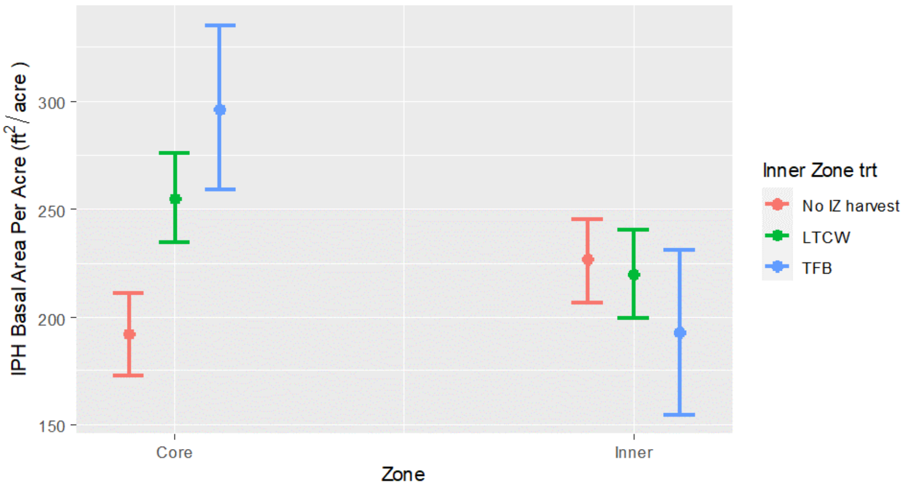

Figure 11: Estimated Live Tree Basal Area per Acre immediately post-harvest as a function of harvest treatment and zone with 95% credible intervals using data from Site Classes II and III.

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[9] The model is IPH.Live.BAPA ~ Zone * IZ_treatment + site_class + (1 | Site)

If we examine species composition immediately post- harvest (IPH) in site class II, which has a relatively balanced sample of 20 sites with and without inner zone harvest, we see that there is a significant correlation between species composition and inner zone treatment ($p<0.001$, $r^2>0.3$). If we force the NMDS into 2 axes for easier interpretability, we see that sites treated with LTCW are associated with higher percent conifer, Douglas Fir and Western Hemlock, while sites that received no inner zone harvest tended to have higher species richness and a higher percentage of western redcedar and red alder. This is true in both the unharvested core zone and the harvested inner zone (Figure 12, Figure 13)

The biggest differences we note between the core zone and inner zone after inner zone harvest is that inner zones in the LTCW sites tended to be conifer dominated while those in sites with no inner zone harvest were more likely to be alder dominated, *but this cannnot be attributed to a harvest effect*. In fact, the opposite is likely the case: under regular prescriptions, harvest would not be permitted in an inner zone that left alder (or other broadleaf species) dominating. These results therefore indicate that there are inherent differences in species composition between sites that receive inner zone harvest and those that don't, and those differences persist after harvest. The main thing we can associate with harvest treatment itself is a reduction in basal area since that is what harvest does.

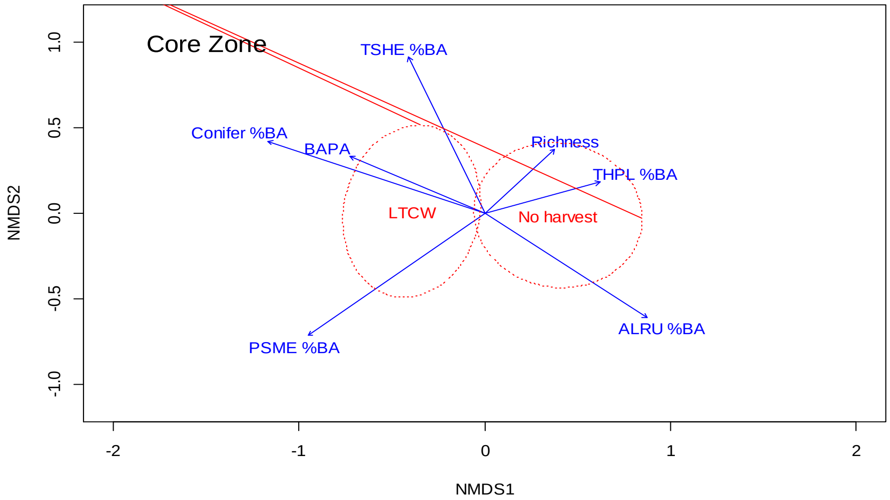

Figure 12: IPH NMDS from site class II core zones. Red dashed lines around the IZ harvest treatment are 1 SD from the central tendency.

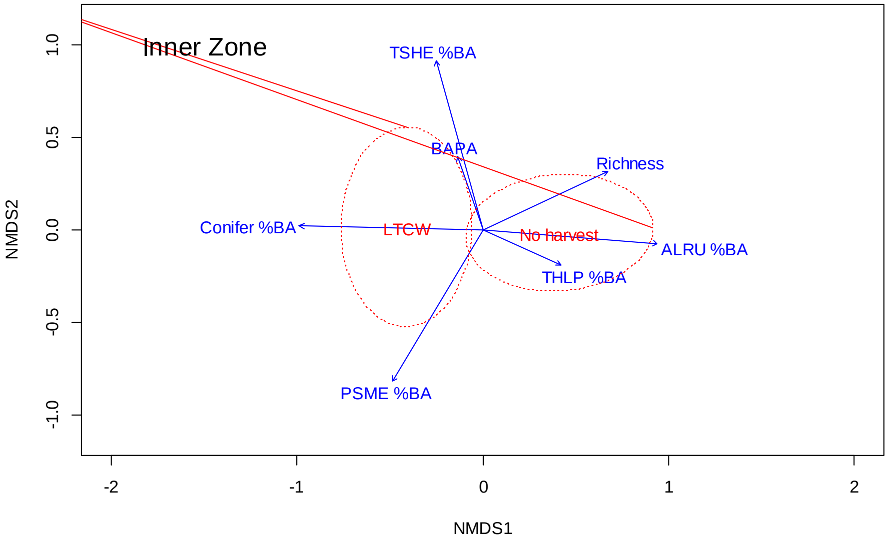

Figure 13: IPH NMDS from site class II inner zones. Red dashed lines around the IZ harvest treatment are 1 SD from the central tendency.

Though not included as a forest practices prescription requirement, the rules appear to leave an average of about 55 buffer trees per 100 feet of stream channel in all variants/site classes, though there is a large range. This appears to be true in sites with and without inner zone harvest and across site class and stream width categories (Figure 14).

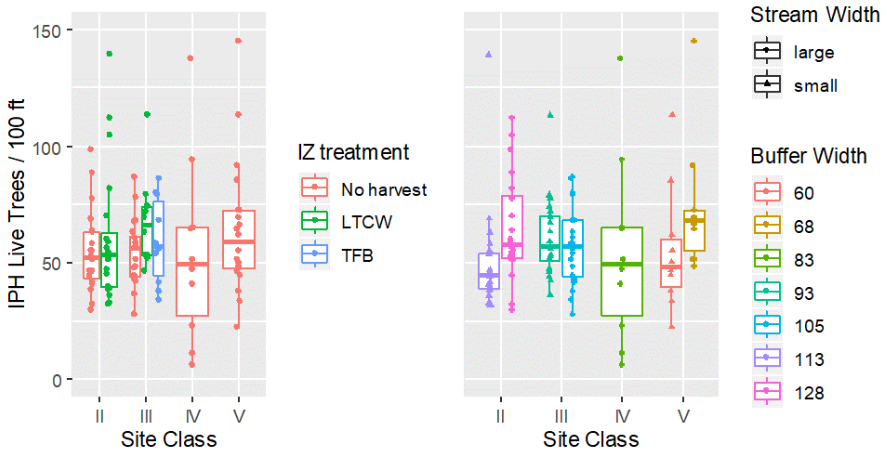

Figure 14: IPH Live Trees per 100 ft by Site Class, IZ treatment, Stream Width Category and Buffer Width.

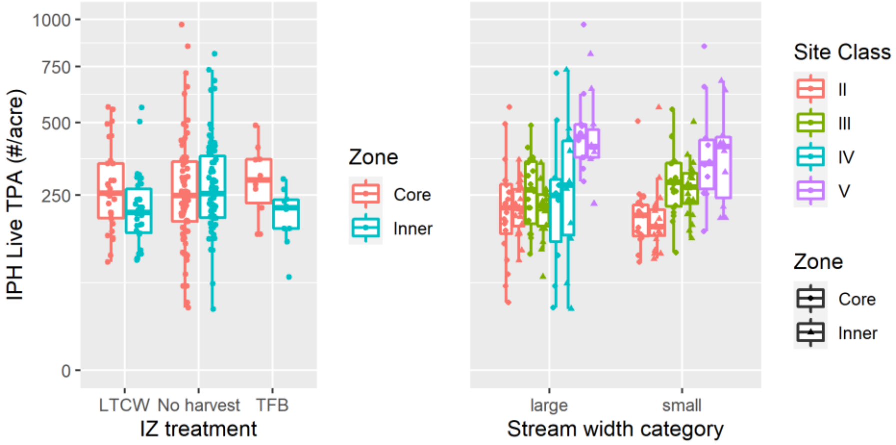

Figure 15. IPH Live trees per acre by buffer zone, inner zone treatment, stream size and site class. Note that the very large TPA values are an artifact of the very small areas (acreages) of the test buffer zones; the actual tree counts are much smaller than the TPA. In a larger zone area than in this study, more realistic TPA values would undoubtedly have been calculated for those sites.

3.3.5 Tree Mortality, In-stream Wood Recruitment, and Residual Stands

Field crews counted 18995 standing trees, of which 987 were determined to have died after harvest and 1467 were determined to have been dead prior to harvest. There were an additional 1827 trees that were determined to have fallen since harvest, creating 2898 pieces of LW in the 110 sites. From these data, we estimate there were 19355[10] live trees immediately post--harvest for an overall mortality of 14.5% in the first three (ostensibly; sometimes it was more but we can't pinpoint precise harvest time) years after harvest. The dominant mortality agent by far was wind (Table 7), with approximately 11.3% of the live buffer trees succumbing to windthrow over the first three years post-harvest. Median mortality tended to be only slightly higher for inner zones than core zones (Figure 16). The number of recruited pieces was highly correlated with mortality in terms of TPA (r^2=0.84) and total recruited wood volume was positively correlated with mortality in terms of BAPA (r^2=0.65).

Table 7: Mortality agent by process

Mortality agent	N	prop
Erosion/flooding	38	1%
Fire	1	0%
Harvest/yarding	11	0%
Other	128	5%
Suppression	222	8%
Wind	**2160**	**78%**
Unknown	254	9%

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[10] 18995-1467+1827 = 19355

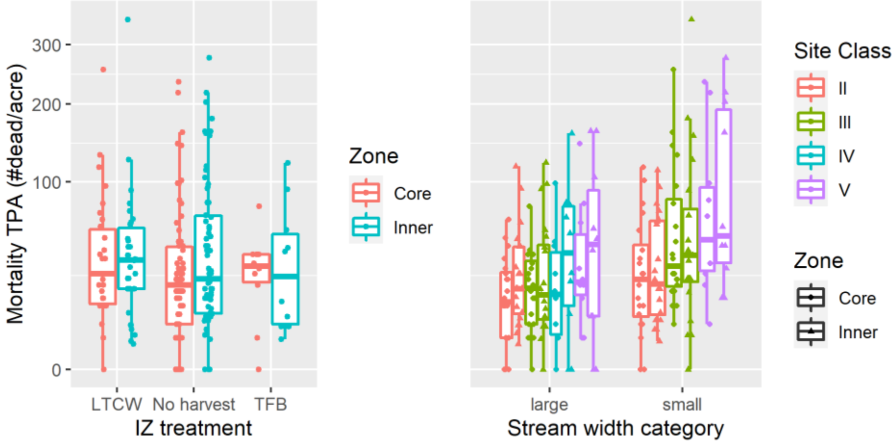

Figure 16. Year-3 mortality reported in trees per acre by buffer zone, inner zone treatment, stream size and site class. Tree mortality appears slightly higher for inner zones than for core buffer zones. Note that the large TPA values are an artifact of the very small areas (acreages) of the test buffer zones; the actual tree counts are much smaller than the calculated TPA values displayed here. Also note that the mortality is shown on a logarithmic scale.

Small streams were associated with higher mortality than large streams ($p<0.001$). Although mortality calculated in trees per acre appears to be normally distributed (Figure 16), mortality in terms of basal area is not normally distributed, and median mortality in small streams was approximately double that of large streams (20 vs 11 ft^2/acre, respectively) (Figure 17). Because of the nature of the distribution, the bulk of the mortality and wood recruitment is from a limited number of sites. A hierarchical cluster analysis conducted on the PCA using all data independently identified 11 sites (9 small streams and 2 large streams) that were characterized by high mortality, high recruitment, low YR3 basal area and percent red alder; and the 7 sites with the greatest mortality were all on streams less than 10’ wide (i.e., small streams). Figure 18 breaks down the mortality yet further by specific variant and zone, which obscures some of the relationships shown above but can provide more detail on sources of variability.

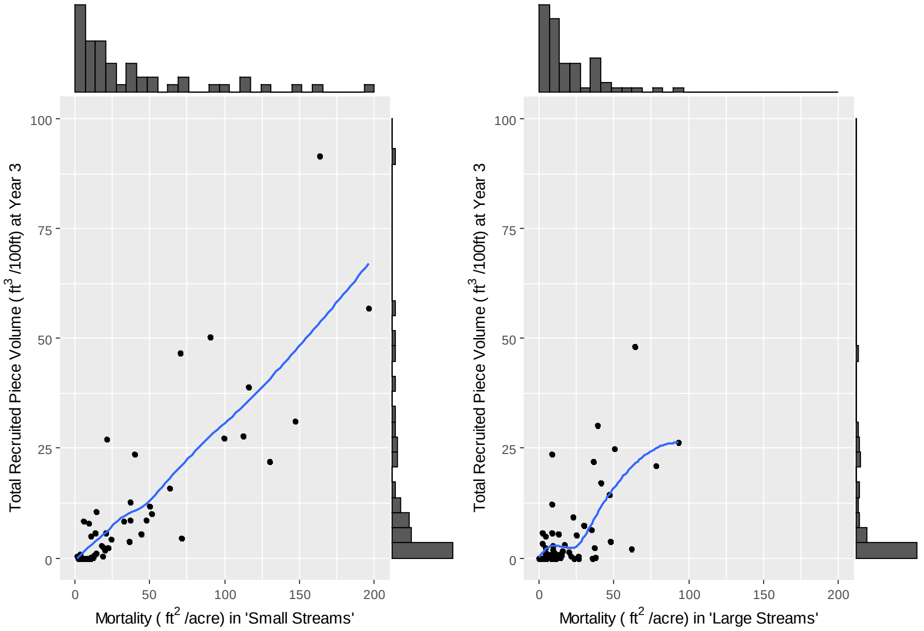

Figure 17: Mortality in terms of basal area per acre and total (not just large wood) recruited wood volume with marginal histograms.

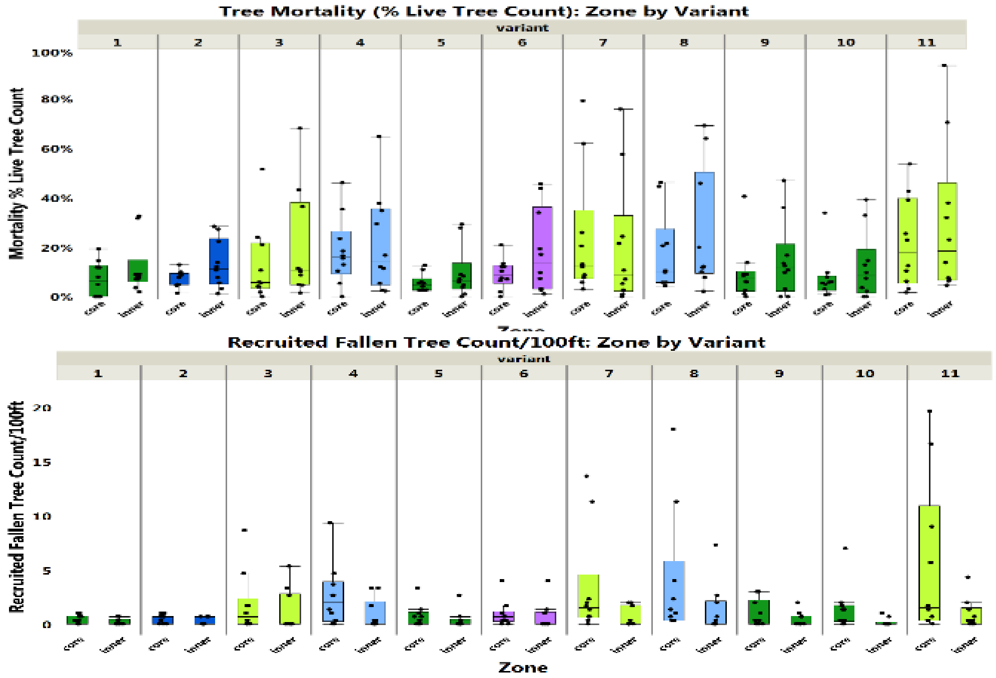

Figure 18. Mortality and Recruitment in the first years post-harvest, by prescription variant and RMZ zone. Prescription variants are represented by color – Green = No-IZ harvest, Blue = LTCW, and Purple = TFB. Darker shades are for Large stream Rx and lighter shades are Small stream Rx. Site Class II is on the left (1 - 4) and Site Class V is on the right (10, 11).

As noted above, windthrow and other mortality mechanisms killed 14.5% of the trees by 3-6 years after harvest, so the average tree count was reduced to approximately 48 buffer trees per hundred feet of stream channel by that time (Appendix B figures). Although mortality is greater in 'small streams', we don't see a big difference in the residual number of trees by stream width category. One difference we do see in the residual stand composition is that sites with higher tree counts tend to be composed of smaller trees, while sites with fewer trees tend to be composed of larger trees (correlation -0.65, Figure 19).

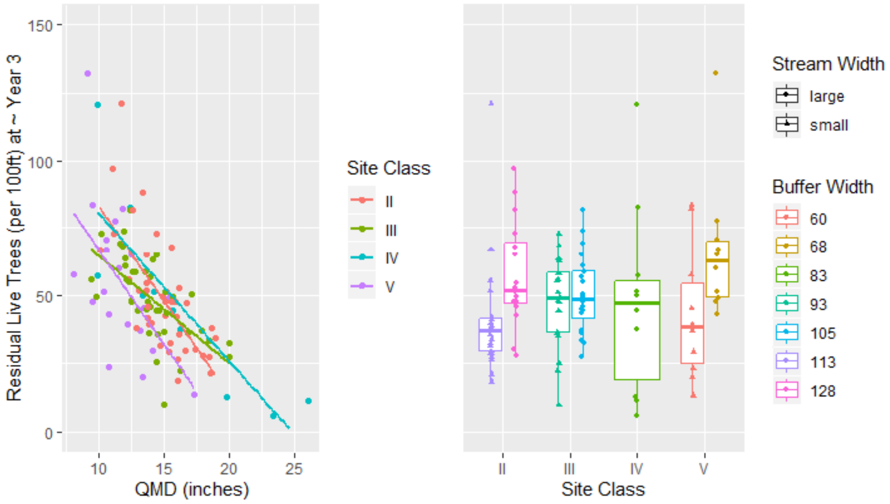

Figure 19: Year 3 residual trees per 100 ft of stream channel as a function of mean diameter (QMD) and site class.

Of the 881 pieces of wood that recruited some portion of wood into the bankfull channel width, only 354 met a large wood (LW) criteria of 4" x 6' *within* the bankfull channel. Most of the that recruited LW (96%) was not found in the active channel but was spanning or suspended. The mean diameter of the recruited LW was 8.4 inches (median 7.4, max 22) (Appendix A, Recruitment table). Most pieces of large wood (87%) came from 307 individual fallen trees, and most (80%) of those trees fell from the core zone (Table 8). Although 9% of the standing trees fell in the studied period, only 1.5% (of the live standing trees) delivered large wood to the channel and there was little difference by inner zone treatment (Figure 21). As might be expected, trees from the inner zone that contributed large wood to or above the channel tended to be larger (Figure 22).

Table 8: Number of trees that contributed LW by Zone

Core Zone	Inner Zone
247	60

Four of the seven sites with high mortality were in site class III, and only buffers on small streams in site class III had a non-zero median proportion of initial standing trees that contributed LW to the channel by year 3 (Figure 20). When we look at Site Class III, we see that even relatively high mortality was not associated with high levels of large wood recruitment (Figure 21).

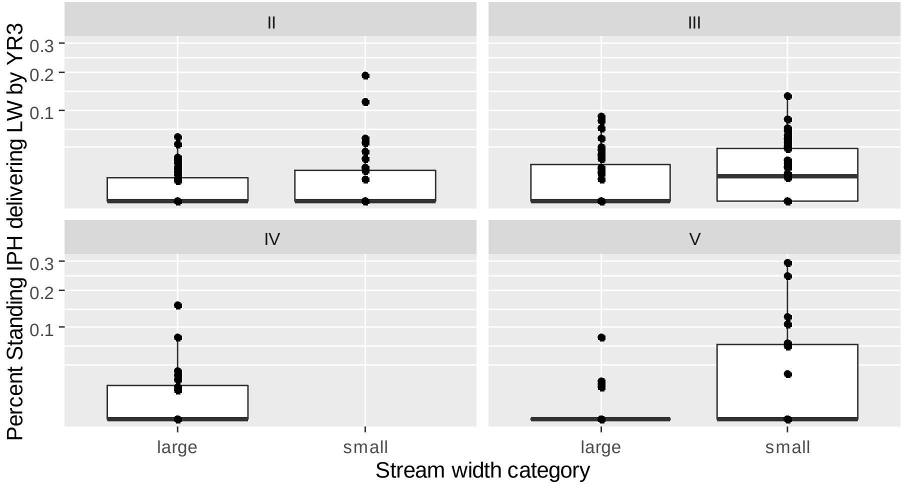

Figure 20. Percentage of initial post-harvest standing trees that delivered wood to the stream channel width by year 3, shown as a function of site class and channel width category. Individual site data shown with median (bar) and +/- 25th percentile boxes.

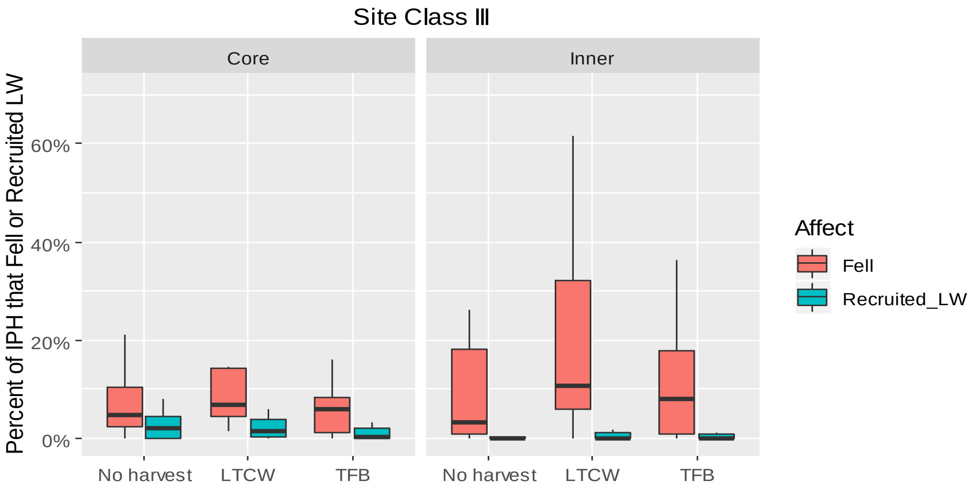

Figure 21. Fallen trees in the 3-year post-harvest period for Site Class III riparian buffers, shown by buffer zone and inner zone harvest treatment. Total fallen trees and fallen trees that contributed large wood (>= 4" midpoint diameter by 6' long) to the stream channel bankfull width. Most of this wood was suspended over or spanning the channel. Boxplots shown with median (bar), +/- 25th percentile boxes, and full-range whiskers.

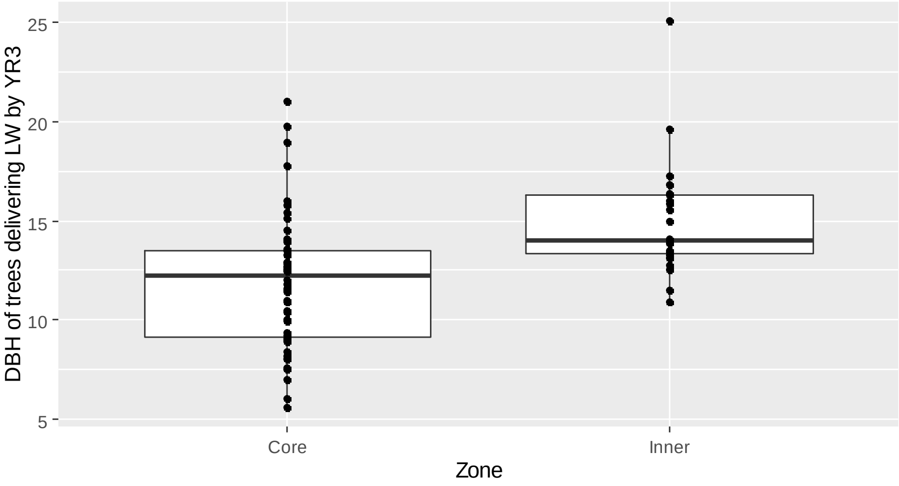

Figure 22: Diameter (inches) of trees recruiting LW to the stream by zone.

3.4 Canopy Closure/Shade

The study included two different measures of canopy closure: Shade 1 is a typical 4-way densiometer measurement that incorporates readings in the upstream, downstream, into buffer and across the stream directions; Shade 2 is a single densiometer reading looking into the buffer only. Shade 2 is particularly relevant in this investigation because we are only studying the buffer on one side of the stream, and Shade 2 is not influenced by conditions on the other side of the channel, while Shade 1 is. Therefore, most of our analyses concentrate on Shade 2 results.

3.4.1 Shade 1

Shade 1 ranged from 4% to nearly 100% with a sample mean and median of 88% and 96% respectively.[11] Not surprisingly, shade 1 varied with stream size with larger streams having lower shade 1 readings on average (Figure 23).

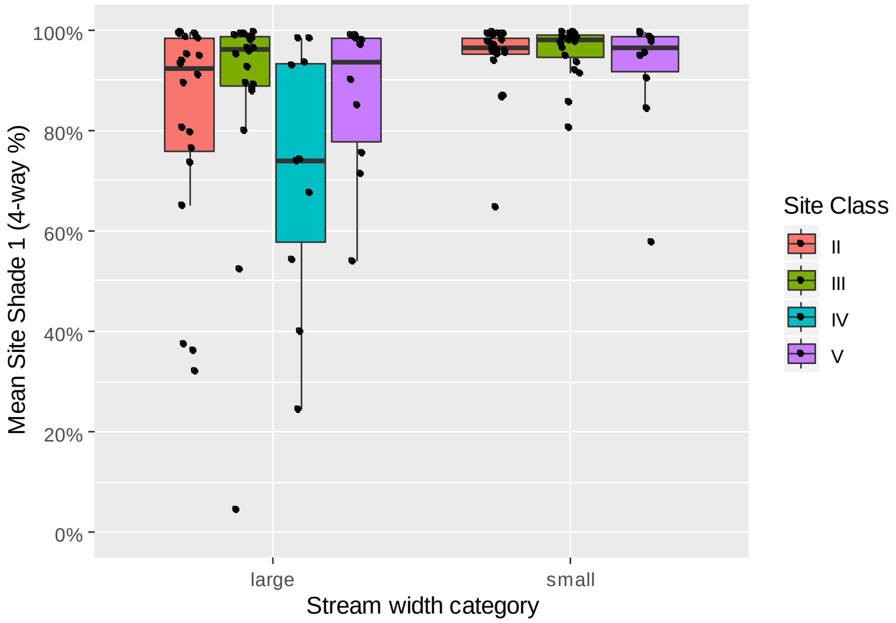

Figure 23: Mean percent shade (4 way densiometer reading; Shade 1) on large and small streams by site class.

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[11] Sample statistics do not represent population statistics in this dataset.

3.4.2 Shade 2

PCA indicated that shade 2 varies with tree density. When plotted as such, we see that there are 10 sites with low tree density (<250 TPA) and shade values less than 80%. It would appear that these 10 sites largely drive this correlation (Figure 24, Figure 25).

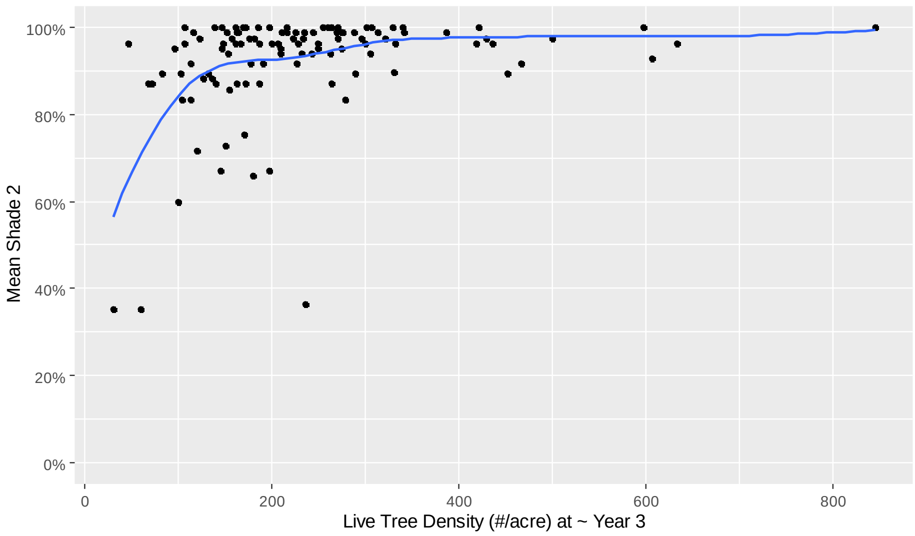

Figure 24: Shade 2 densiometer as a function of live tree density.

Light extinction is correlated with basal area with different species having different light extinction rates (Sonohat et al., 2004). Residual basal area per acre ranged from 57 ft^2/acre to 454 ft^2/acre with a sample mean and median basal area of 224 and 214 ft^2/acre respectively, but the correlation with shade 2 was weak (correlation 0.17, Figure 25). The only obvious pattern in shade 2 with respect to site class or prescription variant is an exceptionally wide variation in results for the Site Class IV variant #9 (see Appendix B, Page B-17). Three of the ten sites driving the apparent correlation are on Type S streams, which are generally wider than many Type F streams, but that ten also includes three small streams. The weak pattern illustrated in Figure 24 held when plotted against the Core Zone basal area (Figure 27). Figure 28 shows that despite generally decreasing basal area with site class, shade remains high overall, and sites with low shade are not necessarily correlated with either low basal area or high mortality. Visual observations of aerial photographs show that two of the Type S sites of Variant #9 with low canopy closure were on low terraces of very large Type S streams (e.g., shorelines) where geomorphic processes had either previously removed trees adjacent to the shoreline or site conditions were not good for growing trees; as a result, the portion of the ‘buffer’ close to the stream had very few trees (See photos in Appendix D.). In one of those, it appears the actual RMZ for the harvest is above the terrace and is a denser conifer stand than where this study’s sample area was laid out. There may well have been a discrepancy between how the forest engineer laying out the harvest unit determined the channel edge and how our survey protocol determined it. Those are two of the lowest-shade sites in the figures. The other site with less than 40% canopy cover is a Type F stream in a tidally-influenced marshy area. One other low shade site had high mortality (Figure 27). The remaining sites with low canopy closure were not part of an obvious pattern.

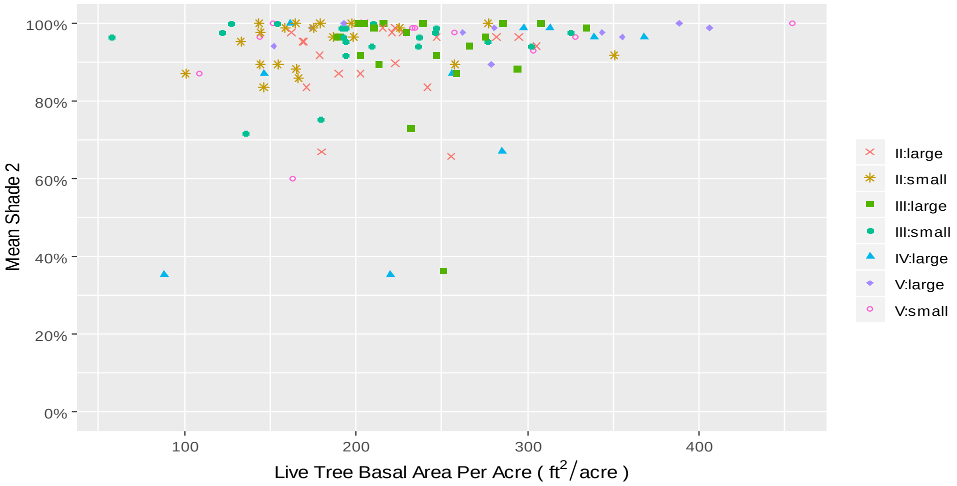

Figure 25: Shade 2 densiometer canopy closure as a function of live tree basal area, site class, and stream width category.

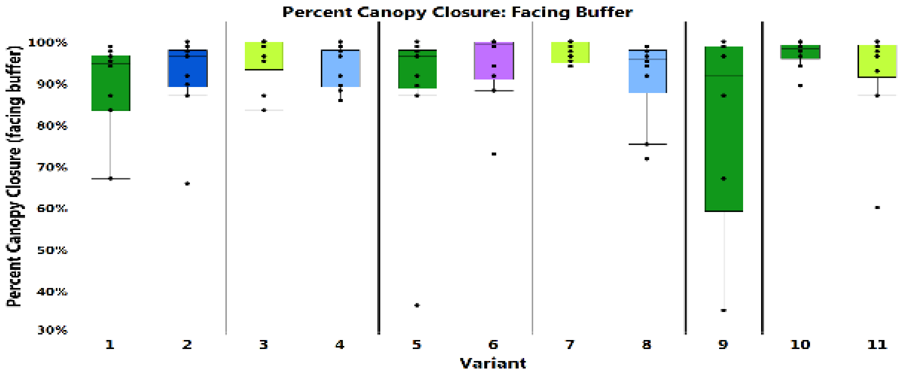

Figure 26. Canopy closure measured facing the subject RMZ only, shown by prescription variant. Prescription variants are represented by color – Green = No-IZ harvest, Blue = LTCW, and Purple = TFB. Darker shades are for Large stream Rx and lighter shades are Small stream Rx. Site Class II is on the left (1 - 4) and Site Class V is on the right (10, 11).

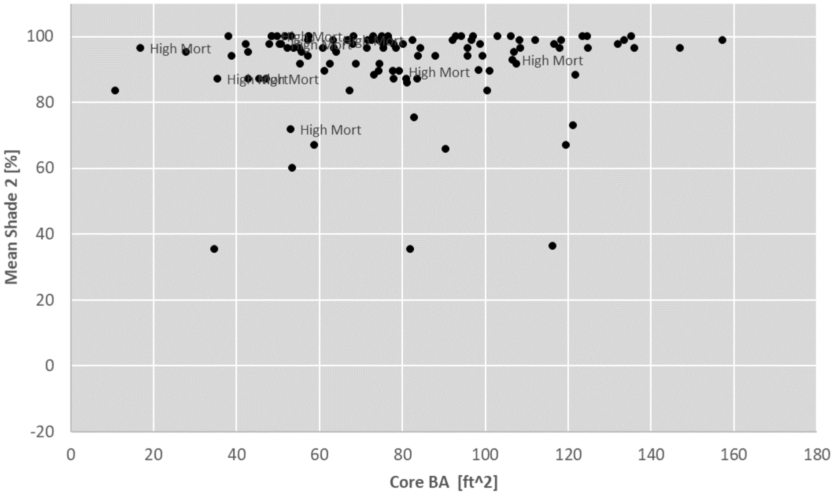

Figure 27. Mean shade (looking into buffer) versus Core Zone basal area. "High Mort" sites are those with more than 60 fallen trees.

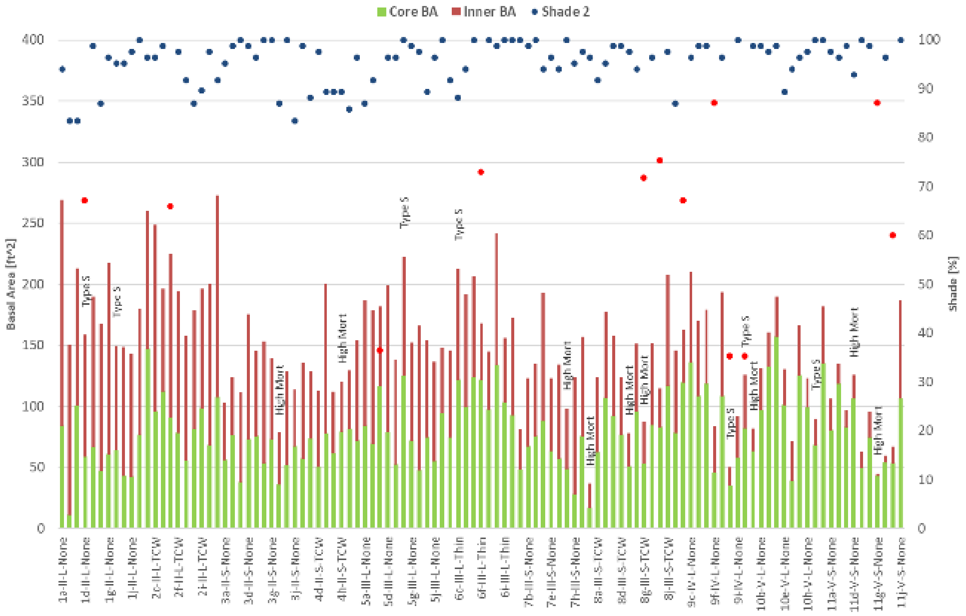

Figure 28. Basal Area contributions from Core and Inner Zones, with average site shade by method 2 (looking into buffer from channel). Note these are total basal areas and not BAPA, so the decrease in total basal area with increasing site class is related to the narrower buffer inner zone as site class increases. Sites with more than 60 fallen trees are identified with "High Mort", as are sites on Type S (presumably larger) channels. Sites whose shade does not meet their respective Board Manual Part 1 shade-temperature nomograph are colored red (see Discussion). Many, but not all, of those are associated with lower basal areas.

3.5 Soil Disturbance and Sediment Delivery

No evidence was observed of harvest-based soil disturbances in any of the study reaches three years after harvest. If it occurred, evidence of any harvest-related soil disturbance had dissipated by the time of our investigation.

3.6 DFC Assessment

The second objective of this study was to evaluate the extent to which post-harvest riparian stands are on trajectory to achieve DFC targets at sites with and without inner zone harvest. The majority (75%) of the riparian buffer stands in this study are projected to meet the Desired Future Condition conifer basal area target by age 140 years (Table 9). Many of the sites that are not on target are projected to be far off target (such as the sparsely-vegetated river-side buffers), which draws down the medians in Figure 29 below. Figure 29 illustrates the factors drawing down those projected conifer basal areas.

Nearly all the sites that are projected to not meet the target are buffers that lost many trees to post-harvest windthrow or are dominated by hardwoods (including one site that has a 100% hardwood buffer). All buffers on larger Type S streams are identified in the figure; more than half of those are not expected to meet the conifer basal area target. Note, however, that sites not expected to meet the DFC target still have hardwood basal area in the buffers, which provides most of the same riparian functions as the conifers the DFC model looks for. Interestingly, there was no consistent relationship between sites that are not on track to meet the DFC target and their current provision of canopy cover/shade.

Table 9. Proportion of sites in each prescription variant projected to meet the DFC basal area target of 325ft^2 at age 140. Prescription variant results are highlighted similarly to the boxplot color scheme.

	Prescription Variant											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
# of Sites	10	**11**	10	**8**	10	**9**	10	**9**	10	10	10	**107**
Proportion Expected to Meet Target	40%	**91%**	50%	**100%**	80%	**89%**	40%	**89%**	60%	100%	90%	**75%**

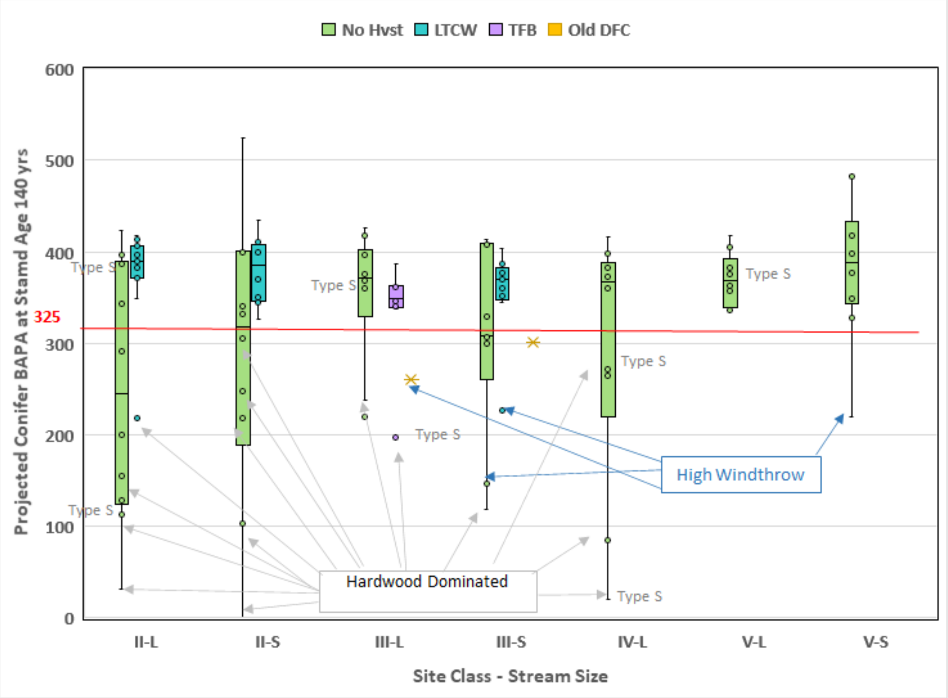

Figure 29. Projected basal area per acre of combined inner and core zones at 140 years of age plotted relative to the desired future condition (DFC) target of 325 ft^2/acre (red line). Survey data from three years post-harvest were used to model the projected BAPA. Dots indicate individual site values. Box edges are at the inner quartiles and display the median line. Whiskers indicate the full range of values up to 1.5 times the interquartile range (Tukey standard).

Close investigation of the buffers that had inner zone harvest revealed that two sites were laid out and approved under the old DFC targets (before 2009) and one site was actually a Type N buffer on a stream where the water type modification hadn't yet been incorporated into the DNR Hydro GIS layer. The Type N buffer site was removed from the dataset. Although the old DFC sites appear in Figure 29 and Figure 30 for comparison, they are not counted in any evaluation of the DFC harvests.

Of the 37 valid sites with inner zone harvest, 34 (92%) are projected to meet or exceed the target basal area at age 140 (Figure 30). One of the inner zone harvest sites that are not projected to meet the target experienced high mortality (> 30%). On the other hand, of six (valid) sites that experienced high mortalities, five are still projected to exceed the DFC BAPA target. All but one of the DFC harvest sites that are not on track to meet the DFC basal area target are currently meeting their shade targets nonetheless. As noted previously, the sites with high mortality tend to be small streams with the LTCW harvest strategy; thinned sites (all on large streams) tend to have mortality rates lower than 30%. The two other sites that are projected to be below the target have high broadleaf (hardwood) compositions. One of those was a very long buffer, of which our study site was only a small proportion. Unfortunately, photo inspection of that site showed that the random selection process we used happened to select a hardwood patch of the long, mixed conifer/hardwood buffer.

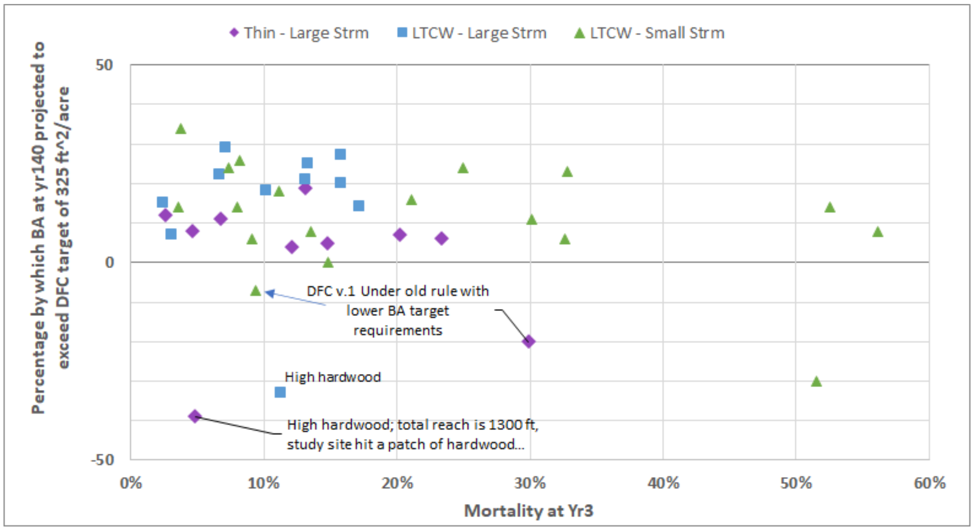

Figure 30. Sites with inner zone harvest - projected basal area/acre target exceedance at age 140 plotted versus stand mortality (mostly windthrow).

3.7 Resurveys

One survey site from each variant class in the study was randomly selected for resurvey. The differences between the metrics calculated from initial survey (IS) data and those from the resurvey (RS) data for each site were calculated. Figure 31 displays boxplots of the differences between the two measurements as a percentage of the initial survey measurement for key variables. This figure demonstrated that variables that tend to have low values can be greatly affected by a small difference in the crew measurements, whereas those with large values tend to have small crew variability. For example, there was one site that had one fallen tree noted by the first crew and two noted by the resurvey crew, which is reflected in a 200% variance in the figure. (Whether a second tree actually fell between the two surveys or the first crew didn't see the second fallen tree, attributed it to pre-harvest fall, or determined it had fallen from outside the study zone, is unknown). Trees per acre and basal area, however, which have very large numbers, show very small variabilities between the crews. Despite the high variabilities in measurements of Dead Standing Trees and Fallen Trees, the calculated Mortality rates to which they contribute are reasonably repeatable (Figure 32).

This small resample study points out the importance of crew training and cross-training throughout the study to ensure surveyors are using methods as consistently as possible. It also illustrates the precision and repeatability that can be expected from various measurements and the importance of repeatable geographic positioning information in the cases where re-measurements will be taken through time to assess change.

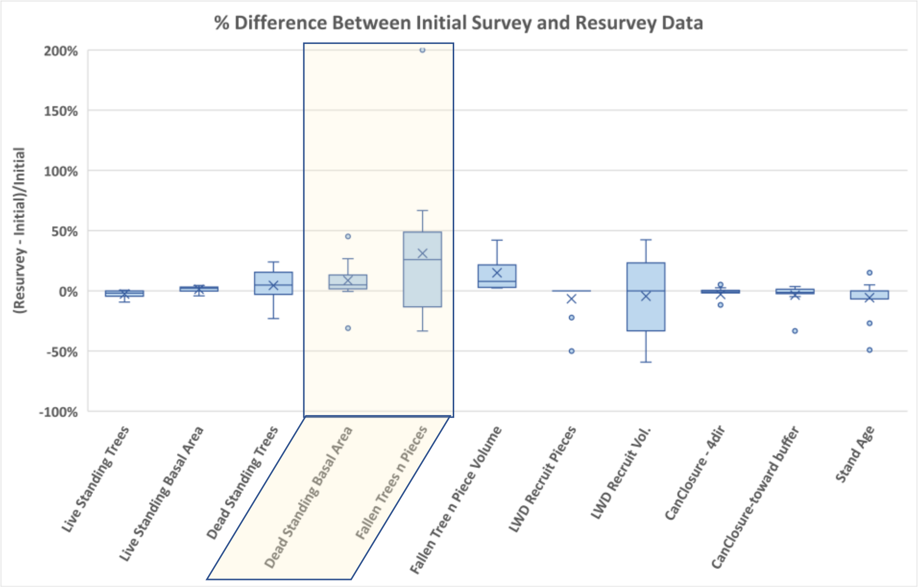

Figure 31. Differences between initial survey and resurvey results, expressed as a percentage of the initial measurement. n = 11 for all except Stand Age, for which n=7.

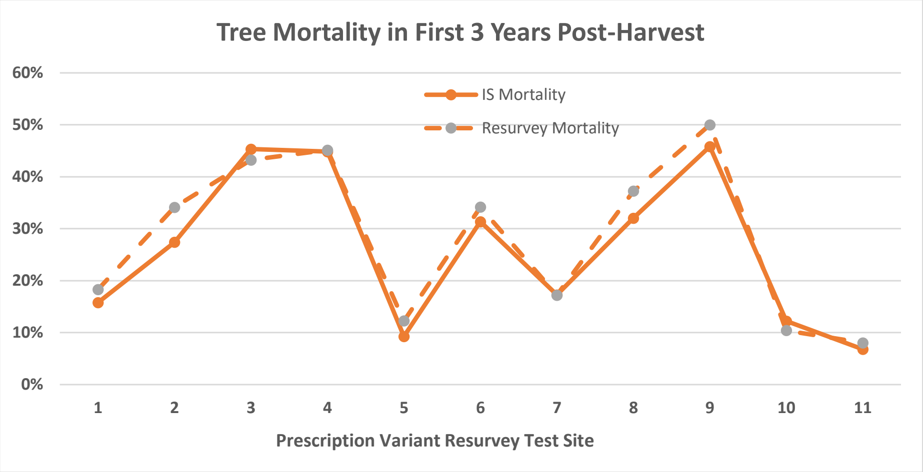

Figure 32. Example of good repeatability of calculated metric despite poor relative repeatability of factors within the calculation (low sensitivity).

4 Discussion

The first objective of this study was to evaluate post-harvest riparian stand conditions and riparian ecological functions across prescription variants with and without inner zone harvest in western Washington timberlands. The Forests and Fish Report and the HCP call out several functions that riparian buffers are meant to address under the Forest Practices Rules (WA DNR, 1999; WA DNR 2005):

- Bank stability,
- recruitment of wood to streams,
- leaf litter fall, nutrients,
- sediment filtering, and
- shade.

In this study, we investigated and measured factors directly related to wood recruitment, shade, and bank stability/erosion, per the HCP targets, and we discuss those here. Other LWD functions with targets called out in the Forests and Fish report, such as pool frequency and instream LWD, are related to channel and wood loadings that are likely to result from conditions other than the buffers we were studyin (e.g. - wood from upstream sources; legacy wood) As such, those in-stream conditions and functions were outside the scope of this study.

We then investigated the post-harvest status of the riparian buffers with regard to the Desired Future Conditions in order to evaluate the extent to which those stands are on trajectory to achieve the DFC targets. Those results are discussed in section 4.5.

4.1 General Stand Investigation

We did not observe large differences in the response variables measured by prescription variant. Response variables did, however, show a relationship with site class. Although the site class is known to often be inaccurate in riparian areas (Schuett-Hames et al. 2005), it still seems to produce identifiable patterns, though with significant variability. The biggest difference among sites in different site classes observed in this study was a difference in species composition. Site class V[12] sites were associated with Western Hemlock while site class II sites were more likely to be associated with Red Alder and Douglas Fir and a lower overall percentage of conifer species. Tree density, basal area, and diameter also varied with site class, with density and basal area increasing with site class while diameter decreased.

Although tree density increases with increasing site class, poorer (higher-numbered) site classes have narrower regulatory buffer widths. The overall effect is that buffers of all site classes tended to have the same number of trees per unit of stream length. The number of residual trees per hundred feet of stream length was similar for all the prescription variants three years after harvest, but the species composition differed. The analysis suggests that site class V (e.g., Western Hemlock) prescriptions, which have a narrower buffer than RMZs in the other site classes, might provide slightly more shade than site class II (deciduous and Doug Fir) prescriptions, which have wider regulatory buffers. Much of the residual variability in the number of trees was correlated with tree diameter. Due to the difficulty and added expense of measuring tree heights and the limited study budget, diameter is used as a surrogate to represent overall tree size in this investigation.

4.2 Mortality, Wood Recruitment, and Potential for Fish Stream Habitat Function

Short and long-term recruitment of large wood into stream channels is an important function of riparian buffers on fish-bearing streams. Factors that are particularly important to the ability of a stand to deliver wood that forms good fish habitat are mortality rates, the width and stocking levels of the buffers, tree height, tree diameters, species compositions, and stream channel width. The size of the trees and dominant mortality agents change over time within a given buffer.

In this study we did not observe large differences among prescription variants in either total wood recruitment or large wood recruitment by post-harvest year three except to note that windthrow is the dominant mortality agent in that period and wood recruitment is highly correlated with windthrow. In a small number of sites (e.g., small streams in this sample) mortality and wood recruitment were much higher than in the rest of the sites (Figure 21). As seen in Figure 21, most of the treefall in these early

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years occurred from the inner zones due to windthrow. This and the range of mortality found in this study are consistent with other findings in timber harvest streamside buffers (e.g., Grizzel et al. 2000). Bug kill, root rot, and fire are even less predictable and more episodic than windthrow but can also have strong effects at a site over short periods. Stem exclusion, on the other hand, is a consistent long-term agent of mortality in a stand and increases in importance on a per stem basis as trees grow, but episodic mechanical events tend to remain important in terms of felling large trees (Lutz and Halpern, 2006).

The study indicated that tree mortality, and therefore wood recruitment, was greater on small streams. This may be related to steeper sideslopes on small streams and narrower, wind tunnel like corridors but those factors were not investigated in this study. Wind was the dominant mortality mechanism (Figure 21), and mortality was exponentially distributed so that a small number of sites exhibited very high mortality and contributed most of the wood and recruited wood. A small percentage of trees recruited wood over 4” x 6’ into the stream channel, and most of those were in the core zone. As one might expect, trees from the inner zone that contributed wood to the stream were larger (and would have had to be larger because the inner zone is farther from the stream). Although mortality was greater on small streams, we do not observe much difference in the size or proportion of standing or fallen trees that recruited LW to the stream as a function of stream width category.

As trees grow, the ability to reach the stream and contribute significant wood increases. At 35-50 years old, the riparian trees in this investigation are generally still relatively small. What trees do reach the channel tend to provide rather small wood debris (Figure 22). The fact that few fallen trees reach the stream channel and that the ones that do contribute small wood sizes suggests that the current sizes of the trees may be limiting their ability to reach the stream channel from outer edges of the buffers. As tree heights were not measured in this study, a Weibull distribution equation (Table 10; Yang et al. 1978) relating dbh to tree height was used to estimate the height of each tree in the buffer and those heights were averaged for each riparian buffer (Table 10) in order to facilitate this discussion of wood recruitment potential. Equations developed by Staudhammer and LeMay (2000) were used for cedar, alder, Douglas fir, and western hemlock ($R^2 = 0.76$ to 0.87). The equation for Sitka spruce used was the 1999 equation developed for ORGANON ($R^2 = 0.62$) (Hanus et al. 1999). To keep things simple for the purposes of this discussion, only those species were used. Only two sites were dominated by a different (deciduous) species, neither of which has a meaningful height-diameter relationship. For those two sites, the average height of the subdominant western hemlocks was used. These equations give tree heights that are within the range but on the low end of actual tree heights in much of the study area. Tree height data from the Olympic Peninsula show 12” dbh Douglas fir heights range from 77 to 111 feet (Joe Murray, personal communication) compared with 77 feet from the equations used here.

Table 10. Equations used to estimate tree height from average stand diameter for the dominant stand species using Yang et al.'s equation with parameters developed for south coastal British Columbia (Staudhammer and LeMay 2000) and Curtis's equation with Hanus et al.'s (1999) parameters for Sitka spruce in Oregon.

$\textbf{\textit{Height}} = 1.3 + El * [l - \exp(E2 \text{ x } \textbf{\textit{dbh}}^{E3})]$			(Yang et al. 1978, in Staudhammer and LeMay 2000) ***dbh*** in cm, ***Height*** 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	
$\textbf{\textit{Height}} = 4.5 + \exp(a0 + a1 * \textbf{\textit{dbh}}^{a2})$			(Curtis 1967, in Hanus et al. 1999) ***dbh*** in inches, ***Height*** in feet	
Tree Species	**a0**	**a1**	**a2**	
Sitka spruce	5.404491308	-6.570862442	-0.819705048	

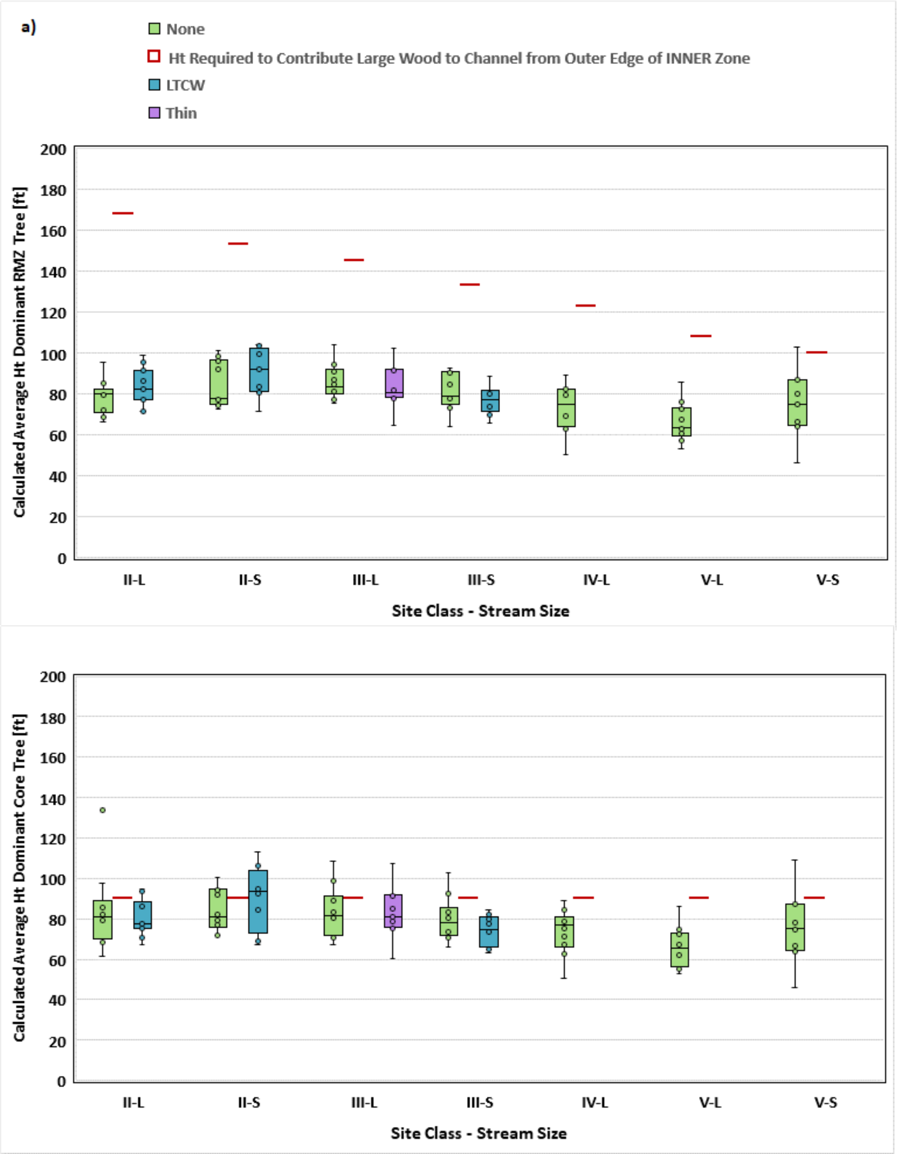

Figure 33. Average calculated heights of dominant trees (by # of trees) in each buffer shown with the height the trees on the outer edge of each zone need to be to reach the stream channel with a minimum functional wood piece size (4" by 6'). Figure 36a shows the Core+Inner combined average dominant tree height and 36b shows the Core Zone average dominant tree height.

Seminal papers on wood recruitment that report source distances consistently find that 10 to 50% of the wood functioning in streams comes from within 1 meter of the bankfull edge (Lienkaemper and Swanson, 1987; Murphy and Koski, 1989; McDade et al., 1990; McKinley, 1997). Trees in the core zones are already large enough to contribute large functional wood to their streams through stem exclusion mortality, bank erosion, deciduous tree maturity mortality, and large branch senescence.

McDade et al. (1990) found that 92% of the large wood in streams adjacent to mature conifer forest stands came from within 30 m (~100 ft) and Murphy and Koski (1989) found that 99% was sourced from within that distance, even in old growth forests. Many of the stands in this study are already that tall, though as noted above, it will take time before the distant trees are large enough to contribute wood of substantial size.

On the other hand, the ability for fallen trees to reach the stream channel from the outer edge of the buffer is important in the early post-harvest years investigated in this study when windthrow dominates mortality and preferentially affects the outer, exposed buffer edges. As Figure 33 shows, only the buffer trees of site classes IV and V are grown tall enough at this first FFR harvest age to reach from the outer part of the Inner Zone to streams. This supports the hypothesis that the currently small size of buffer trees in this study is limiting large wood recruitment to streams. As stated previously, these calculated heights are on the low end of actual values. Tree heights from a different study on stands also being harvested average 84 feet for conifer and 71 for deciduous riparian canopy trees. The maxima are 187 ft and 130 for deciduous (Doug Martin, preliminary data). Nevertheless, Figure 33 illustrates that it may be years before the edge trees of Inner Zones at higher site classes (ie, I, II, III) will reach their streams with large enough diameters to provide much function. The authors of the source distance studies cited above found recruitment from mature hardwood trees occurring from half the distance of the conifers, so the frequent hardwood trees growing nearer the channels have the potential to be contributing functional wood already. Even while the Inner Zone RMZ stands continue to grow, there are hardwood trees in the Core Zone that have the potential to fall into the stream channels to help rebuild habitat. As aging stands shift to other, less frequent mortality modes than windthrow, the longer-lasting conifer trees that fall will be larger and more likely to contribute sizable wood to the channels.

Three quarters of the buffers in this study currently have tree mean diameters that do not meet the 16” minimum diameter recommended in the Forest Practices Board Manual (WA DNR 2013) for large woody debris placement on stream channels from 5 to 16 feet wide (Figure 34), even near their bases. At the tops that reach the stream channels, the wood is much smaller. Assuming that the tree tops are approximately the same shape as small trees, a quick calculation shows that a tree dbh of 5” will provide a bole with at least 6’ of 4” minimum diameter (minimum piece size for LW). Using the equations above, we find that at 5” dbh results in red alder about 35’ tall and Douglas fir 45’ tall. This means that trees falling into the stream channel need not only to reach the channel but at least the top

40’ need to fall over the channel (Figure 33). Over the next harvest rotation, more of the falling trees will reach the stream channel, even from the inner zone, and the wood contributed is likely to be larger.

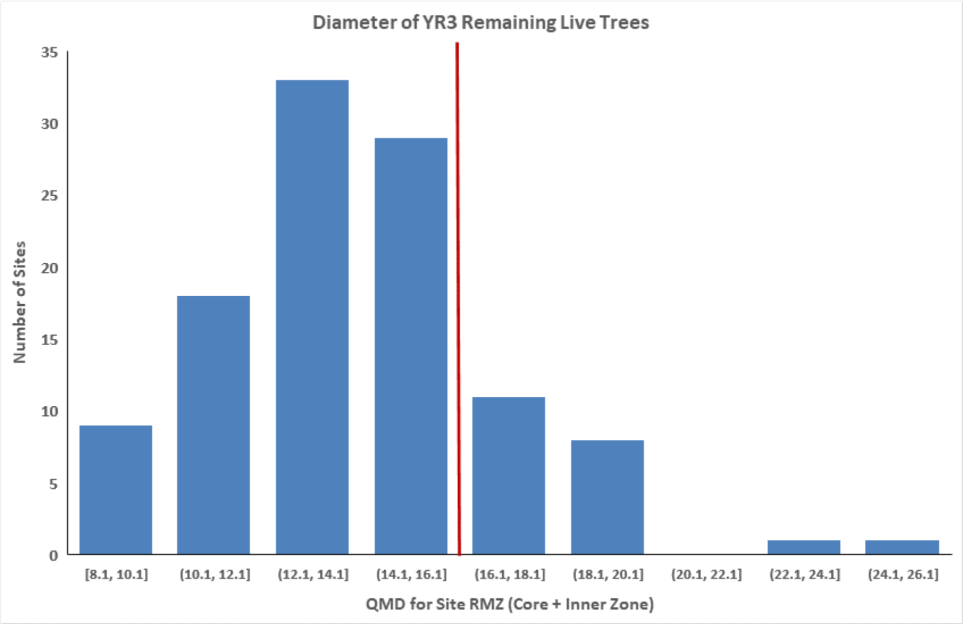

Figure 34. Histogram of quadratic mean diameter of residual riparian stands at Yr 3 post-harvest. Minimum diameter for LWD placement in stream channels specified in the Board Manual (2013) for channels from 5 to 16 feet wide is 16 inches (red line). Larger streams require even larger diameter wood to form stable habitat-forming features (WA DNR 1997).

Buffers in site classes IV and V, which tend to experience more post-harvest windthrow mortality (Figure 16), also already have some potential to provide functional wood to streams from throughout the RMZ, especially to smaller streams where their smaller diameters are more likely to function as habitat forming structures. But it will take some time for the outer portions of better site class buffers to be large enough to contribute wood to the channels. Windthrow events can fell trees of all sizes but tend to preferentially fell the outermost buffer trees that are farthest from the stream, especially in the early post-harvest years covered by this study. However, the stems that experience stem exclusion throughout the buffers as they age will be the smaller trees (Lutz and Halpern, 2006) and so may not contribute a lot of functioning channel wood for several years.

Mortality rates are likely to further decrease relative to the years immediately post-harvest as the stands harden to wind exposure but should become more consistent as stem exclusion becomes the dominant agent. The mortality and treefall would then also be more evenly distributed throughout the buffer and the trees will be larger. By the next harvest, these stands will be two-thirds of the way to the 140-year planned condition (based on pre-harvest stand ages). If riparian rules remain in place, the timber should not only be large and established enough to withstand adjacent harvest but if the stands do experience another round of harvest-related wind mortality, will be large enough to reach and provide substantial wood to the stream channels.

Canopy openings resulting from windthrow and other mortality events can allow not only the remaining stand but also understory trees to be released to grow more quickly than in the dense pre-event stands. Trees in the Option 1 TFB variants and near all the buffer edges also grow faster than the model calculates as a result of extra light and space. As we did not measure trees smaller than 4”, we cannot speak specifically to the availability of small trees in the residual stands of this study and their potential future contributions.

4.3 Stand Composition

Buffers in the study were only moderately diverse. They typically had between three and seven different tree species among trees larger than 4” in diameter (Figure 35). Note that most sites would contain additional species that just did not grow large trunks, such as vine maple. Over 80% of the buffers in this study were dominated by conifers (% conifer over 50%). This bodes well for the wood entering the stream, as coniferous logs persist longer than broadleaf species in the stream channels. However, half of the sites were over 90% conifer and nearly 20% were 98% conifer. These sites tended to have low species richness. Though they will make a good source of shade and long-lived wood in streams, they will be limited in their ability to provide leaf litter and associated nutrient cycling to the streams as well as be less resilient to disease, infestations, and fires. They also may cause too much shading and reduced stream productivity if those conditions exist over long stretches of the stream. As noted in the discussion above, homogeneity in riparian stands should decrease as mortality opens patches that allow influx and growth of both additional species and smaller trees of the same species.

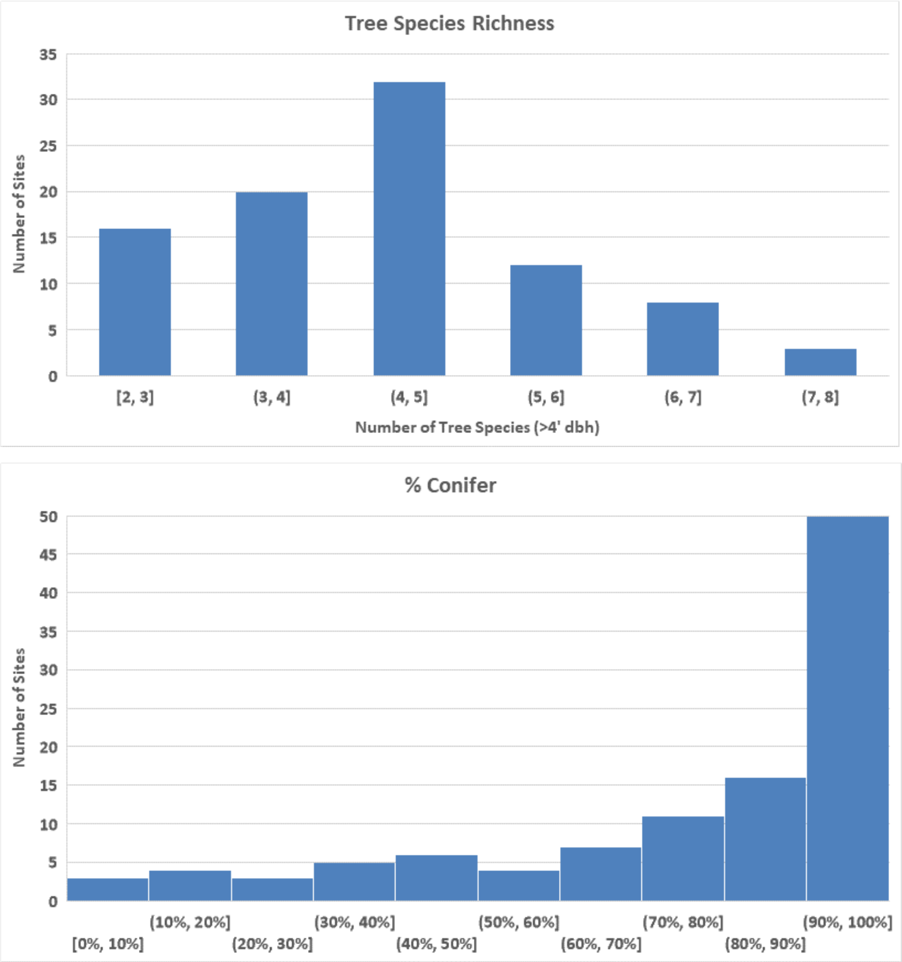

Figure 35. Tree species richness (# of species) and percentage of conifer in study buffers.

4.4 Canopy Closure/Shade

Most (91%) sites had densiometer shade measurements (looking into the buffer) that indicated greater than 80% shade after harvest. The 10 sites with low shade values were characterized by low residual tree density. Inspection of site aerial photography indicated that the reasons for the low density were highly variable, though in some sites the low density appeared to be associated with measured core zone buffers that may have been in the active floodplain and bars of rivers or on newly-colonized low terraces (Appendix D). The effectiveness of current RMZ rule buffers on large rivers to shade those streams is something to investigate further. Tree heights from 60 to 100 feet are little able to shade channels that are 100 feet or more wide. When these buffers are narrow, they are more likely to be composed of shorter deciduous trees that are less effective at shading the full channel width. On the other hand, having some light reach those large rivers can improve primary and secondary productivity. Some balance between tall conifer riparian vegetation and patchy deciduous areas is optimal. Having the large, low-gradient rivers, which are critical and optimal spawning habitat, bound primarily by narrow, short deciduous vegetation would leave them susceptible to high temperatures and overdevelopment of primary (algal) production and result in degraded resting and spawning conditions for critical salmonid species.

Schedule L-1 (Appendix N of the FP HCP) specifies the shade target as at least 85% of all effective shade. In most studies, we use canopy closure as a surrogate measure for effective shade. Allen and Dent (2001) demonstrated that at high shade levels, canopy closures somewhat overestimated effective shade by on average 11% but were closely correlated. Other studies have shown that for unharvested riparian buffers, mean canopy closures range from 91 to 97% (McIntyre et al. 2018; Ehinger et al. 2021).

Table 11. Proportion of sites in each prescription variant that meet their respective shade targets.

	Prescription Variant											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
# of Sites	10	**11**	10	**8**	10	**9**	10	**9**	10	10	10	**107**
Proportion Meeting Target	90%	**91%**	100%	**100%**	90%	**89%**	100%	**78%**	60%	100%	80%	**89%**

Eighty-nine percent of the sites met their respective shade requirements (Table 11). Shade targets in the Forest Practices Rules are based on water quality and stream temperature requirements. The Forest Practices Board Manual (WA FPB 2000), Section 1 calls for canopy cover (shade) measurements to meet or exceed the minimum target line on the elevation-based nomograph for western Washington (Figs 1.2 on page M1.6 of the Board manual). Shade2 results for the study sites are plotted versus site elevation in Figure 36, along with the target lines for streams that are required to be below 16C and 18C. Only one site that was thinned in the inner zone did not meet its shade target and three sites where the inner zone was harvested but all the trees were left adjacent to the core zone (LTCW) did not meet theirs. The remaining eight sites that did not meet their shade requirements had no harvest in the inner zone. Five of the twelve sites that did not have enough shade at Yr3 (three LTCW and two no-IZ-harvest) had greater than 30% mortality (in both the core and inner zones). Interestingly, of the sixteen sites with high mortalities, only these five failed to meet the stream temperature canopy cover requirements afterward. This is probably because most of the high mortality sites (14 out of 16) were on small streams, whereas most of the buffers that did not meet the shade requirements were on large streams (8 of 12). We cannot tell how wide those streams are because channel width data were not collected but as noted previously, some of the sites in this study were on very wide channels that were open as a result of geomorphology, river behavior, soils, and very different species composition than the rest of the sites. Half of the sites that have shade below the targets are site class IV and V, which tend to have many smaller trees and low core and inner zone basal areas (at least early in their stand development) rather than tall, large diameter timber (Figure 28). However, Figure 28 also shows only a very weak relationship between basal area and shade from the total riparian buffer and no relationship between them from the core zone trees. This demonstrates that neither low basal area nor high buffer mortality can be assumed to be an indicator of low stream shade.

Figure 36. Canopy Cover for each site plotted versus elevation and displaying the western Washington temperature nomograph targets for streams that are subject to the 16C (top graph) and 18C (bottom graph) temperature standards. (WA FPB 2000, Section 1, Fig 1.2)

4.5 Sediment Delivery

On the one-hundred ten stream reaches of this study, none had any signs of bank erosion. That should not be taken to imply that streambank erosion does not occur on Forests and Fish lands in Washington, but it does suggest that it is not a widespread problem associated with any of the riparian prescriptions in this study. The absence of stream bank erosion suggests that either no erosion occurred immediately after harvest or erosion was minor and recovered by the time of this study. In either case, the 50 no-cut core zone is intended to, among other things, prevent erosion, and there is no indication that the buffers are not achieving that objective.

4.6 DFC Trajectories

Most of the buffers in this study are predicted to meet the DFC target basal area by age 140. This includes those buffers that did not have any inner zone harvest. Most of the buffers that are predicted to not meet the DFC target started out with smaller trees and lower basal area than other buffers. It is notable that many buffers that meet the DFC projections were *not* harvested in the inner buffer zone. There are many reasons why a landowner might choose not to pursue an inner zone harvest prescription. Leaving these fairly young (35-50 year old) stands to grow now does leave open the possibility that an inner zone harvest strategy, including the Option 1 thinning, may be more enticing and profitable on the next rotation, and we may see more incidence of those variants over the next twenty years.

Despite the higher mortality observed in the buffers with LTCW inner zone harvest, nearly all of those buffers remain on track to meet the DFC 140 year basal area target as well as meeting the stream shade target. The few sites that don't meet DFC and shade targets include two sites that were harvested under old DFC target rules, one that experienced very high windthrow, and one site where our sample reach landed on a hardwood-dominated patch within a very long mixed conifer/deciduous buffer. The higher mortality in LTCW harvest sites did not result in greater recruitment of functional wood to the streams. Buffers where Inner Zone harvest was conducted tended to have larger trees than those with no inner zone harvest and are likely to reach the point where they can contribute functional wood to the streams earlier than buffers that had no inner zone harvest. This is due both to having larger trees to begin with and to having increased growth rates as a result of the IZ harvest.

5 Summary

This study highlights the great natural variability of conditions and function within most of the prescription variants. While there are clear patterns of changes in the central tendency with site class, there is also a lot of variability, and the variability is of similar or greater magnitude than the mean trend. There are many possible reasons for this variability. One key reason is that caused by applying the “Large” stream prescriptions to such a wide range of channels. Much of the variability and poor performance seen, especially in Variant #9, is associated with very large Type S stream buffers. Another is that the DNR site class is not always finely enough delineated to the stream buffer, but often is more broadly based on soils in the adjacent uplands where harvest occurs (see site class map at https://data-wadnr.opendata.arcgis.com/datasets/wadnr::site-class-forest-practices-regulation/explore?location=47.276784%2C-123.638675%2C14.45). Thus, a streamside buffer may in fact have a different tree height potential than that indicated by the site class designation.

The only prescription investigated that stands out for providing inadequate riparian functions in the three-year post-harvest period is Variant #9, Site Class IV-Large, which included the most poorly-performing Type S site buffer and another that may or may not be performing overall (unknown because we did not sample the main part of the buffer due to our survey protocols).

Residual Stands

- The rules appear to leave an average of about 55 buffer trees (core and inner combined) per 100 feet of stream channel in all variants/site classes, though there is a large range. This appears to be true in sites with and without inner zone harvest and across site class and stream width categories. The combined effects of variable core + inner zone widths and stand densities that vary by site class result in consistent linear stand densities within the retained RMZs (Fig 16).
- The tree species composition of buffers is limited. Typically buffers had between three and seven different tree species among trees larger than 4” in diameter.
- Over 80% of the buffers in this study were dominated by conifers (i.e, % conifer >50%).
- Sites with inner zone harvest are associated with a high percentage of conifers whereas sites where no inner harvest was conducted tended to have higher percentages of broadleaf species and greater overall species richness.
- Sites that received Inner Zone harvest started out very different than sites where inner zone harvest was not conducted. For example, unharvested core zones in sites where the LTCW inner zone prescription were used tended to be conifer dominated (as required by the DFC rules), while the no-harvest sites had a higher likelihood of being alder dominated.
    - Core zones in Inner Zone harvest sites had higher basal area than those that did not receive inner zone harvest. This suggests that the ability or decision to do inner zone harvest was affected by basal area (as required under the rules) and species composition.

Tree Mortality and Wood Recruitment

- Mortality was greater on small streams and windthrow was by far the dominant agent on both large and small streams.

- Buffers with LTCW inner zone harvest experienced high mortality events at a greater rate than sites with no inner zone harvest. A higher percentage of sites with inner zone harvest experience high mortality by year 3 than sites without inner zone harvest (20% vs. 10%). Despite this, 5 of the 6 (83%) buffers that experienced high mortality left residual stands that still are projected to meet the DFC target and shade requirements (Figure 30).
- Despite the windthrow that occurred in many stands, the small sizes of the trees and the wide riparian buffer zones combine to result in temporarily low rates of functional wood recruitment at this time.
    - 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 provide functional wood on small streams from throughout the buffer.
- Trees in better site class buffers are estimated to be nearly 100 ft tall and able to reach the streams from the distance at which previous studies on recruitment have found nearly all instream wood falls. Although they are not yet of a size where the most distant trees (which are most likely to fall from windthrow) can contribute sizable wood, the nearer trees can. As the stands become more windfirm and stem exclusion becomes more important as a mortality agent, the trees near the stream will become more important sources of wood to the streams. Moreover, hardwoods that often are found in the Core zone should be nearing maturity and senescence and can provide wood for the short-term while the larger conifers continue to mature.

Shade

- Shade remains high overall despite generally decreasing basal area with poorer site class. However, low shade was commonly, though not consistently, associated with extremely low basal area values (Figure 28).
- The vast majority (89%) of sites met the stream shade requirements for their sites, and inner zone harvest appeared to have little, if any, association with that (Table 11). Sites that did not meet their shade requirements tended to be either very large streams or were small streams that experienced high buffer mortalities.
- Inner zone harvesting did not appear to directly result in reductions to stream shade in these sites.
- The performance of current riparian buffers on very large streams (>100 feet wide) appears from this study to be poor and indicate the need for additional study. This result is stronger than any indication that a particular prescription variant warrants further study. The poor overall performance seen for Variant #9 are driven by the results from two sites on large Type S rivers. Such rivers tend to migrate and create shifting bars and banks and to have deeper deciduous vegetation on the banks. Although we avoided sites with channel migration zones, some sites with poorly-developed, ephemeral, deciduous streamside vegetation were included

in our sample. Three of the seven Type S stream sites in this study had low shade values, and two of those were in Variant #9 (one of those may have been sampled within what the forester concluded was active channel; additional coniferous RMZ is apparent behind the sampled area).

- The presence of these large Type S stream sites in this study added variability to the results.

Soil Disturbance and Sediment Delivery

- There was no evidence in this dataset that any of the Type F riparian prescriptions studied destabilize stream banks and cause sediment delivery in the first three years after harvest. 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 adequate in providing protection against streambank erosion and sediment input to stream channels from overland, non-road related sources under ordinary circumstances, whether or not there was harvest in the inner zone. There were no trends or differences observed among the prescription variants.

DFC Trajectories

- The majority (74%) of all the riparian buffer stands in this study are projected to meet the Desired Future Condition target by age 140 years. Many of the sites that are not on target are projected to be way off, which draws down the medians for each prescription variant (Figure 29).
    - Half of the sites that had no inner zone harvest were on track to meet the DFC target.
    - Ninety-two percent of the sites that did have inner zone harvest (TFB or LTCW) remain on track to meet the DFC basal area target at 140 years old (Figure 30).
        - The few TFB/LTCW sites (8%) that are projected to be below the target include two that were harvested under old DFC target rules, one that experienced very high windthrow, and one site where we happened to sample a hardwood-dominated segment of a very long mixed conifer/deciduous buffer.
- Ninety-two percent of the sites that had inner zone harvest meet their required shade target, even after many experienced high post-harvest windthrow (Table 11, Figure 30).
    - Only one site that was projected to be off the DFC target (due to high windthrow) did not meet its temperature regulation shade target.

5.1 Implications for further research

Results of the GIS desktop analysis and this exploratory study provide insight and help narrow the focus for planning the main Type F Riparian Effectiveness study to answer those critical questions. The purpose of that study is to determine how riparian stand conditions respond over time to the Western

Washington Type F riparian prescriptions and to evaluate the effectiveness of the prescriptions in meeting FPHCP functional objectives and performance targets (Schuett-Hames et al. 2015).

The critical questions for that study are:

1. Riparian Stand Characteristics and Riparian Functions

   a) How do the RMZ and no-RMZ harvest[13] prescriptions affect riparian stand characteristics and riparian functions?
   b) How do the characteristics of riparian forest stands and associated riparian functions in areas with RMZ and without RMZ harvest change over time?
   c) (The third riparian buffer critical question about the DFC trajectories from the scoping document is addressed in this exploratory study report.)

2. Physical Stream Characteristics and Processes

   a) How do physical stream characteristics and processes respond to changes in riparian functions in areas with RMZ and without RMZ harvest?
   b) Do physical stream characteristics and processes meet performance targets?

3. Aquatic Biological Response

   a) What is the aquatic biological response to changes in riparian functions in areas with RMZ and without RMZ harvest?

As shown in the BAS/Scoping document for the Type F Riparian Effectiveness Monitoring set of projects, in order to robustly assess whether the application of any given riparian buffer prescription is what influenced the residual shade and LW supply potential, we will need to randomly assign a treatment/no treatment to similar sites and then compare outcomes.

The findings from this exploratory study show that although the rules appear to have a homogenizing effect on RMZ tree counts, there remains a great deal of variability among and, importantly, within, regulatory RMZ prescriptions. While the variability among RMZs is large, the rules are, as noted by the performance targets, intended to limit the overall impact of harvest to small effect sizes. In order to resolve small effects in a variable landscape, the effectiveness study will require an experimental design that helps control for variability while providing both power and precision in resolving effects if it is to produce reasonable estimates of effect size and be able to discern causal relationships between forest practices and riparian conditions. A study that is expected to attribute the effectiveness of one or more particular prescriptions to the application of those prescriptions will require a carefully conducted experiment with multiple replicates, and precise and accurate measurement of responses will be required because the study will need the power to resolve potentially small effects.

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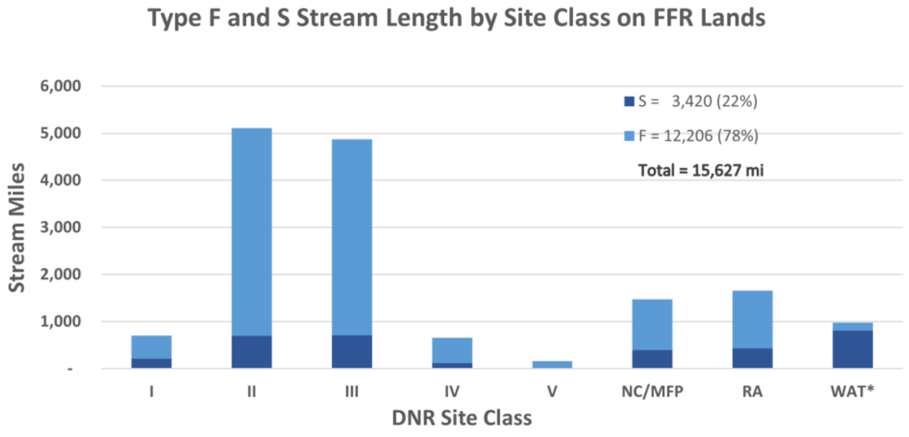
[13] The portion of the RMZ harvest addressed in these studies is the Inner Zone harvest, not harvest in the Outer Zone.

Very large streams often have inherent geomorphic and vegetation characteristics that make them outliers among the rest of our data. Based on air photo analysis, it appears these sites are often exposed to a different set of geomorphic processes and have different species compositions. Lumping sites on very large rivers with those sites on smaller “large” width category rivers and streams adds noise and may confound interpretation of results. The riparian buffers on large river sites (channel widths greater than 100 ft) in this investigation do not appear to be providing the desired functions. Having information on the distribution of various channel widths on the FFR landscape would aid in interpreting the importance of our findings overall. We know that many Type S streams are not the wide rivers of concern, but having no other surrogate for channel width at this time, we resort to looking at Type S versus Type F streams. A GIS analysis shows that Type S streams make up 22% (3,420 miles) of the stream length on FFR lands in addition to an unknown number of miles of sea-shoreline (Figure 37). Even though not all of those miles are wide rivers, that is still a substantial length of shoreline. Because large rivers are such important salmonid habitat, the effectiveness of riparian buffering rules on them warrants specific investigation.



* WATer is the designated site class polygon for portions of many lakes and large rivers. This summation did not include determining the site classes of those shorelines.

Figure 37. Length of stream designated Type F and Type S in each site class on lands subject to Forests and Fish forest practices rules.

That same GIS analysis shows that Site class II and III are the most common on CMER lands and account for approximately 62% of the Type F and S stream length in Western Washington to which the rules are applied (Figure 4 and Figure 37). This is consistent with the FPA analysis that was conducted prior to this study which showed that >58% of the randomly selected FPA Type F and S stream buffers were in site class II or III. Most of those (>50% of the total number of F/S buffers) had no inner zone harvest. Whether the lack of IZ harvest was a result of not meeting the basal area requirement for inner zone harvest or a landowner decision based on cost/benefit is unknown. The most common inner zone prescription was LTCW, and this pilot did demonstrate that sites with LTCW had greater basal area and more conifers than sites where inner zone harvest was not conducted. However, in order to definitively assess whether inner zone harvest is what influenced the residual shade and LW supply potential, we would need to randomly assign a treatment/no treatment to similar sites that all qualified for inner zone harvest and then compare outcomes. Since Site Class II and III constitute the majority of the FFR stream length and FPAs, it would make sense to target such a study to buffers in those site classes.

Windthrow is an important mortality agent, particularly when it comes to contributing large, mature timber into channels (Lutz and Halpern, 2006), but it is also a potential confounding factor in an effectiveness study that might prove too difficult to control for experimentally and may significantly impact a small number of stands. Potential confounding by windthrow should be expected in future effectiveness studies and treatment/reference pairs and number of replicates should be adjusted to reflect this possibility.

This study only evaluated the 3-year post-harvest buffer condition, but the implications of harvest are very likely to be resolved over much longer timescales. Although the RMZ stands in this study are already capable of contributing some functional wood to stream channels, it will take more time for them to grow to a size where trees falling from the inner zone have the size to function as key pieces in most streams.   Long-timescale modeling, on the order of the DFC target age of 140 years for the residual stands, of stand condition may be required to evaluate the long-term effects of harvest on the ability of buffers to provide large wood to the channel.

The incidence of mortality combined with other edge effects on the buffers can be expected to result in more diverse, multilayered buffer stands in future harvest rotations. A companion study investigating the development and function of Forests and Fish RMZs from the early 2000s on a twenty-year timescale could be conducted to investigate that hypothesis as well as the hypothesis that the Forests and Fish buffers would lead to well-functioning riparian zones and fish habitat. Such a study could be conducted in parallel with a more intensive BACI study investigating specific questions and particular prescriptions on a shorter timescale.

Other points to consider in designing a future study that were highlighted in this one are:

- Investigate whether the rate of high mortality events in LCTW harvest sites is somehow an effect of the harvesting. Separate the data for the no-cut portion of the Inner Zone from that of the harvested portion to further elucidate the relationship with high mortality in these prescriptions.

- Investigate whether the finding that mortality, especially from windthrow, is greater on small streams holds true on a wider basis across the landscape. If so, explore to determine the reason.
- In-stream channel attributes, especially channel width, are critical to being able to evaluate buffer performance in providing desired functions.
- Lumping all “large stream” width category sites is not recommended in future studies due to the extreme variability in the functionality of buffers on streams 10’ wide compared with those on larger rivers.
- Measuring tree heights will allow for better assessment of wood recruitment potential, shade modeling, and growth modeling of residual riparian stands.
- Information (such as quantities, sizes, percent crowns) on suppressed and very young trees in the understory in future work will allow us to assess potential for release of established trees in the event of mortality in the current stand.

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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 displays general attributes of each site, including whether it was selected for the resurvey.

Table A-3displays the stands 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-4 displays data on mortality, fallen trees, wood recruitment, and shade.

Table A-1. Variables calculated for each study site

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, as assessed by field crew by counting rings in cut stumps or, for Inner Zone harvest sites, by adding years to harvest to the age reported in DFC data
	Plot Length (ft)	300 ft for all sites, per our sample design
	Core Zone Width (ft)	50 ft for all sites, per Forests and 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
Standing Trees (only those on the Species List)		
	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 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 Species Richness	IPH

Topic	Variable	Definition and Time Frame
	Percent Conifer	Percent of total basal area at IPH made up by conifer trees
	Percent Douglas Fir	Percent of total basal area at IPH made up by Douglas fir trees
	Percent Alder	Percent of total basal area at IPH made up by red alder trees
	Percent W. Hemlock	Percent of total basal area at IPH made up by western hemlock trees
	Percent W. Redcedar	Percent of total basal area at IPH made up by redcedar trees
	Percent Big Leaf Maple	Percent of total basal area at IPH made up by big leaf maple trees
	Dominant Species	By basal area at IPH
	Mortality Count/100ft	# of trees that were determined to have died from IPH-YR3 per 100’ of stream length
	Mortality BA/100ft	Basal area of trees that were determined to have died IPH-YR3 per 100’ of stream length
	Mortality TPA	# of trees that were determined to have died from IPH-YR3 divided by the total number of standing live trees at IPH, per acre
	Mortality BAPA	Basal area of trees that were determined to have died IPH-YR3 per acre
	Mortality QMD	Sqrt(Total Mortality basal area/Total # of trees that died between IPH-YR3/.005454)
	Mortality % Live Count	# of trees that died in the period IPH-YR3 / # of IPH live trees
	Mortality % Live BA	BA of trees that died in the period IPH-YR3 / BA of live trees at IPH
	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 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)
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
	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 from IPH to YR3

Topic	Variable	Definition and Time Frame
	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 from IPH to YR3
	Recruited LWD pieces/100ft	Number of wood pieces that have more than than 4"x6' in or over the channel/100 ft of channel that were recruited from IPH to YR3
	Recruited LWD volume/100ft	Volume of only pieces that have more than than 4"x6' in or over the channel/100 ft of channel that were recruited from IPH to YR3
Shade		
	Shade (procedure 1)	YR3
	Shade (procedure 2)	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 at Year 3 post-harvest (these values are what were collected)
IPH-YR3	change from immediately post-harvest to the time of study sampling

Table A-2. General site characteristics. Greyed out sites are those that were discovered during analysis to not meet the study requirements.

SiteID	Prescription Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone LvTrees	Stand Age	Stream Bank [Riv Rt, Riv Left]	Survey Date	Resurvey	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
1a	1	II	large	No harvest	Dispersed	47	RR	8/15/2019		50	78	128	0.882
1b	1	II	large	No harvest	Combo	75	RL	7/24/2019		50	78	128	0.882
1c	1	II	large	No harvest	Dispersed	42	RL	8/15/2019		50	78	128	0.882
1d	1	II	large	No harvest	Dispersed	62	RL	5/28/2019	R	50	78	128	0.882
1e	1	II	large	No harvest	Combo	52	RR	7/24/2019		50	78	128	0.882
1f	1	II	large	No harvest	Dispersed	42	RR	8/13/2019		50	78	128	0.882
1g	1	II	large	No harvest	Dispersed	53	RL	8/22/2019		50	78	128	0.882
1h	1	II	large	No harvest	Combo	38	RL	7/31/2019		50	78	128	0.882
1i	1	II	large	No harvest	Combo	69	RL	7/23/2019		50	78	128	0.882
1j	1	II	large	No harvest	Clumped	76	RL	8/8/2019		50	78	128	0.882
2a	2	II	large	LTCW	Xchnged4IZ	47	RL	6/11/2019		50	78	128	0.882
2b	2	II	large	LTCW	Clumped	46	RR	6/12/2019	R	50	78	128	0.882
2c	2	II	large	LTCW	Clumped	50	RL	6/12/2019		50	78	128	0.882
2d	2	II	large	LTCW	Dispersed	45	RR	8/7/2019		50	78	128	0.882
2e	2	II	large	LTCW	Combo	52	RR	6/21/2019		50	78	128	0.882
2f	2	II	large	LTCW	Dispersed	42	RL	8/21/2019		50	78	128	0.882
2g	2	II	large	LTCW	Combo	63	RR	8/2/2019		50	78	128	0.882
2h	2	II	large	LTCW	Clumped	46	RR	6/18/2019		50	78	128	0.882
2i	2	II	large	LTCW	Clumped	45	RL	8/6/2019		50	78	128	0.882
2j	2	II	large	LTCW	Clumped	48	RL	7/30/2019		50	78	128	0.882
2k	2	II	large	LTCW	Clumped	60	RR	8/8/2019		50	63	113	0.778
3a	3	II	small	No harvest	Dispersed	35	RL	7/17/2019		50	63	113	0.778
3b	3	II	small	No harvest	Dispersed	35	RR	5/29/2019		50	63	113	0.778
3c	3	II	small	No harvest	Dispersed	33	RL	5/30/2019		50	63	113	0.778
3d	3	II	small	No harvest	Dispersed	51	RL	5/29/2019		50	63	113	0.778

SiteID	Prescription Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone LvTrees	Stand Age	Stream Bank [Riv Rt, Riv Left]	Survey Date	Resurvey	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
3e	3	II	small	No harvest	Dispersed	37	RL	8/7/2019		50	63	113	0.778
3f	3	II	small	No harvest	Combo	37	RR	5/24/2019		50	63	113	0.778
3g	3	II	small	No harvest	Dispersed	35	RR	5/28/2019		50	63	113	0.778
3h	3	II	small	No harvest	Combo	44	RR	5/14/2019		50	63	113	0.778
3i	3	II	small	No harvest	Dispersed	35	RL	5/30/2019		50	63	113	0.778
3j	3	II	small	No harvest	Dispersed	41	RR	8/7/2019	R	50	63	113	0.778
4a	Stream was really a Large; Data moved to become Site 2k												
4b	4	II	small	LTCW	Dispersed	44	RR	8/7/2019		50	63	113	0.778
4c	4	II	small	LTCW	Clumped	76	RL	8/20/2019		50	63	113	0.778
4d	4	II	small	LTCW	Xchnged4IZ	44	RR	5/31/2019		50	63	113	0.778
4e	Stream was really a Type N												
4f	4	II	small	LTCW	Combo	47	RL	8/16/2019		50	63	113	0.778
4g	4	II	small	LTCW	Combo	44	RL	8/13/2019	R	50	63	113	0.778
4h	4	II	small	LTCW	Combo	44	RR	7/25/2019		50	63	113	0.778
4i	4	II	small	LTCW	Combo	45	RR	7/16/2019		50	63	113	0.778
4j	4	II	small	LTCW	Dispersed	60	RL	8/2/2019		50	63	113	0.778
5a	5	III	large	No harvest	Dispersed	53	RR	8/8/2019		50	55	105	0.723
5b	5	III	large	No harvest	Dispersed	116	RL	7/31/2019		50	55	105	0.723
5c	5	III	large	No harvest	Dispersed	39	RR	7/17/2019		50	55	105	0.723
5d	5	III	large	No harvest	Clumped	43	RR	5/17/2019		50	55	105	0.723
5e	5	III	large	No harvest	Clumped	52	RR	7/9/2019		50	55	105	0.723
5f	5	III	large	No harvest	Combo	42	RR	8/14/2019		50	55	105	0.723
5g	5	III	large	No harvest	Dispersed	37	RR	5/21/2019	R	50	55	105	0.723
5h	5	III	large	No harvest	Combo	39	RR	5/23/2019		50	55	105	0.723
5i	5	III	large	No harvest	Dispersed	46	RL	6/19/2019		50	55	105	0.723
5j	5	III	large	No harvest	Combo	41	RL	6/20/2019		50	55	105	0.723
6a	6	III	large	TFB	Dispersed	57	RR	6/5/2019		50	55	105	0.723

SiteID	Prescription Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone LvTrees	Stand Age	Stream Bank [Riv Rt, Riv Left]	Survey Date	Resurvey	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
6b	6	III	large	TFB	Dispersed	49	RR	6/25/2019		50	55	105	0.723
6c	6	III	large	TFB	Dispersed	40	RR	5/2/2019		50	55	105	0.723
6d	6	III	large	TFB	Dispersed	53	RR	5/8/2019		50	55	105	0.723
6e	6	III	large	TFB	Dispersed	49	RR	6/4/2019		50	55	105	0.723
6f	6	III	large	TFB	Dispersed	46	RL	5/1/2019		50	55	105	0.723
6g	6	III	large	TFB	Clumped	55	RL	7/10/2019	R	50	55	105	0.723
6h	6	III	large	TFB	Clumped	45	RR	5/15/2019		50	55	105	0.723
6i	6	III	large	TFB	Clumped	50	RR	5/8/2019		50	55	105	0.723
6j	6	III	large	TFB	Clumped	44	RR	6/4/2019		50	55	105	0.723
7a	7	III	small	No harvest	Dispersed	30	RL	8/1/2019		50	43	93	0.640
7b	7	III	small	No harvest	Dispersed	41	RR	6/6/2019		50	43	93	0.640
7c	7	III	small	No harvest	Dispersed	44	RL	7/12/2019		50	43	93	0.640
7d	7	III	small	No harvest	Clumped	40	RR	6/20/2019		50	43	93	0.640
7e	7	III	small	No harvest	Clumped	43	RL	5/22/2019		50	43	93	0.640
7f	7	III	small	No harvest	Dispersed	41	RL	10/18/2018		50	43	93	0.640
7g	7	III	small	No harvest	Clumped	48	RL	7/23/2019		50	43	93	0.640
7h	7	III	small	No harvest	Clumped	53	RL	7/18/2019		50	43	93	0.640
7i	7	III	small	No harvest	Combo	38	RL	5/22/2019	R	50	43	93	0.640
7j	7	III	small	No harvest	Combo	43	RR	5/23/2019		50	43	93	0.640
8a	8	III	small	LTCW	Dispersed	45	RL	6/27/2019		50	43	93	0.640
8b	8	III	small	LTCW	Dispersed	57	RL	5/1/2019	R	50	43	93	0.640
8c	8	III	small	LTCW	Dispersed	41	RR	5/8/2019		50	43	93	0.640
8d	8	III	small	LTCW	Dispersed	54	RR	5/9/2019		50	43	93	0.640
8e	8	III	small	LTCW	Dispersed	45	RR	7/25/2019		50	43	93	0.640
8f	8	III	small	LTCW	Dispersed	43	RL	5/2/2019		50	43	93	0.640
8g	8	III	small	LTCW	Dispersed	43	RL	6/28/2019		50	43	93	0.640
8h	8	III	small	LTCW	Dispersed	37	RR	6/27/2019		50	43	93	0.640

SiteID	Prescription Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone LvTrees	Stand Age	Stream Bank [Riv Rt, Riv Left]	Survey Date	Resurvey	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
8i	8	III	small	LTCW	Clumped	61	RL	7/19/2019		50	43	93	0.640
8j	8	III	small	LTCW	Clumped	39	RL	7/9/2019		50	43	93	0.640
9a	9	IV	large	No harvest	Dispersed	56	RR	8/6/2019		50	33	83	0.572
9b	9	IV	large	No harvest	Combo	51	RR	7/31/2019		50	33	83	0.572
9c	9	IV	large	No harvest	Clumped	48	RR	8/9/2019		50	33	83	0.572
9d	9	IV	large	No harvest	Dispersed	49	RR	7/11/2019		50	33	83	0.572
9e	9	IV	large	No harvest	Clumped	49	RL	7/10/2019		50	33	83	0.572
9f	9	IV	large	No harvest	Dispersed	105	RR	7/30/2019	R	50	33	83	0.572
9g	9	IV	large	No harvest	Dispersed	68	RR	6/13/2019		50	33	83	0.572
9h	9	IV	large	No harvest	Combo	88	RR	6/18/2019		50	33	83	0.572
9i	9	IV	large	No harvest	Combo	40	RL	8/1/2019		50	33	83	0.572
9j	9	IV	large	No harvest	Clumped	49	RL	7/19/2019		50	33	83	0.572
10a	10	V	large	No harvest	Clumped	41	RL	7/2/2019		50	18	68	0.468
10b	10	V	large	No harvest	Dispersed	39	RR	7/11/2019		50	18	68	0.468
10c	10	V	large	No harvest	Dispersed	39	RL	6/7/2019		50	18	68	0.468
10d	10	V	large	No harvest	Dispersed	35	RR	6/5/2019		50	18	68	0.468
10e	10	V	large	No harvest	Dispersed	102	RR	4/30/2019		50	18	68	0.468
10f	10	V	large	No harvest	Dispersed	35	RL	7/19/2019		50	18	68	0.468
10g	10	V	large	No harvest	Clumped	45	RL	5/15/2019		50	18	68	0.468
10h	10	V	large	No harvest	Dispersed	71	RL	7/24/2019	R	50	18	68	0.468
10i	10	V	large	No harvest	Dispersed	36	RL	5/3/2019		50	18	68	0.468
10j	10	V	large	No harvest	Clumped	50	RL	7/3/2019		50	18	68	0.468
11a	11	V	small	No harvest	Dispersed	35	RL	5/7/2019		50	10	60	0.413
11b	11	V	small	No harvest	Dispersed	33	RL	6/26/2019	R	50	10	60	0.413
11c	11	V	small	No harvest	Dispersed	40	RR	5/1/2019		50	10	60	0.413
11d	11	V	small	No harvest	Dispersed	42	RL	6/26/2019		50	10	60	0.413
11e	11	V	small	No harvest	Dispersed	36	RR	7/18/2019		50	10	60	0.413

SiteID	Prescription Variant	Site Class	Channel Width Category	Inner Zone Trtmt	Outer Zone LvTrees	Stand Age	Stream Bank [Riv Rt, Riv Left]	Survey Date	Resurvey	Core Zone Width* [ft]	Inner Zone Width [ft]	Core + Inner Width [ft]	Core + Inner Area [acres]
11f	11	V	small	No harvest	Combo	45	RR	6/6/2019		50	10	60	0.413
11g	11	V	small	No harvest	Dispersed	42	RR	5/16/2019		50	10	60	0.413
11h	11	V	small	No harvest	Dispersed	40	RR	7/25/2019		50	10	60	0.413
11i	11	V	small	No harvest	Combo	47	RL	7/30/2019		50	10	60	0.413
11j	11	V	small	No harvest	Dispersed	35	RR	4/29/2019		50	10	60	0.413

Table A-3. Riparian stand characteristics pre-harvest (for sites with buffer harvest), immediately post-harvest (IPH), and at survey date approximately three years post-harvest (Yr3). Pre-harvest data are from DFC runs for sites with inner zone harvest. For sites with no inner zone harvest, IPH data are assumed to be "pre-harvest."

SiteID	Pre-hvst Live TPA	Pre-hvst Live BAPA	Pre-hvst %Conifer	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]
1a				264	321	14.9	92%	PSME	4	231	305	15.6
1b				110	176	17.1	48%	ALRU	6	103	171	17.4
1c				302	262	12.6	84%	TSHE	4	279	242	12.6
1d				151	184	15.0	6%	ALRU	5	145	180	15.1
1e				175	225	15.4	62%	PSME	6	163	216	15.6
1f				188	195	13.8	42%	PSME	7	186	190	13.7
1g				179	261	16.3	19%	ALRU	5	161	247	16.8
1h				335	207	10.6	74%	PSME	6	250	170	11.2
1i				101	175	17.8	4%	ALRU	5	95	169	18.0
1j				218	224	13.7	66%	TSHE	5	157	162	13.8
2a	174	196.2	98.0	204	231	14.4	95%	PSME	5	169	205	14.9
2b	247	203.8	96.1	357	330	13.0	95%	TSHE	4	301	295	13.4
2c	233	243.3	99.8	278	307	14.2	91%	TSHE	4	250	282	14.4

SiteID	Pre-hvst Live TPA	Pre-hvst Live BAPA	Pre-hvst %Conifer	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]
2d	252	134.7	87.6	175	232	15.6	90%	PSME	4	162	223	15.9
2e	152	194.5	95.9	185	259	16.0	94%	TSHE	7	180	255	16.1
2f	166	158.0	78.6	182	223	15.0	69%	PSME	4	176	221	15.2
2g	265	253.7	68.8	200	189	13.2	48%	ALRU	5	177	179	13.6
2h	182	195.8	97.0	193	225	14.6	99%	TSHE	5	162	202	15.1
2i	282	216.1	97.0	382	238	10.7	88%	PSME	4	331	223	11.1
2j	247	178.9	94.2	238	232	13.4	88%	PSME	4	222	227	13.7
2k	242	218.1	95.2	537	368	11.2	100%	TSHE	5	466	351	11.7
3a				224	183	12.2	87%	PSME	5	146	133	12.9
3b				157	161	13.7	0%	ALRU	3	152	159	13.9
3c				266	145	10.0	42%	TSHE	5	260	143	10.1
3d				179	236	15.6	72%	TSHE	6	163	225	15.9
3e				213	193	12.9	18%	ALRU	5	200	187	13.1
3f				149	203	15.8	78%	PSME	7	139	197	16.1
3g				243	193	12.1	38%	ALRU	7	216	179	12.3
3h				180	217	14.9	86%	PSME	5	72	101	16.0
3i				170	168	13.5	39%	PSME	5	161	165	13.7
3j				162	179	14.2	18%	ALRU	7	113	146	15.4
4a												
4b	105	145.3	94.2	126	186	16.4	93%	PSME	3	116	175	16.7
4c	118	307.7	100.0	148	202	15.8	100%	PSME	2	126	165	15.5
4d	179	181.2	78.4	181	181	13.5	70%	PSME	4	122	145	14.7
4e	no DFC	no DFC	no DFC	152	280	18.4	67%	PSME	5	146	277	18.6
4f	158	215.6	99.9	137	263	18.7	98%	PSME	3	132	258	18.9
4g	162	184.4	99.0	153	181	14.8	97%	PSME	3	103	144	16.0
4h	113	154.5	100.0	173	284	17.3	100%	TSHE	2	82	155	18.6
4i	121	130.7	100.0	206	206	13.6	100%	PSME	2	154	166	14.1
4j	150	248.1	74.4	123	218	18.0	71%	PSME	5	107	198	18.5

SiteID	Pre-hvst Live TPA	Pre-hvst Live BAPA	Pre-hvst %Conifer	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]
5a				177	309	17.9	97%	PSME	4	140	259	18.4
5b				115	249	19.9	22%	PSME	6	113	247	20.0
5c				252	278	14.2	75%	TSHE	8	236	251	13.9
5d				213	284	15.6	84%	TSHE	6	206	275	15.6
5e				201	199	13.5	87%	PSME	5	187	191	13.7
5f				283	316	14.3	86%	PSME	3	271	308	14.4
5g				261	219	12.4	37%	PSME	6	243	211	12.6
5h				184	231	15.2	80%	PSME	5	181	229	15.2
5i				360	260	11.5	100%	TSHE	4	289	213	11.6
5j				241	196	12.2	100%	TSHE	5	228	189	12.3
6a	235	164.5	68.8	282	269	13.2	62%	ALRU	4	198	205	13.8
6b	293	227.2	78.7	224	212	13.2	90%	TSHE	4	191	202	13.9
6c	131	160.8	79.6	142	318	20.2	39%	ALRU	5	136	294	19.9
6d	179	194.0	96.3	158	268	17.7	91%	TSHE	4	153	266	17.8
6e	257	233.2	74.1	357	290	12.2	66%	TSHE	5	340	286	12.4
6f	195	266.0	97.5	171	262	16.7	97%	TSHE	5	151	232	16.8
6g	280	222.2	94.2	332	249	11.7	91%	TSHE	5	254	201	12.0
6h	246	296.8	96.6	242	370	16.7	86%	TSHE	6	210	335	17.1
6i	255	286.2	95.8	232	233	13.6	94%	PISI	6	185	216	14.6
6j	204	139.6	78.8	329	248	11.7	75%	TSHE	4	307	239	11.9
7a				276	129	9.3	17%	ALRU	7	264	127	9.4
7b				269	212	12.0	58%	ALRU	4	225	192	12.5
7c				198	234	14.7	83%	TSHE	4	172	210	15.0
7d				264	323	15.0	100%	TSHE	5	242	302	15.1
7e				170	195	14.5	77%	TSHE	5	167	192	14.5
7f				315	253	12.1	97%	PSME	6	262	209	12.1
7g				264	350	15.6	98%	TSHE	5	106	154	16.3
7h				223	203	12.9	35%	ALRU	5	209	193	13.0

SiteID	Pre-hvst Live TPA	Pre-hvst Live BAPA	Pre-hvst %Conifer	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]
7i				365	260	11.4	100%	PSME	4	322	246	11.8
7j				206	205	13.5	93%	TSHE	3	47	57	15.0
8a	202	202.0	96.4	250	202	12.2	71%	TSHE	5	226	193	12.5
8b	250	184.3	80.1	348	328	13.1	92%	TSHE	4	275	276	13.6
8c	245	239.8	84.0	297	265	12.8	69%	TSHE	3	275	247	12.8
8d	289	157.4	83.8	372	209	10.1	99%	TSHE	4	342	194	10.2
8e	351	166.7	100.0	531	234	9.0	100%	TSHE	3	233	122	9.8
8f	242	209.4	92.3	217	242	14.3	95%	PSME	4	209	236	14.4
8g	220	187.8	80.1	248	235	13.2	82%	TSHE	7	120	135	14.4
8h	277	203.7	100.0	337	249	11.6	100%	PSME	3	300	237	12.0
8i	387	277.6	96.7	244	242	13.5	96%	TSHE	5	170	179	13.9
8j	269	187.7	71.4	326	337	13.8	67%	TSHE	3	297	324	14.2
9a				269	260	13.3	100%	TSHE	6	264	256	13.3
9b				215	289	15.7	41%	THPL	7	198	285	16.3
9c				495	409	12.3	96%	PSME	6	436	368	12.4
9d				343	335	13.4	97%	TSHE	6	269	298	14.2
9e				248	325	15.5	92%	TSHE	5	234	313	15.6
9f				121	239	19.1	42%	ACMA	4	68	146	19.8
9g				724	375	9.7	98%	PSME	6	633	339	9.9
9h				31	88	22.7	22%	ALRU	3	30	88	23.3
9i				338	177	9.8	27%	ALRU	5	301	162	9.9
9j				59	220	26.0	79%	PISI	5	59	220	26.0
10a				425	252	10.4	98%	TSHE	5	275	174	10.8
10b				414	292	11.4	58%	ALRU	3	386	280	11.5
10c				587	382	10.9	59%	ALRU	5	500	343	11.2
10d				331	415	15.2	74%	TSHE	4	314	406	15.4
10e				463	292	10.7	97%	THPL	7	453	279	10.6
10f				310	155	9.6	93%	TSHE	8	305	152	9.6

SiteID	Pre-hvst Live TPA	Pre-hvst Live BAPA	Pre-hvst %Conifer	IPH Live TPA	IPH Live BAPA	IPH Live QMD [in]	IPH %conifer	IPH Dominant Species (by BA)	IPH Species Richness (# of spp)	Yr3 Live TPA	Yr3 Live BAPA	Yr3 Live QMD [in]
10g				446	364	12.2	91%	TSHE	4	419	355	12.5
10h				465	271	10.3	100%	TSHE	5	429	262	10.6
10i				331	193	10.4	97%	PSME	4	329	193	10.4
10j				931	410	9.0	97%	TSHE	4	846	388	9.2
11a				365	305	12.4	87%	TSHE	4	271	257	13.2
11b				339	331	13.4	89%	TSHE	7	332	328	13.5
11c				244	256	13.9	96%	TSHE	5	215	234	14.1
11d				825	374	9.1	99%	TSHE	5	607	304	9.6
11e				450	162	8.1	96%	THPL	8	421	152	8.1
11f				324	252	11.9	53%	ALRU	5	288	233	12.2
11g				402	272	11.1	92%	PSME	6	172	109	10.8
11h				276	235	12.5	100%	PSME	2	148	144	13.4
11i				162	234	16.3	87%	PSME	5	99	163	17.3
11j				620	458	11.6	100%	TSHE	5	598	454	11.8

Table A-4. Site response variables - tree mortality, wood recruitment, and shade. Wood recruitment and shade are calculated and reported using two different methods (see Methods section).

SiteID	% Mortality	Fallen Trees	Fallen meanDBH [in]	Fallen Trees reaching Channel	FPW-LW Recruitmnt [pcs/100']	FPW-LW Recruitmnt [ft^3/100']	BFW-LW Recruitmnt [pcs/100']	BFW-LW Recruitmnt [ft^3/100']	Shade1 [%]	Shade2 [%]
1a	12%	12	10.7	8	1.0	2.0	1.00	1.66	93	94
1b	6%	9	14.9	23	4.0	20.3	0.33	0.85	65	83
1c	8%	12	13.3	1	0.0	0.0	0.33	1.40	80	83
1d	4%	3	10.6	3	0.0	0.0	0.33	2.23	32	67
1e	6%	2	9.0	11	3.0	24.9	0.00	0.00	99	99

SiteID	% Mortality	Fallen Trees	Fallen meanDBH [in]	Fallen Trees reaching Channel	FPW-LW Recruitmnt [pcs/100']	FPW-LW Recruitmnt [ft^3/100']	BFW-LW Recruitmnt [pcs/100']	BFW-LW Recruitmnt [ft^3/100']	Shade1 [%]	Shade2 [%]
1f	1%	2	20.0	0	0.0	0.0	0.00	0.00	80	87
1g	10%	13	11.2	3	0.3	0.4	0.00	0.00	91	96
1h	25%	59	9.0	3	1.0	1.7	0.67	1.88	37	95
1i	6%	6	14.3	4	1.3	5.2	0.00	0.00	95	95
1j	28%	54	12.6	3	1.0	2.8	0.67	2.08	76	98
2a	17%	26	12.7	8	2.0	16.9	0.00	0.00	99	100
2b	16%	54	11.1	1	0.3	5.8	0.00	0.00	73	96
2c	10%	13	11.1	0	0.0	0.0	1.33	5.22	99	96
2d	7%	18	11.5	0	0.0	0.0	1.00	2.82	98	99
2e	2%	2	15.9	1	0.0	0.0	0.00	0.00	36	66
2f	3%	2	8.5	24	6.3	45.9	0.67	3.28	99	98
2g	11%	14	12.0	1	0.0	0.0	0.67	1.10	95	92
2h	16%	28	10.9	14	2.0	7.5	1.00	9.20	89	87
2i	13%	18	7.3	2	0.0	0.0	0.33	0.69	94	90
2j	7%	2	7.8	4	0.3	0.8	0.00	0.00	100	98
2k	13%	37	8.2	4	0.7	5.0	1.00	2.01	96	92
3a	34%	50	11.1	76	4.3	13.3	1.67	2.68	97	95
3b	3%	4	10.5	3	1.0	8.5	0.00	0.00	99	99
3c	2%	5	6.1	21	3.3	6.2	0.33	0.45	96	100
3d	9%	14	10.8	0	0.0	0.0	0.33	0.92	99	99
3e	6%	5	10.8	7	2.0	30.1	0.00	0.00	98	96
3f	7%	0	0.0	5	0.0	0.0	0.00	0.00	95	100
3g	11%	18	9.4	42	3.3	10.8	0.67	1.95	99	100
3h	60%	77	13.4	56	12.7	44.0	5.33	34.93	95	87
3i	5%	2	6.3	1	0.3	0.9	0.00	0.00	99	100
3j	30%	47	10.2	5	1.3	5.4	2.00	6.82	87	83
4a										

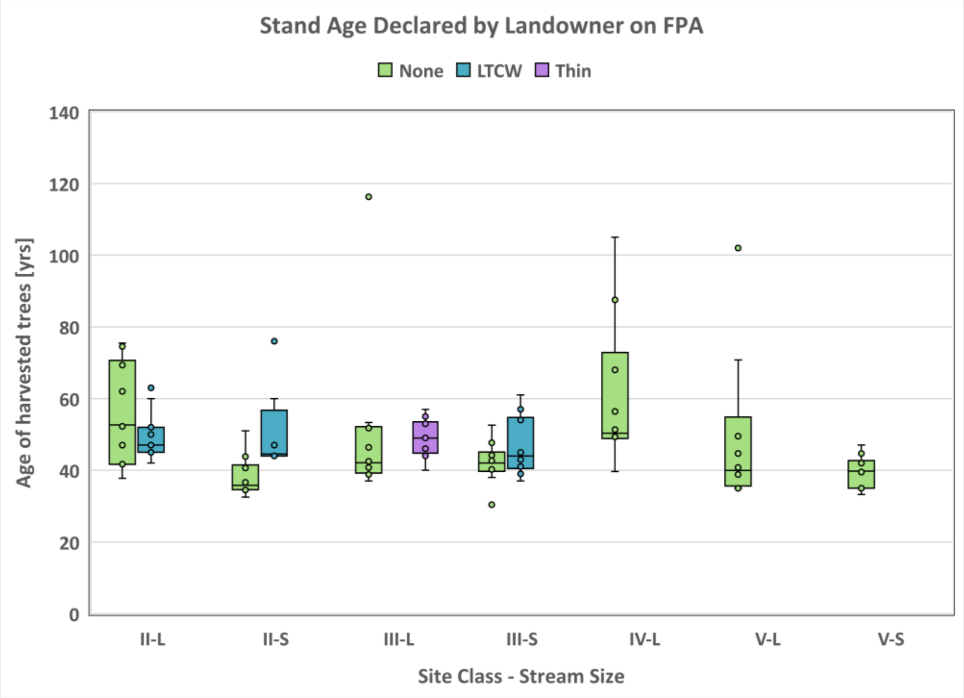
SiteID	% Mortality	Fallen Trees	Fallen meanDBH [in]	Fallen Trees reaching Channel	FPW-LW Recruitmnt [pcs/100']	FPW-LW Recruitmnt [ft^3/100']	BFW-LW Recruitmnt [pcs/100']	BFW-LW Recruitmnt [ft^3/100']	Shade1 [%]	Shade2 [%]
4b	8%	6	13.9	2	0.3	0.8	0.00	0.00	96	99
4c	15%	13	17.2	0	0.0	0.0	0.00	0.00	65	88
4d	33%	42	10.5	1	0.0	0.0	2.33	11.13	98	98
4e	3%	3	12.9	0	0.0	0.0	0.00	0.00	99	100
4f	4%	0	0.0	1	0.3	5.0	0.00	0.00	96	89
4g	33%	23	10.8	2	0.0	0.0	0.67	2.93	96	89
4h	53%	99	17.3	0	0.0	0.0	0.33	0.62	94	89
4i	25%	40	12.0	2	0.0	0.0	1.67	18.89	87	86
4j	14%	14	15.0	0	0.0	0.0	0.33	0.52	98	96
5a	21%	22	15.6	3	0.7	7.4	3.00	24.90	89	87
5b	1%	1	16.0	3	0.0	0.0	0.33	5.84	89	92
5c	6%	13	17.9	2	0.7	2.2	0.00	0.00	4	36
5d	3%	5	15.3	1	0.0	0.0	0.67	1.67	95	96
5e	7%	6	10.3	6	0.7	5.1	0.00	0.00	99	96
5f	4%	5	9.8	7	1.3	2.3	0.00	0.00	93	100
5g	7%	9	9.7	0	0.0	0.0	1.33	23.74	96	99
5h	2%	1	20.0	4	0.3	3.0	0.00	0.00	97	98
5i	20%	52	10.8	13	2.3	14.5	1.33	13.19	80	89
5j	5%	5	11.4	61	13.3	84.0	0.00	0.00	98	96
6a	30%	56	11.7	40	6.7	35.9	6.33	45.88	99	100
6b	15%	25	7.5	15	3.0	24.6	0.33	0.83	96	92
6c	5%	4	28.0	1	0.3	0.6	0.00	0.00	52	88
6d	3%	0	0.0	22	1.7	2.7	0.00	0.00	98	94
6e	5%	5	8.2	6	1.3	6.3	0.33	4.95	100	100
6f	12%	17	16.2	3	0.7	1.7	0.67	7.37	88	73
6g	23%	50	10.0	3	0.7	2.9	0.33	2.96	98	100
6h	13%	24	13.6	0	0.0	0.0	1.33	6.30	89	99

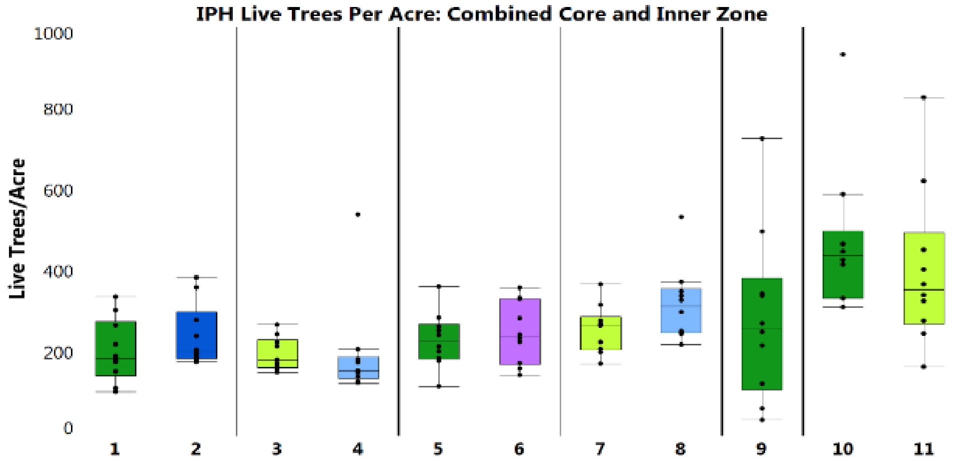
SiteID	% Mortality	Fallen Trees	Fallen meanDBH [in]	Fallen Trees reaching Channel	FPW-LW Recruitmnt [pcs/100']	FPW-LW Recruitmnt [ft^3/100']	BFW-LW Recruitmnt [pcs/100']	BFW-LW Recruitmnt [ft^3/100']	Shade1 [%]	Shade2 [%]
6i	20%	27	7.4	0	0.0	0.0	0.67	2.92	99	100
6j	7%	11	8.7	5	1.3	12.0	1.33	12.00	99	100
7a	5%	0	0.0	12	3.0	21.5	0.00	0.00	99	100
7b	16%	23	9.5	5	0.0	0.0	1.33	5.37	99	99
7c	13%	16	12.9	0	0.0	0.0	1.33	2.26	99	100
7d	8%	12	14.0	2	0.7	3.3	2.00	26.95	94	94
7e	2%	2	11.1	2	0.3	0.9	0.00	0.00	99	96
7f	17%	24	12.5	5	0.7	2.6	0.33	3.94	80	94
7g	60%	104	14.5	16	2.3	11.1	5.67	35.57	91	100
7h	6%	5	13.0	2	0.3	1.4	1.00	4.04	95	95
7i	12%	15	8.5	0	0.0	0.0	1.33	7.11	99	98
7j	77%	104	12.7	2	0.7	1.1	2.67	8.19	92	96
8a	9%	14	8.5	1	0.3	2.2	0.00	0.00	98	92
8b	21%	41	11.0	0	0.0	0.0	2.00	7.50	97	95
8c	7%	17	13.5	4	1.0	9.2	0.00	0.00	99	99
8d	8%	18	9.2	3	0.3	0.7	0.33	0.77	99	99
8e	56%	190	8.0	0	0.0	0.0	4.33	13.33	98	98
8f	4%	4	10.6	1	0.3	0.5	1.00	8.46	98	94
8g	52%	79	11.5	0	0.0	0.0	3.33	10.82	86	72
8h	11%	14	7.3	0	0.0	0.0	0.00	0.00	98	96
8i	30%	43	12.1	0	0.0	0.0	2.33	14.46	96	75
8j	9%	18	8.0	1	0.0	0.0	0.33	0.59	99	98
9a	2%	1	5.2	3	0.3	0.9	0.00	0.00	74	87
9b	8%	3	6.4	5	0.7	1.9	0.33	0.38	54	67
9c	12%	19	12.1	1	0.0	0.0	2.00	16.87	93	96
9d	21%	35	9.3	2	0.0	0.0	0.00	0.00	93	99
9e	6%	11	14.2	4	1.3	23.7	0.00	0.00	98	99

SiteID	% Mortality	Fallen Trees	Fallen meanDBH [in]	Fallen Trees reaching Channel	FPW-LW Recruitmnt [pcs/100']	FPW-LW Recruitmnt [ft^3/100']	BFW-LW Recruitmnt [pcs/100']	BFW-LW Recruitmnt [ft^3/100']	Shade1 [%]	Shade2 [%]
9f	43%	28	17.2	2	0.0	0.0	3.00	24.63	68	87
9g	13%	34	8.0	0	0.0	0.0	3.00	21.46	74	96
9h	6%	0	0.0	15	0.7	2.9	0.00	0.00	40	35
9i	11%	13	8.9	0	0.0	0.0	0.33	0.73	98	100
9j	0%	1	31.5	0	0.0	0.0	0.00	0.00	24	35
10a	35%	67	9.2	6	2.0	26.9	4.00	20.28	71	99
10b	7%	9	9.2	1	0.0	0.0	0.00	0.00	99	99
10c	15%	28	8.8	0	0.0	0.0	2.00	30.09	99	98
10d	5%	6	16.2	1	0.3	0.7	0.33	0.94	98	99
10e	2%	5	18.6	2	0.3	3.9	0.67	5.04	97	89
10f	1%	1	5.5	5	0.7	2.0	0.00	0.00	85	94
10g	6%	9	8.0	38	0.3	0.6	0.00	0.00	98	96
10h	8%	15	7.9	40	5.7	35.6	0.67	5.14	90	98
10i	1%	0	0.0	5	1.0	4.0	0.00	0.00	54	100
10j	9%	17	6.8	18	1.7	18.9	0.00	0.00	75	100
11a	26%	31	9.8	5	0.3	0.5	3.33	6.23	95	98
11b	2%	3	12.0	7	1.3	7.1	0.00	0.00	99	96
11c	12%	11	10.9	42	5.3	34.9	0.00	0.00	98	99
11d	26%	77	7.6	12	1.3	13.2	12.67	44.04	96	93
11e	6%	4	9.2	0	0.0	0.0	0.00	0.00	98	100
11f	11%	15	9.8	15	2.0	6.8	0.67	2.18	99	99
11g	57%	96	10.4	2	0.0	0.0	13.33	83.98	90	87
11h	46%	50	10.8	47	2.7	8.2	6.67	35.93	85	96
11i	39%	37	14.3	2	0.7	2.1	0.67	2.62	58	60
11j	4%	9	5.9	0	0.0	0.0	0.00	0.00	100	100

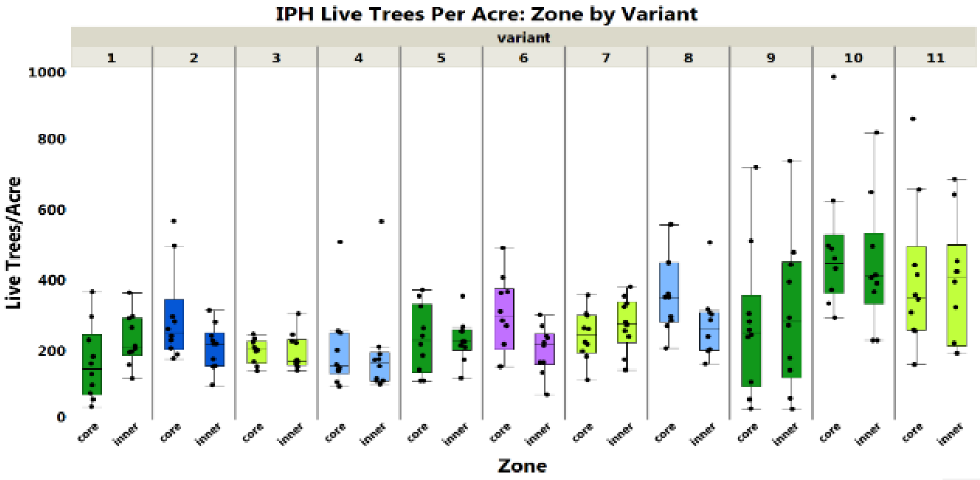
Appendix B. Data Distributions by Prescription Variant

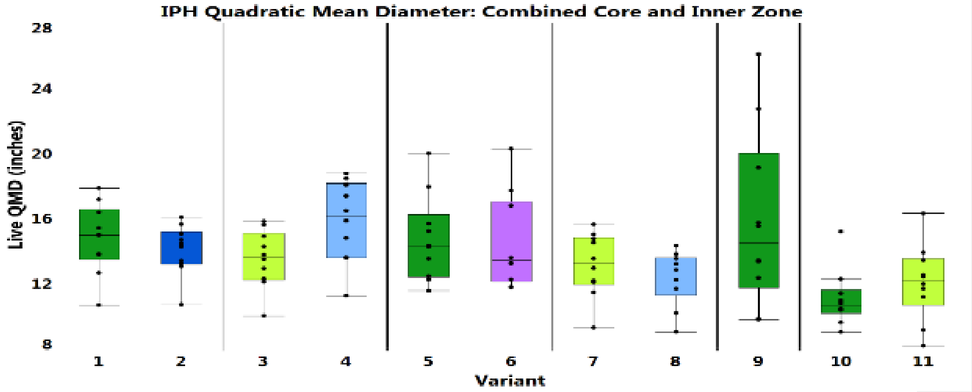
The following figures and tables show distributions of the measured data for each prescription variant and by Core and Inner zone within each variant. The boxplot bars represent the median; the boxes range from the 25th to the 75th percentiles, the whiskers show the value range up to 1.5x the box length, and outliers are plotted individually beyond that. 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 colors indicate large channels and lighter shades indicate small channels.



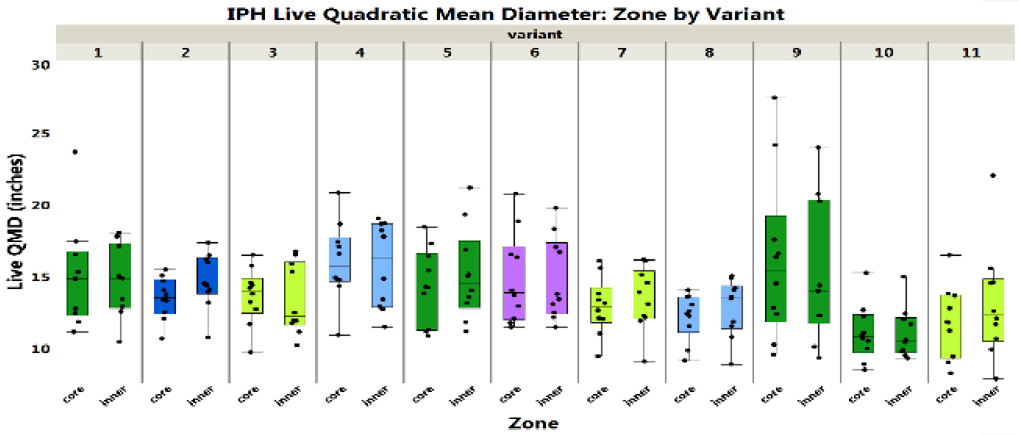


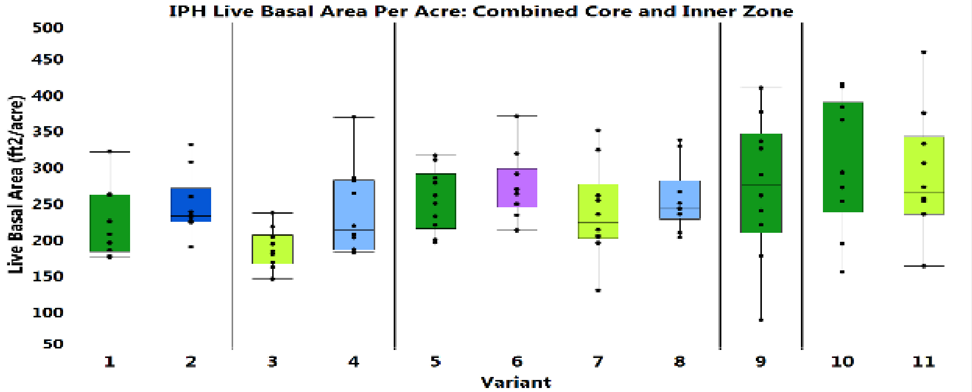
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	183.8	201.9	179.3	152.3	226.8	237.2	263.9	311.5	258.9	435.6	352.1
Mean	202.3	239.4	194.2	193.6	228.6	247.0	255.1	316.9	284.5	470.4	400.8
Standard Error	24.6	23.9	12.6	39.0	21.2	24.2	18.4	28.9	66.0	57.4	61.3



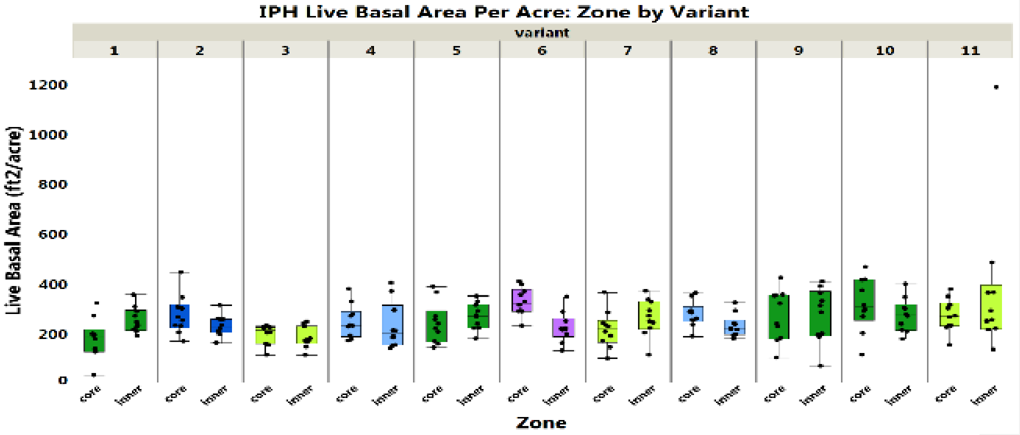


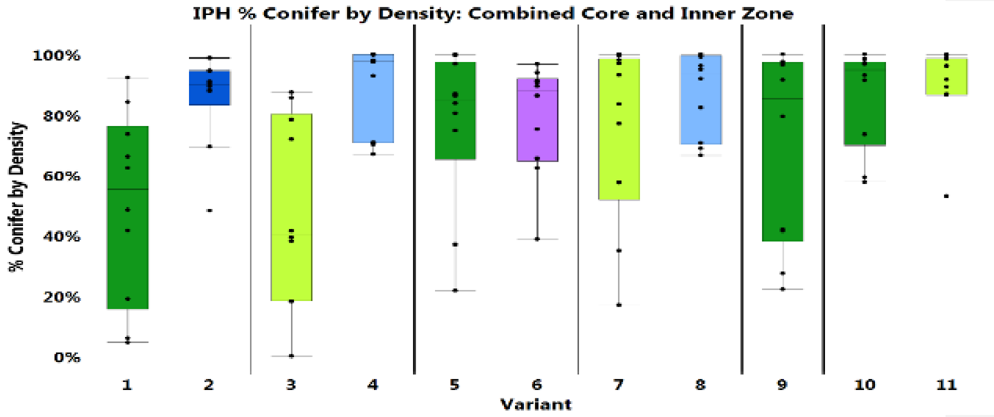
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	14.9	14.3	13.6	16.1	14.3	13.4	13.2	13.0	14.4	10.6	12.2
Mean	14.7	14.0	13.5	15.8	14.7	14.7	13.1	12.4	15.7	11.0	12.0
Standard Error	0.7	0.5	0.6	0.8	0.8	0.9	0.6	0.5	1.7	0.5	0.7



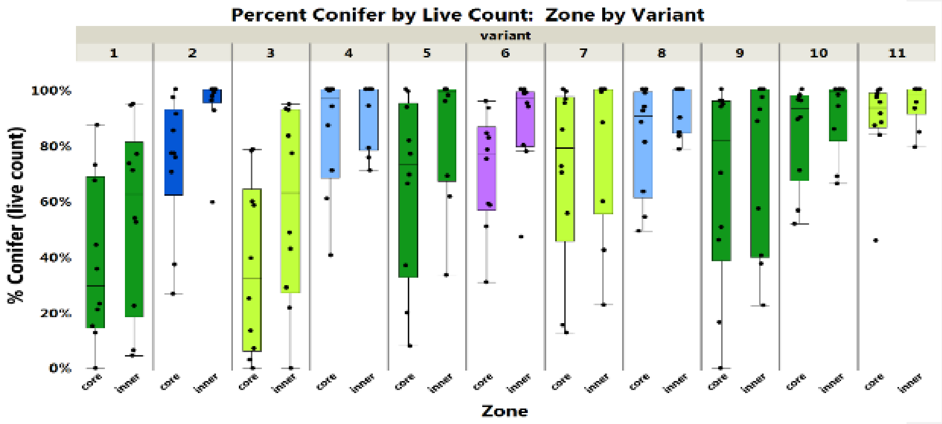

IPH Live Basal Area Per Acre: Combined Core and Inner Zone

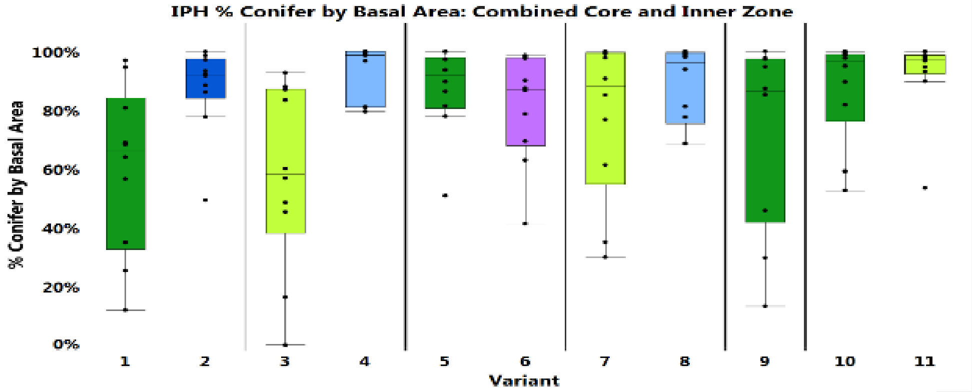
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	215.6	232.1	188.0	212.3	254.5	265.2	223.3	241.9	274.6	291.8	264.1
Mean	223.0	246.6	187.7	237.1	254.1	271.8	236.4	254.3	271.8	302.6	288.0
Standard Error	14.7	13.2	8.5	19.3	13.6	14.3	20.3	14.3	30.4	28.3	26.4


IPH Live Basal Area Per Acre: Zone by Variant

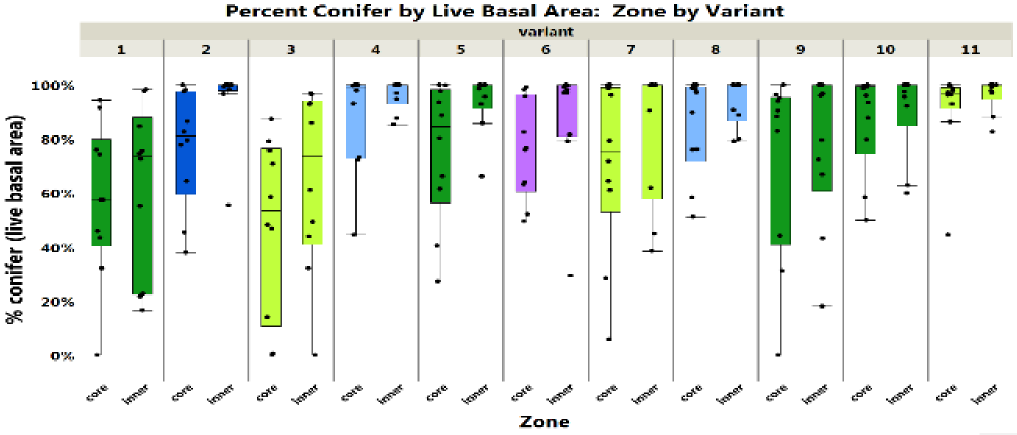


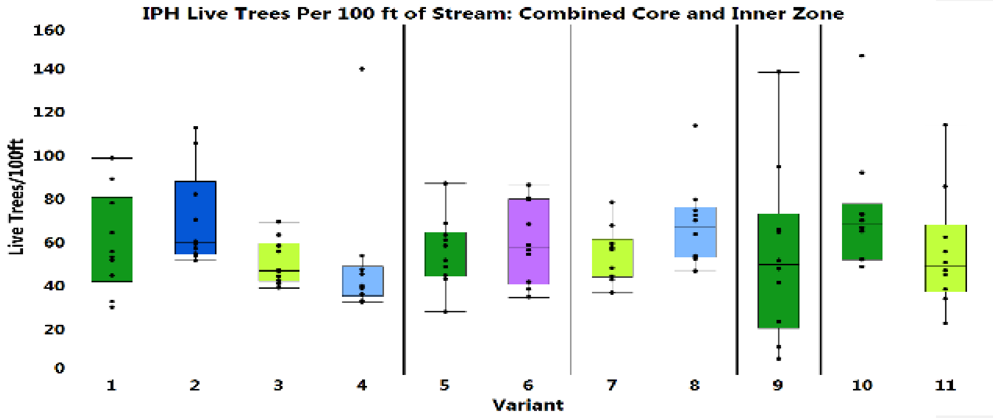
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	55.4%	89.9%	40.5%	97.8%	85.1%	87.9%	88.4%	93.5%	85.5%	95.0%	93.8%
Mean	49.8%	85.2%	47.9%	89.6%	76.7%	79.0%	75.8%	87.1%	69.6%	86.4%	89.8%
Standard Error	10.0%	4.8%	9.9%	4.5%	8.4%	5.9%	9.4%	4.3%	10.2%	5.2%	4.4%



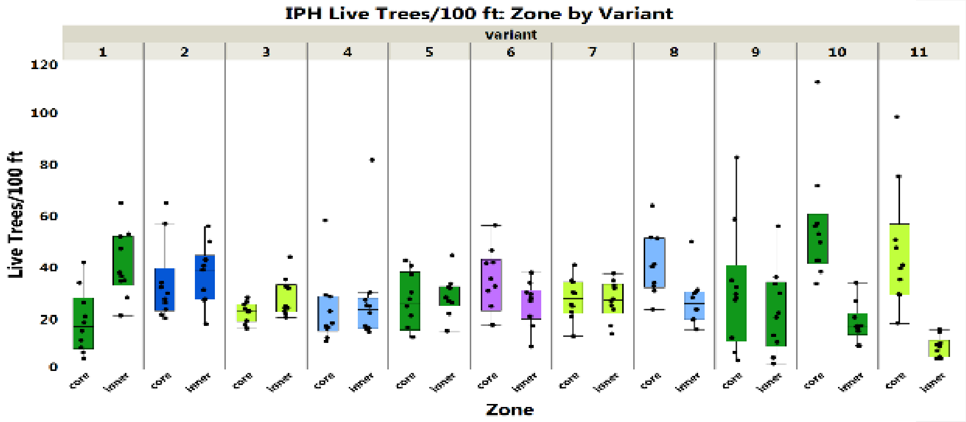

IPH % Conifer by Basal Area: Combined Core and Inner Zone

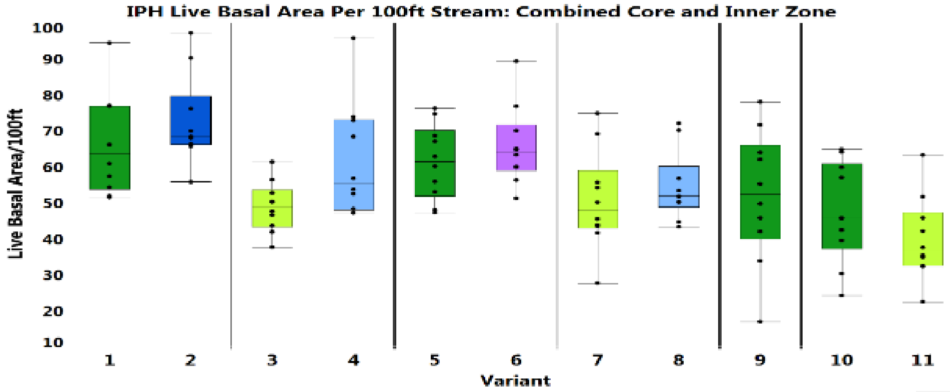
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	66.2%	92.0%	58.5%	99.0%	91.8%	87.2%	88.0%	96.1%	86.4%	96.5%	97.1%
Mean	60.3%	87.5%	57.9%	93.6%	87.1%	81.2%	77.6%	88.7%	73.7%	87.4%	92.2%
Standard Error	9.0%	4.7%	10.0%	2.9%	4.7%	5.9%	8.5%	4.2%	10.1%	5.6%	4.4%


Percent Conifer by Live Basal Area: Zone by Variant

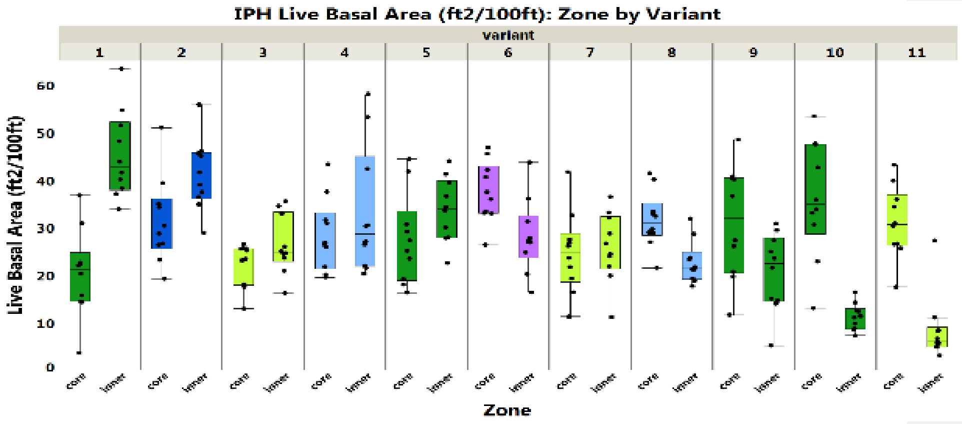

IPH Live Trees Per 100 ft of Stream: Combined Core and Inner Zone

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
Median	54.0	59.3	46.5	39.5	54.7	57.2	56.3	66.5	49.3	68.0	48.5
Mean	59.4	70.3	50.4	50.2	55.1	59.5	54.5	67.7	54.2	73.4	55.2
Standard Error	7.2	7.0	3.3	10.1	5.1	5.8	3.9	6.2	12.6	9.0	8.4

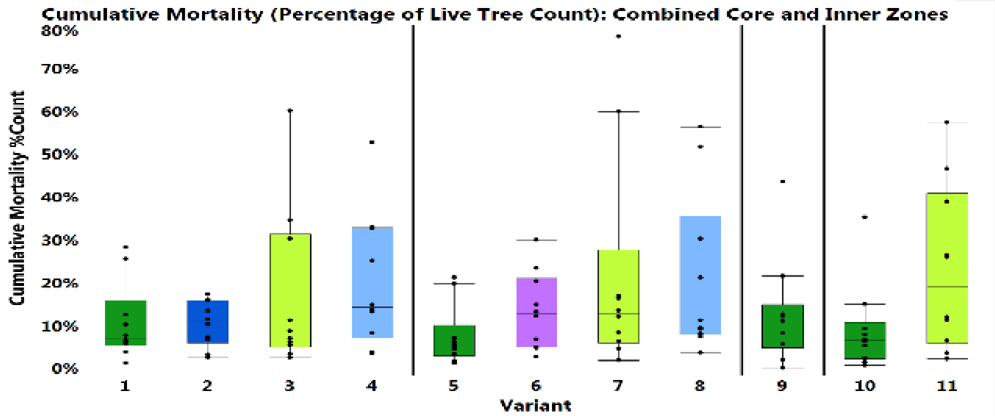

IPH Live Trees/100 ft: Zone by Variant



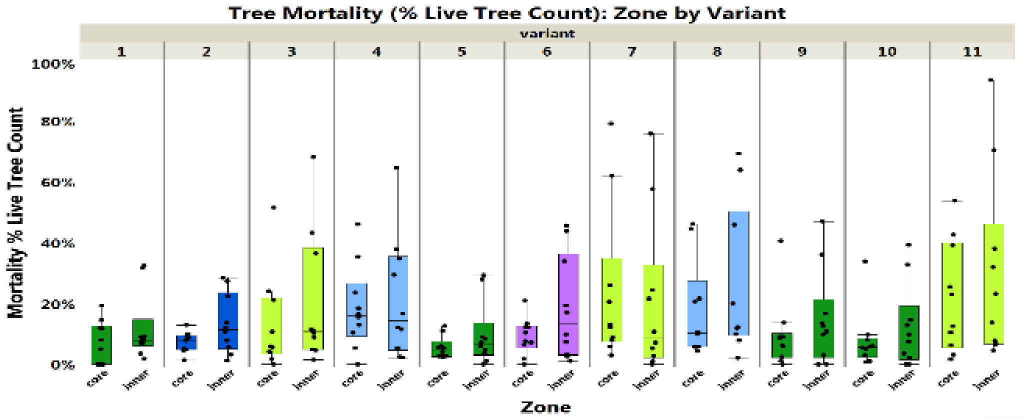
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	63.3	68.2	48.8	55.1	61.3	63.9	47.7	51.6	52.3	45.6	36.4
Mean	65.5	72.5	48.7	61.5	61.2	65.5	50.5	54.3	51.8	47.2	39.7
Standard Error	4.3	3.9	2.2	5.0	3.3	3.4	4.3	3.0	5.8	4.4	3.6

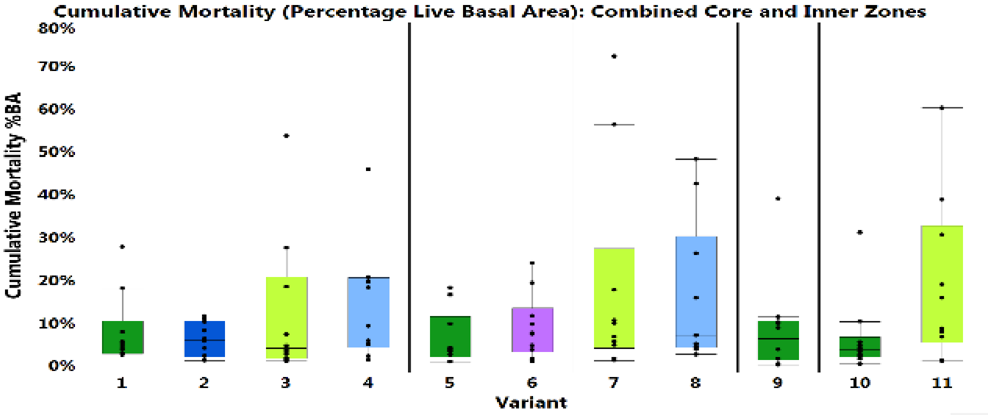


The following figures show distributions of mortality, recruitment, and canopy closure at the time of sampling.

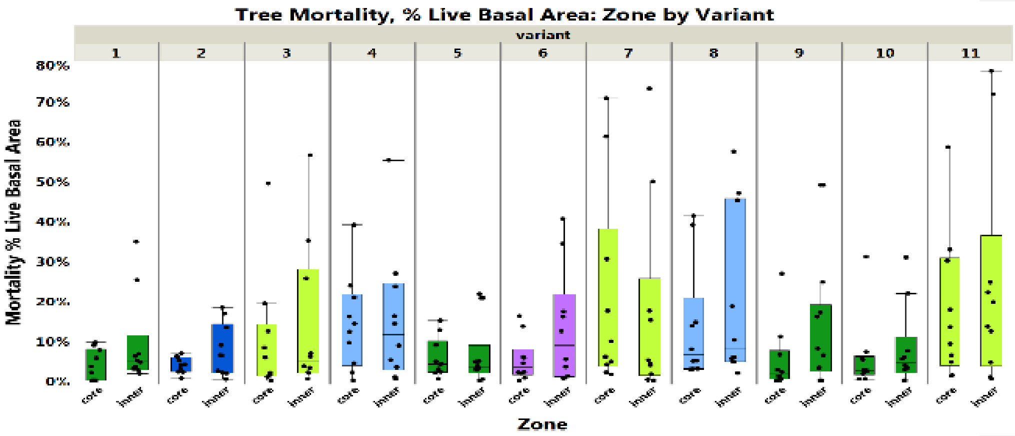


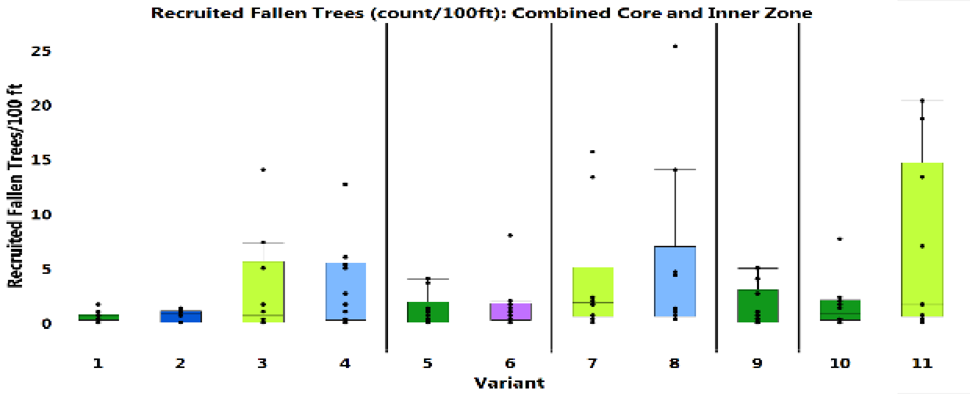
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	7.0%	10.8%	7.8%	14.2%	5.6%	12.6%	12.7%	10.2%	9.5%	6.5%	18.9%
Mean	10.7%	10.3%	16.8%	20.0%	7.6%	13.2%	21.6%	20.7%	12.2%	8.9%	23.0%
Standard Error	2.9%	1.7%	6.0%	5.0%	2.2%	2.9%	8.1%	6.0%	4.0%	3.2%	6.1%



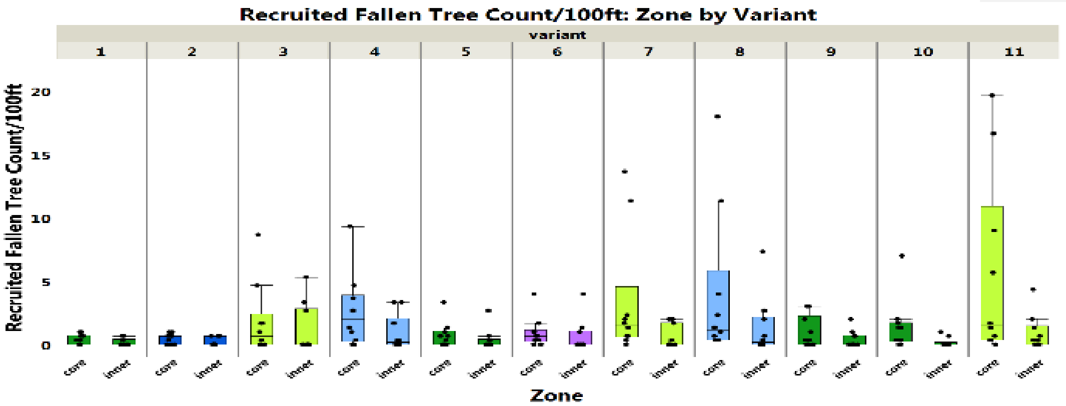

Cumulative Mortality (Percentage Live Basal Area): Combined Core and Inner Zones

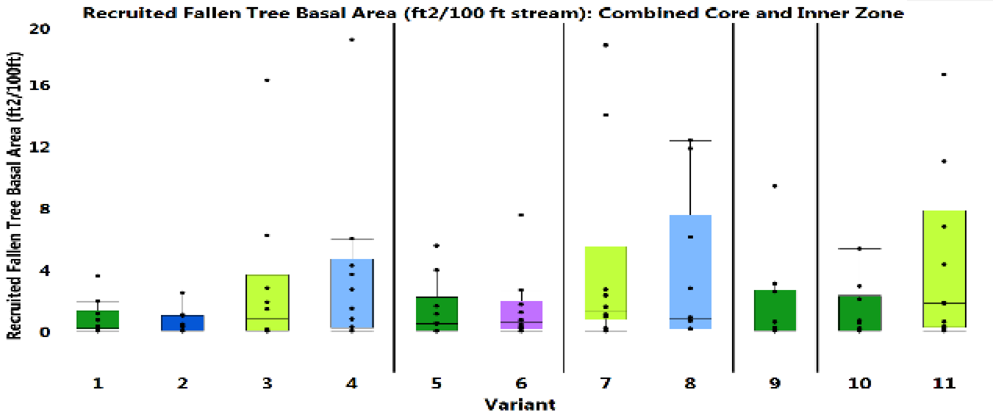
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	4.5%	5.9%	4.0%	13.6%	3.7%	7.4%	8.2%	7.0%	6.1%	3.6%	12.1%
Mean	7.9%	6.0%	12.1%	14.7%	6.3%	8.9%	18.5%	16.1%	8.5%	6.4%	18.9%
Standard Error	2.6%	1.2%	5.4%	4.2%	2.0%	2.4%	7.8%	5.4%	3.6%	2.9%	6.0%


Tree Mortality, % Live Basal Area: Zone by Variant

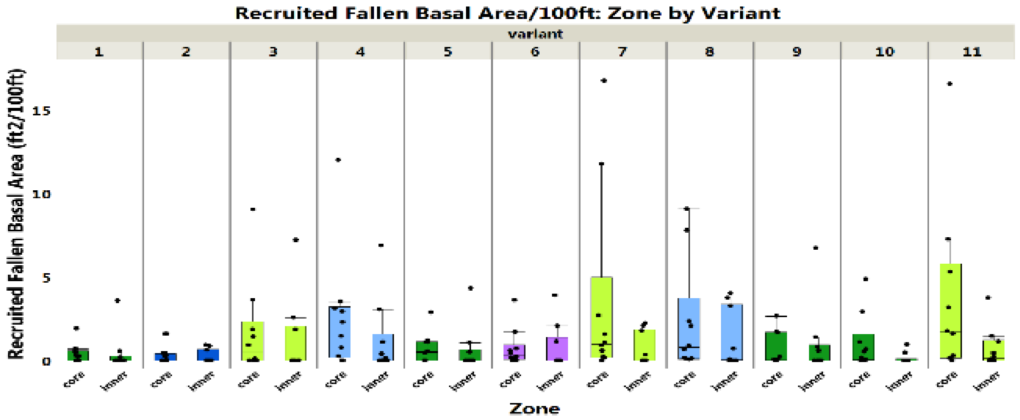


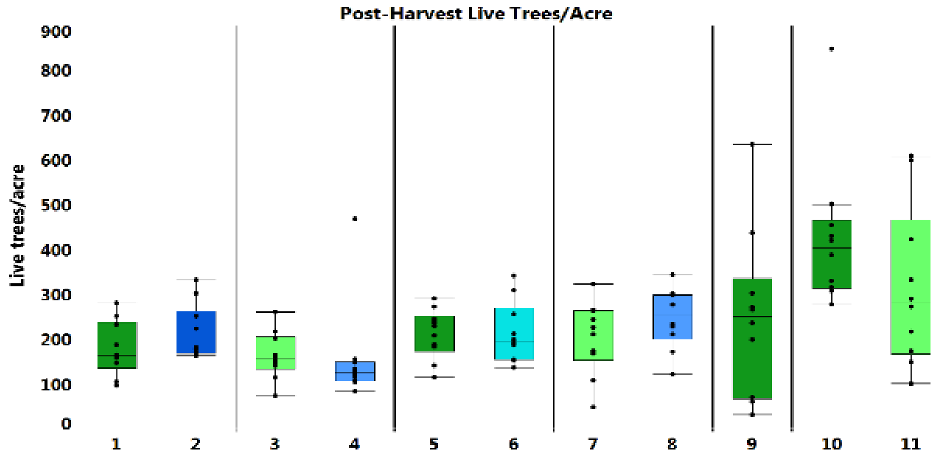
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	0.7	0.8	0.7	2.2	0.5	1.0	1.8	1.2	0.5	0.8	1.7
Mean	0.6	0.7	2.9	3.5	1.1	1.6	4.0	5.3	1.4	1.6	6.4
Standard Error	0.2	0.2	1.5	1.3	0.5	0.7	1.8	2.6	0.6	0.7	2.5



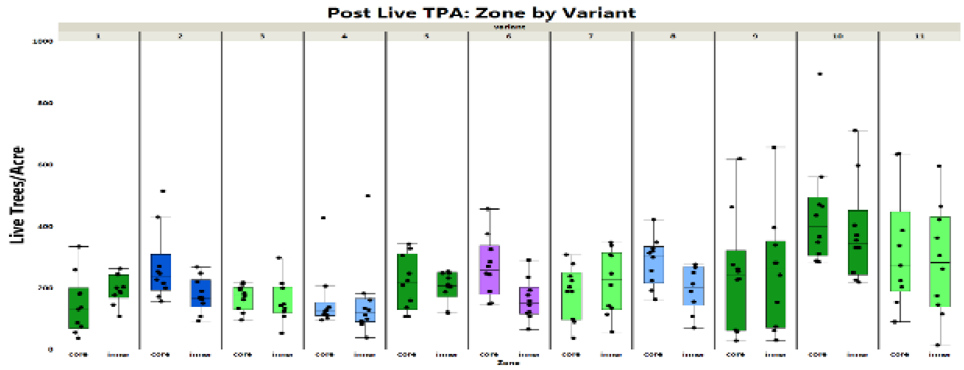


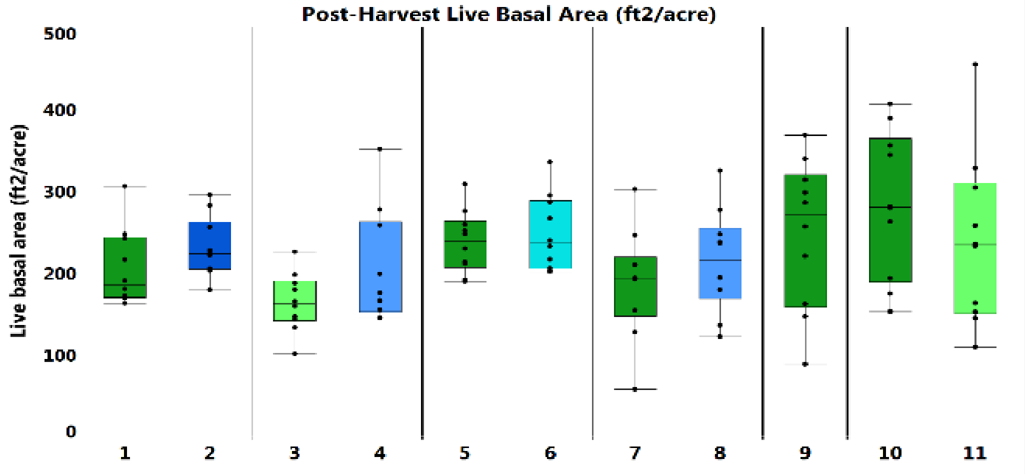
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	0.5	0.3	0.8	2.1	0.5	0.6	1.3	0.8	0.1	0.4	1.8
Mean	0.9	0.6	2.9	3.8	1.3	1.5	4.2	3.5	1.6	1.2	4.3
Standard Error	0.4	0.2	1.6	1.8	0.6	0.7	2.1	1.5	0.9	0.6	1.8



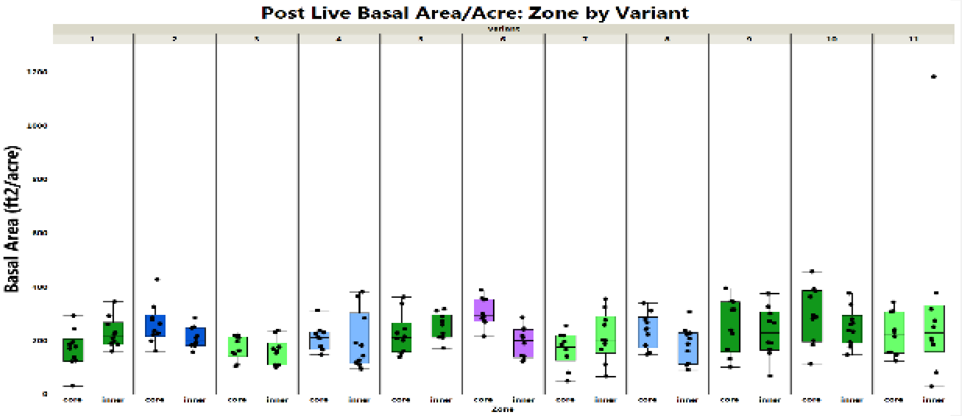


Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	162.2	178.7	156.1	124.0	217.1	194.3	217.0	253.7	249.3	402.5	279.5
Mean	177.1	213.0	162.2	155.5	209.5	212.5	201.6	244.7	249.3	425.6	315.1
Standard Error	19.1	19.4	16.8	35.2	17.6	21.5	25.7	21.0	58.2	52.0	56.2

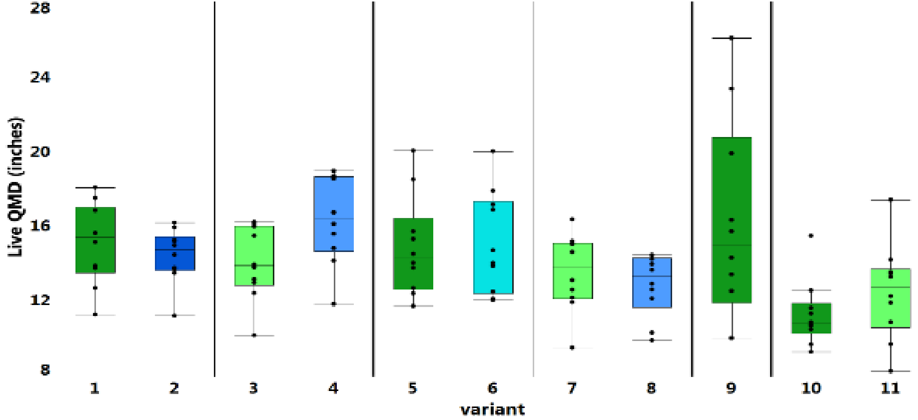




Site Class	II				III				IV	V	
Stream Width	L		S				S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	184.9	222.9	161.8	170.7	238.2	235.5	192.9	215.0	270.4	279.6	233.5
Mean	205.1	231.1	163.5	203.3	237.2	247.5	188.1	214.4	247.4	283.3	237.6
Standard Error	14.8	11.4	11.2	21.9	12.0	14.5	20.9	19.7	28.8	28.4	33.0

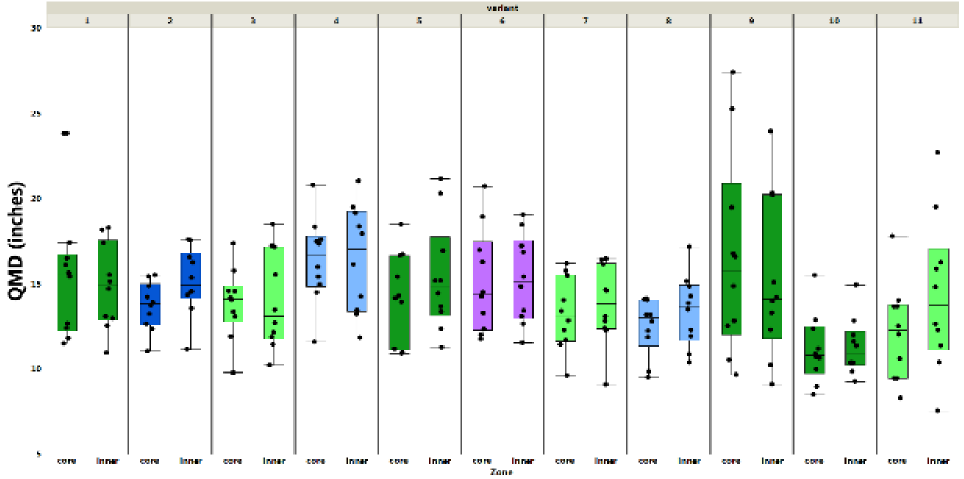


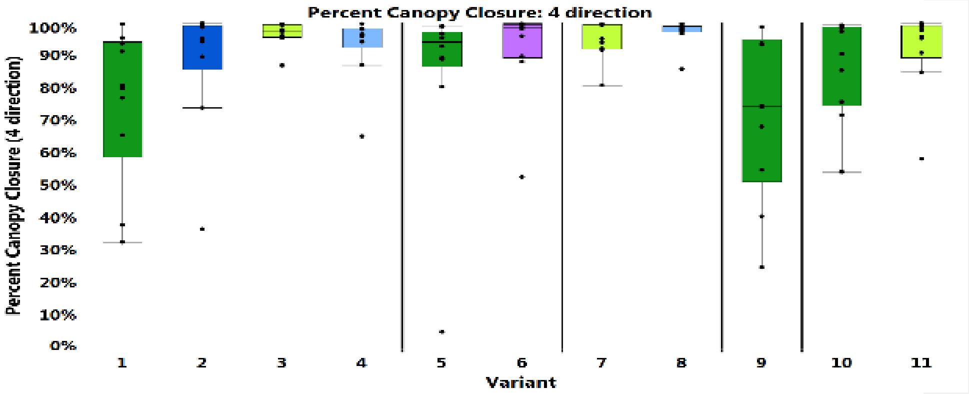
Post-Harvest Live Quadratic Mean Diameter (inches)



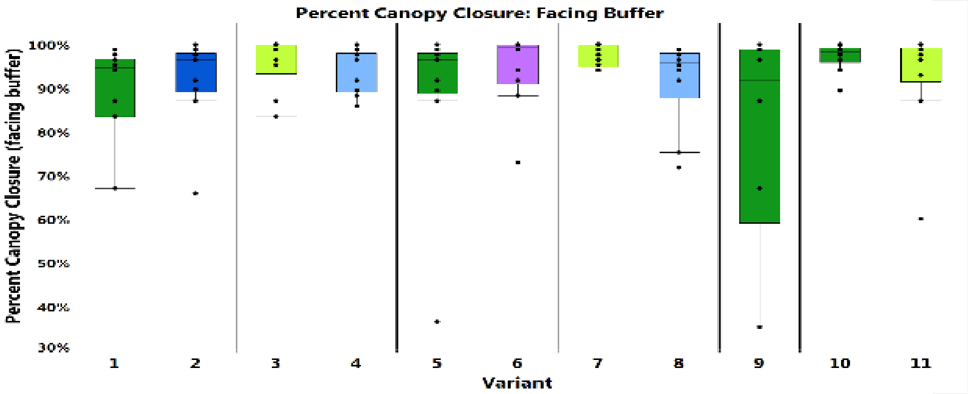
Site Class	II				III				IV	V	
Stream Width	L		S		L		S		L	L	S
IZ Harvest	No	LTCW	No	LTCW	No	TFB	No	LTCW	No	No	No
CZ&IZ width (ft)	128	100+	113	80+	105	105	93	80+	83	68	60
Median	15.3	14.6	13.8	16.4	14.2	14.3	13.8	13.2	14.9	10.7	12.7
Mean	15.0	14.3	13.9	16.3	14.8	15.0	13.5	12.8	16.1	11.2	12.4
Standard Error	0.7	0.5	0.6	0.8	0.8	0.9	0.7	0.5	1.7	0.6	0.8

Post Live Quadratic Mean Diameter: Zone by Variant





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
Median	80.0%	96.6%	97.3%	96.0%	93.8%	98.1%	96.9%	97.9%	74.0%	93.6%	96.5%
Mean	75.0%	88.2%	96.4%	92.4%	84.0%	91.8%	94.8%	96.8%	71.8%	86.7%	91.7%
Standard Error	7.5%	6.3%	1.2%	3.3%	9.0%	4.6%	1.9%	1.3%	8.1%	4.9%	4.1%



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
Median	94.7%	96.4%	98.8%	90.6%	96.4%	99.4%	97.0%	95.8%	91.7%	98.2%	97.0%
Mean	89.8%	92.1%	96.0%	92.7%	89.0%	94.6%	97.3%	91.7%	80.2%	97.1%	92.8%
Standard Error	3.1%	3.2%	1.9%	1.6%	6.0%	2.8%	0.7%	3.1%	8.1%	1.0%	3.9%

The following tables provide the variant means and (standard errors) in a tabular form.

IPH Stand Structure

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	202 (25)	239 (24)	194 (13)	194 (39)	229 (21)	247 (24)	255 (18)	317 (29)	284 (66)	470 (57)	401 (61)
Core	162 (33)	292 (42)	195 (11)	199 (38)	230 (30)	299 (34)	240 (22)	355 (33)	274 (66)	482 (62)	402 (66)
Inner	228 (23)	206 (20)	194 (16)	189 (43)	227 (19)	200 (21)	273 (24)	273 (30)	301 (68)	438 (57)	392 (55)
Live BAPA (ft^2)											
Combined	223 (15)	247 (13)	188 (9)	237 (19)	254 (14)	272 (14)	236 (20)	254 (14)	272 (30)	303 (28)	288 (26)
Core	177 (25)	273 (25)	195 (13)	247 (21)	240 (26)	326 (18)	215 (23)	275 (16)	271 (32)	314 (34)	271 (21)
Inner	253 (16)	229 (13)	182 (13)	229 (29)	267 (17)	223 (19)	261 (24)	230 (14)	272 (34)	272 (21)	375 (95)
Live QMD (in)											
Combined	14.7 (0.7)	14.3 (0.5)	13.5 (0.6)	15.8 (0.8)	14.7 (0.8)	14.7 (0.9)	13.1 (0.6)	12.4 (0.5)	15.7 (1.7)	11.0 (0.5)	12.0 (0.7)
Core	15.0 (1.2)	13.5 (0.5)	13.6 (0.6)	16.0 (0.9)	14.3 (0.8)	14.8 (1.0)	12.9 (0.6)	12.2 (0.5)	16.1 (1.8)	11.0 (0.6)	11.8 (0.8)
Inner	14.7 (0.8)	14.6 (0.6)	13.4 (0.8)	15.7 (0.9)	15.1 (1.0)	14.8 (0.9)	13.4 (0.7)	12.8 (0.6)	15.1 (1.5)	11.0 (0.6)	13.1 (1.2)
%conifer (cnt)											
Combined	50 (10.0)	85 (4.8)	48 (9.9)	90 (4.5)	77 (8.4)	79 (5.9)	76 (9.4)	87 (4.3)	70 (10.2)	86 (5.2)	90 (4.4)
Core	38 (9.2)	74 (7.6)	36 (9.7)	85 (6.6)	65 (10.4)	71 (6.5)	70 (10.4)	82 (6.2)	66 (11.6)	85 (5.7)	89 (5.1)
Inner	55 (10.6)	94 (4.0)	58 (10.9)	92 (3.8)	86 (7.4)	89 (5.3)	81 (9.1)	94 (2.7)	74 (9.7)	91 (4.2)	95 (2.3)
%conifer (BA)											
Combined	60 (9.0)	88 (4.7)	58 (10.0)	94 (2.9)	87 (4.7)	81 (5.9)	78 (8.5)	89 (4.2)	74 (10.1)	87 (5.6)	92 (4.4)
Core	57 (9.1)	77 (6.8)	48 (10.3)	88 (6.0)	76 (8.2)	76 (5.8)	71 (10.2)	85 (5.8)	72 (10.9)	86 (5.8)	91 (5.3)
Inner	62 (9.9)	95 (4.4)	65 (10.5)	96 (1.8)	94 (3.4)	88 (7.0)	84 (7.9)	94 (2.7)	77 (8.9)	91 (5.0)	96 (1.9)

Yr3 Stand Structure

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	177 (19)	213 (19)	162 (17)	155 (35)	210 (18)	213 (22)	202 (26)	245 (21)	249 (58)	426 (52)	315 (56)
Core	148 (30)	268 (36)	169 (13)	159 (31)	217 (28)	269 (31)	186 (27)	286 (25)	248 (58)	442 (58)	321 (59)
Inner	196 (15)	178 (18)	156 (21)	153 (40)	203 (15)	161 (21)	220 (33)	196 (23)	252 (60)	379 (50)	286 (57)
Live BAPA (ft^2)											
Combined	205 (15)	231 (11)	164 (11)	203 (22)	237 (12)	248 (14)	188 (21)	214 (20)	247 (29)	283 (28)	238 (33)
Core	168 (23)	262 (24)	174 (14)	208 (15)	225 (24)	308 (17)	165 (20)	239 (20)	258 (32)	295 (34)	223 (25)
Inner	229 (18)	211 (12)	155 (16)	199 (34)	249 (15)	192 (18)	215 (29)	186 (22)	231 (29)	250 (22)	310 (102)
Live QMD (in)											
Combined	15.0 (0.7)	14.3 (0.5)	13.9 (0.6)	16.3 (0.8)	14.8 (0.8)	15.0 (0.9)	13.5 (0.7)	12.8 (0.5)	16.1 (1.7)	11.2 (0.6)	12.4 (0.8)
Core	15.3 (1.2)	13.7 (0.4)	13.9 (0.7)	16.4 (0.8)	14.3 (0.8)	15.1 (1.0)	13.3 (0.7)	12.5 (0.5)	16.6 (1.9)	11.2 (0.6)	12.1 (0.9)
Inner	14.9 (0.8)	15.1 (0.6)	14.0 (0.9)	16.5 (1.0)	15.4 (1.0)	15.3 (0.8)	13.8 (0.7)	13.4 (0.7)	15.3 (1.5)	11.3 (0.5)	14.3 (1.4)

Recruitment Potential (IPH and YR3)

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	59 (7.2)	70 (7.0)	50 (3.3)	50 (10.1)	55 (5.1)	60 (5.8)	54 (3.9)	68 (6.2)	54 (12.6)	73 (9.0)	55 (8.4)
Core	19 (3.8)	33 (4.8)	22 (1.2)	23 (4.3)	26 (3.5)	34 (4.0)	28 (2.5)	41 (3.8)	31 (7.5)	55 (7.1)	46 (7.5)
Inner	41 (4.1)	37 (3.6)	28 (2.4)	27 (6.2)	29 (2.4)	25 (2.7)	27 (2.4)	27 (3.0)	23 (5.2)	18 (2.3)	9 (1.3)
IPH BA/100ft (ft^2)											
Combined	66 (4.3)	72 (3.9)	49 (2.2)	62 (5.0)	61 (3.3)	66 (3.4)	50 (4.3)	54 (3.0)	52 (5.8)	47 (4.4)	40 (3.6)
Core	20 (2.9)	31 (2.9)	22 (1.5)	28 (2.4)	28 (3.0)	37 (2.0)	25 (2.7)	32 (1.9)	31 (3.7)	36 (3.9)	31 (2.4)
Inner	45 (2.9)	41 (2.4)	26 (1.9)	33 (4.3)	34 (2.1)	28 (2.4)	26 (2.3)	23 (1.4)	21 (2.6)	11 (0.9)	9 (2.2)
Trees/100ft)	**(YR3**										
Combined	52 (5.6)	63 (5.7)	42 (4.3)	40 (9.1)	51 (4.2)	51 (5.2)	43 (5.5)	52 (4.5)	48 (11.1)	66 (8.1)	43 (7.7)
Core	17 (3.4)	31 (4.2)	19 (1.5)	18 (3.6)	25 (3.2)	31 (3.5)	21 (3.1)	33 (2.8)	28 (6.7)	51 (6.6)	37 (6.7)
Inner	35 (2.7)	32 (3.2)	23 (3.1)	22 (5.8)	26 (2.0)	20 (2.6)	22 (3.2)	19 (2.3)	19 (4.5)	16 (2.1)	7 (1.3)
BA/100ft (ft^2)	**(YR3**										
Combined	60 (4.3)	68 (3.4)	42 (2.9)	53 (5.7)	57 (2.9)	60 (3.5)	40 (4.5)	46 (4.2)	47 (5.5)	44 (4.4)	33 (4.5)
Core	19 (2.6)	30 (2.7)	20 (1.6)	24 (1.7)	26 (2.7)	35 (1.9)	19 (2.3)	27 (2.3)	30 (3.6)	34 (3.9)	26 (2.8)
Inner	41 (3.2)	38 (2.2)	22 (2.3)	29 (4.9)	31 (1.9)	24 (2.3)	21 (2.8)	18 (2.1)	18 (2.2)	10 (0.9)	7 (2.3)

Recruitment (IPH-YR3)

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	0.6 (0.2)	0.7 (0.2)	2.9 (1.5)	3.5 (1.3)	1.1 (0.5)	1.6 (0.7)	4.0 (1.8)	5.3 (2.6)	1.4 (0.6)	1.6 (0.7)	6.4 (2.5)
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)
Recruiting Tree Basal Area/100ft (ft^2)											
Combined	0.9 (0.4)	0.6 (0.2)	2.9 (1.6)	3.8 (1.8)	1.3 (0.6)	1.5 (0.7)	4.2 (2.1)	3.5 (1.5)	1.6 (0.9)	1.2 (0.6)	4.3 (1.8)
Core	0.5 (0.2)	0.3 (0.2)	1.7 (0.9)	2.6 (1.1)	0.7 (0.3)	0.8 (0.4)	3.6 (1.8)	2.3 (1.1)	0.6 (0.3)	1.0 (0.5)	3.6 (1.6)
Inner	0.4 (0.4)	0.2 (0.1)	1.2 (0.7)	1.2 (0.7)	0.6 (0.4)	0.7 (0.4)	0.6 (0.3)	1.2 (0.6)	1.0 (0.7)	0.1 (0.1)	0.7 (0.4)
Large Wood Pieces/100ft											
Combined	0.6 (0.2)	0.7 (0.2)	2.9 (1.5)	3.5 (1.3)	1.1 (0.5)	1.6 (0.7)	4.3 (1.8)	5.3 (2.6)	1.4 (0.6)	1.6 (0.7)	6.5 (2.5)
Large Wood Volume/100ft (ft^3)											
Combined	1.1 (0.3)	2.3 (1.0)	7.0 (3.8)	7.6 (2.8)	7.2 (3.2)	8.7 (4.5)	14.9 (5.7)	9.2 (3.5)	6.7 (3.4)	6.4 (3.3)	20.7 (10)

Mortality (IPH-YR3)

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	10.7 (2.9)	10.3 (1.7)	16.8 (6.0)	20.0 (5.0)	7.6 (2.2)	13.2 (2.9)	21.6 (8.1)	20.7 (6.0)	12.2 (4.0)	8.9 (3.2)	23.0 (6.1)
Core	7.0 (2.2)	7.3 (1.0)	12.9 (5.0)	18.4 (4.3)	5.5 (1.1)	9.2 (1.9)	23.8 (8.2)	17.5 (5.0)	9.7 (3.7)	7.9 (3.0)	21.8 (5.7)
Inner	11.8 (3.5)	13.3 (3.1)	20.0 (6.9)	21.7 (6.3)	9.7 (3.3)	18.4 (5.4)	20.6 (8.2)	25.5 (7.8)	14.9 (4.8)	12.3 (4.3)	29.6 (9.6)
Percent BA											
Combined	7.9 (2.6)	6.0 (1.2)	12.1 (5.4)	14.7 (4.2)	6.3 (2.0)	8.9 (2.4)	18.5 (7.8)	16.1 (5.4)	8.5 (3.6)	6.4 (2.9)	18.9 (6.0)
Core	3.7 (1.2)	4.0 (0.6)	10.1 (4.8)	14.2 (3.7)	5.7 (1.5)	5.2 (1.7)	20.8 (8.0)	13.5 (4.6)	5.2 (2.6)	5.9 (2.9)	17.5 (5.7)
Inner	9.3 (3.6)	7.6 (2.1)	14.1 (6.0)	15.4 (5.3)	6.5 (2.5)	13.1 (4.5)	17.0 (7.8)	20.1 (6.7)	12.7 (4.8)	8.1 (3.2)	24.7 (8.7)
TPA											
Combined	25 (9)	26 (6)	32 (11)	38 (10)	19 (7)	34 (9)	54 (18)	72 (28)	35 (10)	45 (15)	86 (26)
Core	15 (5)	23 (6)	26 (10)	41 (12)	14 (4)	30 (7)	54 (17)	68 (24)	26 (10)	40 (14)	82 (26)
Inner	32 (12)	28 (6)	37 (12)	36 (9)	24 (9)	39 (13)	53 (20)	77 (32)	49 (16)	59 (20)	106 (31)
BAPA											
Combined	18 (6)	15 (4)	24 (11)	34 (12)	17 (6)	24 (6)	48 (21)	40 (13)	24 (9)	19 (7)	50 (16)
Core	9 (3)	11 (2)	21 (10)	39 (13)	15 (5)	18 (6)	50 (22)	36 (12)	13 (6)	18 (8)	47 (17)
Inner	24 (10)	18 (5)	27 (13)	30 (11)	18 (8)	30 (10)	47 (22)	44 (14)	41 (16)	21 (8)	65 (20)

Percent Canopy Closure (YR3)

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
Procedure 1	75 (7.5)	88 (6.3)	96 (1.2)	92 (3.3)	84 (9.0)	92 (4.6)	95 (1.9)	97 (1.3)	72 (8.1)	87 (4.9)	92 (4.1)
Procedure 2	90 (3.1)	92 (3.2)	96 (1.9)	93 (1.6)	89 (6.0)	95 (2.8)	97 (0.7)	92 (3.1)	80 (8.1)	97 (1.0)	93 (3.9)

Appendix C. Principal Component Analysis on Full Dataset summarized by Site

The following is the complete PCA analysis of this dataset with text provided by the FactoInvestigate package (Thuleau and Husson, 2019).

This dataset contains 110 sites and 45 variables, 6 quantitative variables are considered as illustrative, 4 qualitative variables are considered as illustrative.

C-1. Study of the outliers

The analysis of the graphs does not detect any outlier.

C-2. Inertia distribution

The inertia of the first dimensions shows if there are strong relationships between variables and suggests the number of dimensions that should be studied.

The first two dimensions of analyse express **57.47%** of the total dataset inertia; that means that 57.47% of the sites (or variables) cloud total variability is explained by the plane. This percentage is relatively high and thus the first plane well represents the data variability. This value is strongly greater than the reference value that equals **13.12%**, the variability explained by this plane is thus highly significant (the reference value is the 0.95-quantile of the inertia percentages distribution obtained by simulating 3100 data tables of equivalent size on the basis of a normal distribution).

From these observations, it should be better to also interpret the dimensions greater or equal to the third one.

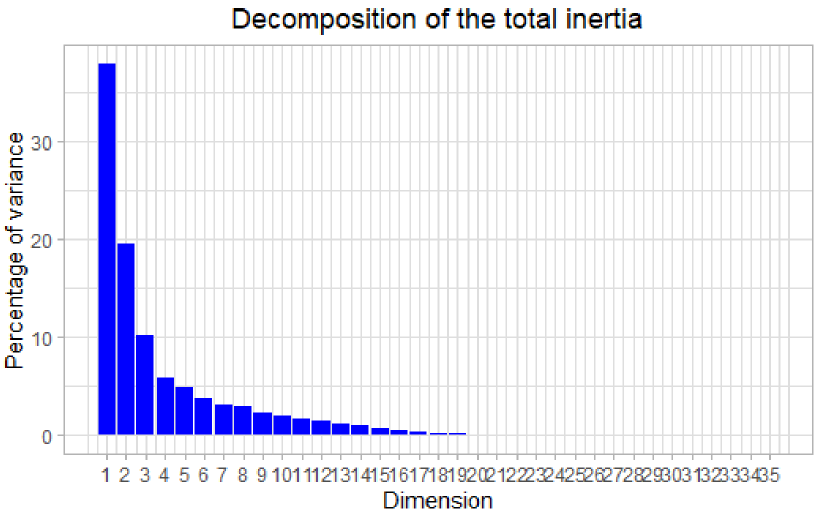


Figure 2 - Decomposition of the total inertia

An estimation of the right number of axis to interpret suggests to restrict the analysis to the description of the first 4 axis. These axis present an amount of inertia greater than those obtained by the 0.95-quantile of random distributions (73.63% against 24.22%). This observation suggests that only these axis are carrying a real information. As a consequence, the description will stand to these axis.

C-3. Description of the plane 1:2

```
PCA.dim1 <- dimdesc(res, axes=c(1))
PCA.dim1[[1]]

## $quanti
##                            correlation      p.value
## Mortality.BAPA               0.9739241 2.090541e-71
## Pct_Mort_BA                  0.9659747 2.947634e-65
## Pct_Mort                     0.9550705 7.299347e-59
## Fall.Recruit.BA              0.9433446 1.464805e-53
## Fallen.BAPA                  0.9432842 1.549044e-53
## Mortality.BA                 0.9382315 1.357384e-51
## Fallen.TPA                   0.9341472 3.860789e-50
## Fallen.Trees                 0.9320490 1.984990e-49
## Fall.Recruit.BAPA            0.9315527 2.901370e-49
## Fall.Recruit.Trees           0.9297749 1.104513e-48
## Site_Pieces                  0.9291101 1.804601e-48
## Mortality.Trees              0.8957494 8.081334e-40
## Mortality.TPA                0.8948060 1.280949e-39
## Fallen.BA                    0.8909090 8.206844e-39
## Fall.Recruit.TPA             0.8666922 2.114378e-34
## Site_Vol_2                   0.8151909 2.269138e-27
## Site_Total_Vol               0.8076485 1.585739e-26
## Fall.Recruit.Trees.GT24DBH   0.3682673 7.547060e-05
## Fall.Recruit.Mean_DBH        0.3566569 1.310453e-04
## IPH.PctConfier               0.3156577 7.818542e-04
## IPH.PctTSHE                  0.2361091 1.301855e-02
## Mortality.QMD                0.2094863 2.806020e-02
## IPH.Richness                -0.1910341 4.559259e-02
## YR3.Live.Trees              -0.2722095 4.016312e-03
## IPH.PctAlru                 -0.3147385 8.115419e-04
## YR3.Live.BAPA               -0.4053203 1.120427e-05
## YR3.Live.BA                 -0.4791593 1.186413e-07
##
## $quali
##                               R2      p.value
## stream_width_category 0.1009678 0.0007178287
##
## $category
##                               Estimate      p.value
## stream_width_category=small  1.162370 0.0007178287
## Dom_Species=ALRU            -1.915633 0.0217056567
## stream_width_category=large -1.162370 0.0007178287
##
## attr(,"class")
## [1] "condes" "list "
```

Contributions to Dimension 2

```
PCA.dim2 <- dimdesc(res, axes=c(2))
PCA.dim2[[1]]
```

```
## $quanti
##                             correlation      p.value
## IPH.Live.TPA                  0.9210420 4.893597e-46
## YR3.Live.TPA                  0.9145430 2.938522e-44
## IPH.Live.Trees                0.9065168 3.010246e-42
## YR3.Live.Trees                0.8853562 1.028477e-37
## IPH.Live.BAPA                 0.6385821 6.127083e-14
## YR3.Live.BAPA                 0.6253401 2.815521e-13
## IPH.PctTSHE                   0.5295969 2.699088e-09
## IPH.PctConfier                0.4816469 9.983310e-08
## Mean_site_Shade2              0.3451533 2.217979e-04
## YR3.Live.BA                   0.3289213 4.506418e-04
## IPH.Live.BA                   0.3029908 1.293240e-03
## Mortality.TPA                 0.3021160 1.337891e-03
## Mortality.Trees               0.2524153 7.806276e-03
## Mean_site_Shade1              0.1973300 3.879676e-02
## Fall.Recruit.Trees.GT24DBH   -0.2433098 1.042764e-02
## Fallen.Mean_DBH              -0.3216413 6.116685e-04
## IPH.PctACMA                  -0.3650350 8.818913e-05
## Mortality.QMD                -0.3930645 2.159997e-05
## IPH.PctAlru                  -0.4146520 6.678416e-06
## IPH.Live.QMD                 -0.7126636 2.506003e-18
## YR3.Live.QMD                 -0.7229278 4.786659e-19
##
## $quali
##                     R2      p.value
## Dom_Species 0.3087272 8.045552e-07
## site_class  0.1565717 4.128612e-04
##
## $category
##                    Estimate      p.value
## Dom_Species=TSHE   2.245029 1.075891e-07
## site_class=V       1.838140 1.047098e-04
## Dom_Species=ACMA -5.177205 1.650490e-02
## site_class=II    -1.107537 4.097711e-03
## Dom_Species=ALRU -1.089292 3.060863e-05
##
## attr(,"class")
## [1] "condes" "list "
```

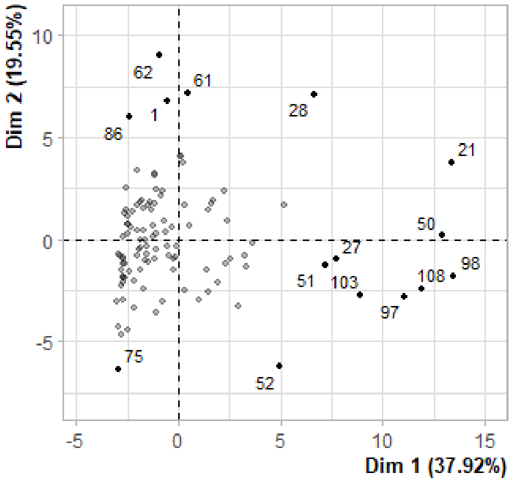


Figure C3.1 - Sites factor map (PCA) *The labeled sites are those with the higher contribution to the plane construction.*

The Wilks test p-value indicates which variable factors are the best separated on the plane (i.e. which one explain the best the distance between sites).

```
##           Dom_Species stream_width_category            site_class
##          5.618514e-06          1.662074e-03          1.868585e-03
##          IZ_treatment
##          9.388365e-01
```

The best qualitative variable to illustrate the distance between sites on this plane is : *Dom_Species*.

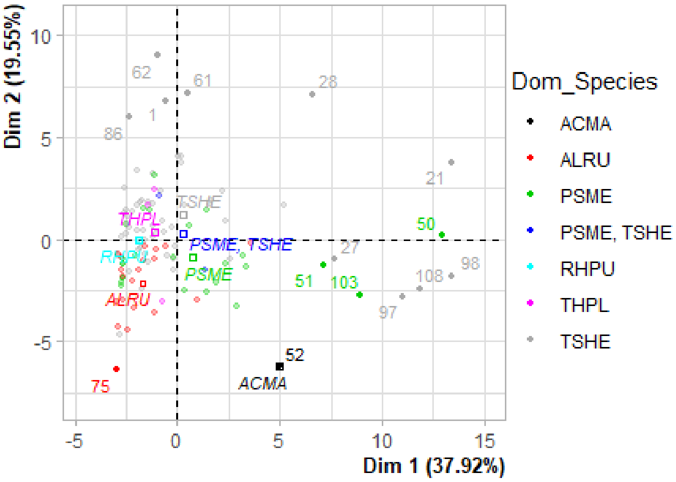


Figure C3.2 - Sites factor map (PCA) *The labeled sites are those with the higher contribution to the plane construction. The sites are coloured after their category for the variable* Dom_Species.

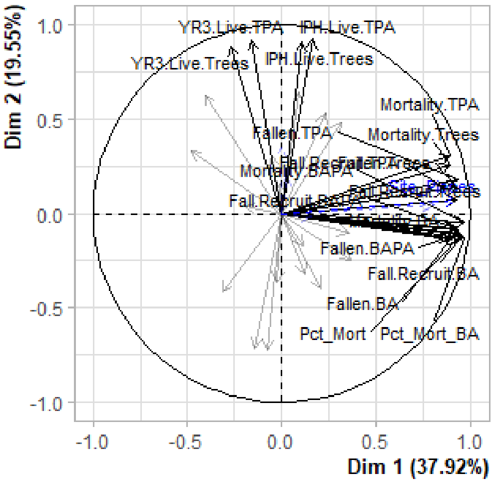


Figure C3.3 - Variables factor map (PCA) *The variables in black are considered as active whereas those in blue are illustrative. The labeled variables are those the best shown on the plane.*

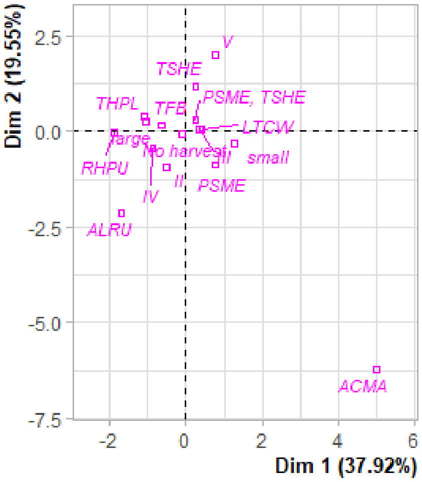


Figure C3.4 - Qualitative factor map (PCA) *The labeled factors are those the best shown on the plane.*

The **dimension 1** opposes sites such as *108*, *103*, *27*, *50*, *21*, *97*, *98* and *51* (to the right of the graph, characterized by a strongly positive coordinate on the axis) to sites such as *62*, *61*, *28*, *1*, *86* and *75* (to the left of the graph, characterized by a strongly negative coordinate on the axis).

The group in which the sites *108*, *103*, *27*, *50*, *21*, *97*, *98* and *51* stand (characterized by a positive coordinate on the axis) is sharing :

- high values for variables like *Fall.Recruit.BA*, *Fall.Recruit.BAPA*, *Pct_Mort_BA*, *Mortality.BAPA*, *Pct_Mort*, *Mortality.BA*, *Fallen.BAPA*, *Site_Pieces*, *Fall.Recruit.Trees* and *Fallen.BA* (variables are sorted from the strongest).
- low values for the variables *YR3.Live.BA*, *YR3.Live.BAPA*, *YR3.Live.Trees* and *YR3.Live.TPA* (variables are sorted from the weakest).

The group in which the individual *75* stands (characterized by a negative coordinate on the axis) is sharing :

- high values for the variables *IPH.Live.QMD*, *YR3.Live.QMD*, *IPH.PctAlru*, *IPH.PctACMA* and *IPH.PctPSME* (variables are sorted from the strongest).
- low values for variables like *IPH.PctTSHE*, *IPH.Live.TPA*, *IPH.Live.BAPA*, *IPH.Live.Trees*, *Mortality.TPA*, *Mortality.Trees*, *YR3.Live.TPA*, *IPH.PctConfier*, *Fallen.TPA* and *Fallen.Trees* (variables are sorted from the weakest).

The group in which the sites *62*, *61*, *28*, *1* and *86* stand (characterized by a negative coordinate on the axis) is sharing :

- high values for variables like *YR3.Live.TPA*, *YR3.Live.Trees*, *YR3.Live.BAPA*, *IPH.Live.Trees*, *IPH.Live.TPA*, *IPH.Live.BAPA*, *IPH.PctTSHE*, *YR3.Live.BA*, *IPH.Live.BA* and *IPH.PctConfier* (variables are sorted from the strongest).
- low values for the variables *YR3.Live.QMD*, *IPH.Live.QMD*, *Mortality.QMD*, *IPH.PctPSME*, *Fallen.Mean_DBH*, *Fall.Recruit.BA* and *Pct_Mort_BA* (variables are sorted from the weakest).

Note that the variables *Mortality.BAPA*, *Pct_Mort* and *Pct_Mort_BA* are highly correlated with this dimension (respective correlation of 0.95, 0.91, 0.93). These variables could therefore summarize themselve the dimension 1.

The **dimension 2** opposes sites such as *62*, *61*, *28*, *1* and *86* (to the top of the graph, characterized by a strongly positive coordinate on the axis) to sites such as *108*, *103*, *27*, *50*, *21*, *97*, *98*, *51* and *75* (to the bottom of the graph, characterized by a strongly negative coordinate on the axis).

The group in which the sites *62*, *61*, *28*, *1* and *86* stand (characterized by a positive coordinate on the axis) is sharing :

- high values for variables like *YR3.Live.TPA*, *YR3.Live.Trees*, *YR3.Live.BAPA*, *IPH.Live.Trees*, *IPH.Live.TPA*, *IPH.Live.BAPA*, *IPH.PctTSHE*, *YR3.Live.BA*, *IPH.Live.BA* and *IPH.PctConfier* (variables are sorted from the strongest).
- low values for the variables *YR3.Live.QMD*, *IPH.Live.QMD*, *Mortality.QMD*, *IPH.PctPSME*, *Fallen.Mean_DBH*, *Fall.Recruit.BA* and *Pct_Mort_BA* (variables are sorted from the weakest).

The group in which the individual *75* stands (characterized by a negative coordinate on the axis) is sharing :

- high values for the variables *IPH.Live.QMD*, *YR3.Live.QMD*, *IPH.PctAlru*, *IPH.PctACMA* and *IPH.PctPSME* (variables are sorted from the strongest).
- low values for variables like *IPH.PctTSHE*, *IPH.Live.TPA*, *IPH.Live.BAPA*, *IPH.Live.Trees*, *Mortality.TPA*, *Mortality.Trees*, *YR3.Live.TPA*, *IPH.PctConfier*, *Fallen.TPA* and *Fallen.Trees* (variables are sorted from the weakest).

The group in which the sites *108*, *103*, *27*, *50*, *21*, *97*, *98* and *51* stand (characterized by a negative coordinate on the axis) is sharing :

- high values for variables like *Fall.Recruit.BA*, *Fall.Recruit.BAPA*, *Pct_Mort_BA*, *Mortality.BAPA*, *Pct_Mort*, *Mortality.BA*, *Fallen.BAPA*, *Site_Pieces*, *Fall.Recruit.Trees* and *Fallen.BA* (variables are sorted from the strongest).

- low values for the variables *YR3.Live.BA*, *YR3.Live.BAPA*, *YR3.Live.Trees* and *YR3.Live.TPA* (variables are sorted from the weakest).

C-4. Description of the plane 3:4

Contributions to Dimension 3

```
PCA.dim3 <- dimdesc(res, axes=c(3))
PCA.dim3[[1]]
```

```
## $quanti
##                              correlation      p.value
## IPH.Live.BA                    0.8135254 3.512338e-27
## YR3.Live.BA                    0.6877300 1.050762e-16
## IPH.Live.BAPA                  0.6133837 1.049868e-12
## IPH.Live.QMD                   0.5509482 4.474426e-10
## YR3.Live.QMD                   0.5387850 1.264815e-09
## Fallen.Mean_DBH                0.5383642 1.310141e-09
## YR3.Live.BAPA                  0.5294501 2.731477e-09
## Mortality.QMD                  0.5058421 1.730729e-08
## IPH.PctTSHE                    0.3274980 4.786653e-04
## IPH.PctConfier                 0.3060064 1.149522e-03
## Fall.Recruit.Trees.GT24DBH     0.2250146 1.810778e-02
## Fallen.BA                      0.2202364 2.078123e-02
## IPH.PctAlru                   -0.3216875 6.104966e-04
##
## $quali
##                                 R2     p.value
## stream_width_category 0.07046301 0.005067501
## IZ_treatment          0.08025373 0.011382559
## Dom_Species           0.13604512 0.017707670
##
## $category
##                                 Estimate     p.value
## stream_width_category=large  0.5048440 0.005067501
## Dom_Species=TSHE             0.4028368 0.005392043
## site_class=V                -0.9499018 0.005490472
## stream_width_category=small -0.5048440 0.005067501
## Dom_Species=ALRU            -1.1693788 0.003818907
## IZ_treatment=No harvest     -0.8065721 0.003799154
##
## attr(,"class")
## [1] "condes" "list "
```

Contributions to Dimension 4

```
PCA.dim4 <- dimdesc(res, axes=c(4))
PCA.dim4[[1]]
```

```
## $quanti
##                             correlation      p.value
## IPH.Richness                  0.5102783 1.236453e-08
## IPH.PctAlru                   0.4420069 1.336608e-06
## IPH.PctTHPL                   0.4317202 2.488336e-06
## IPH.PctACMA                   0.4269388 3.299010e-06
## Fall.Recruit.Trees.GT24DBH    0.3614365 1.046833e-04
## Fall.Recruit.Mean_DBH         0.3071294 1.099833e-03
## Fallen.Mean_DBH               0.2834663 2.692149e-03
## Mortality.QMD                 0.2051755 3.153559e-02
## YR3.Live.TPA                  0.1953475 4.083859e-02
## IPH.PctConfier               -0.5358267 1.618432e-09
## IPH.PctPSME                  -0.6631247 2.958060e-15
##
## $quali
##                               R2      p.value
## Dom_Species           0.54306035 1.299644e-15
## IZ_treatment          0.18005037 2.441258e-05
## stream_width_category 0.03513056 4.990757e-02
##
## $category
##                                Estimate      p.value
## Dom_Species=ALRU              0.4708686 9.954865e-07
## IZ_treatment=No harvest       0.5942157 3.703103e-05
## Dom_Species=ACMA              3.9055739 6.673103e-04
## Dom_Species=THPL              1.2035076 1.020669e-02
## stream_width_category=large   0.2706750 4.990757e-02
## stream_width_category=small  -0.2706750 4.990757e-02
## IZ_treatment=LTCW            -0.8022668 5.681757e-06
## Dom_Species=PSME             -2.2556546 9.155691e-09
##
## attr(,"class")
## [1] "condes" "list "
```

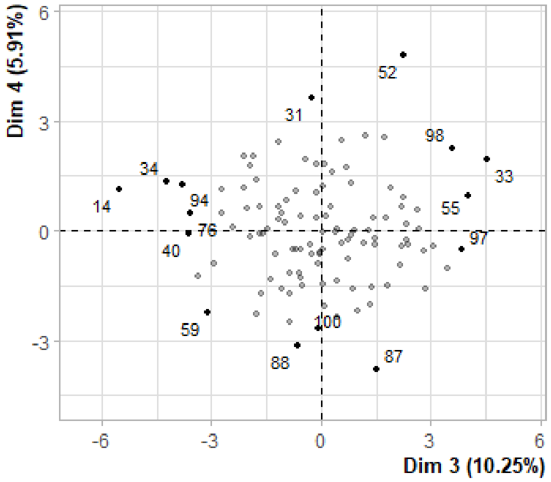


Figure C4.1 - Sites factor map (PCA) *The labeled sites are those with the higher contribution to the plane construction.*

The Wilks test p-value indicates which variable factors are the best separated on the plane (i.e. which one explain the best the distance between sites).

```
##          Dom_Species          IZ_treatment stream_width_category
##         5.556405e-15          2.737437e-06          2.553394e-03
##           site_class
##         4.302073e-02
```

The best qualitative variable to illustrate the distance between sites on this plane is : *Dom_Species*.

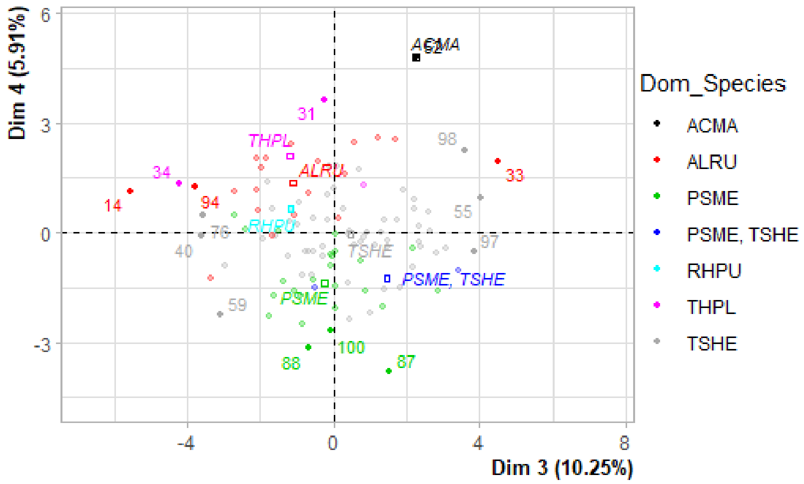


Figure C4.2 - Sites factor map (PCA) *The labeled sites are those with the higher contribution to the plane construction. The sites are coloured after their category for the variable* Dom_Species.

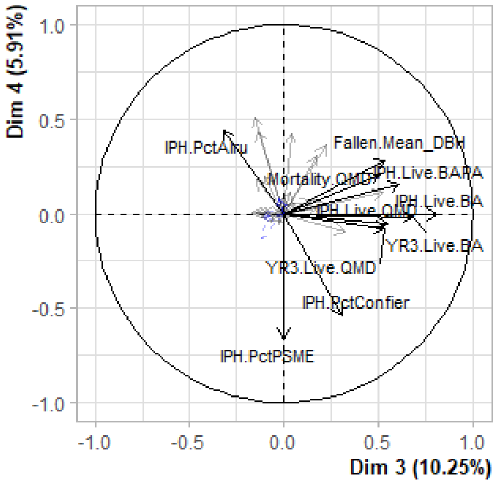


Figure C4.3 - Variables factor map (PCA) *The variables in black are considered as active whereas those in blue are illustrative. The labeled variables are those the best shown on the plane.*

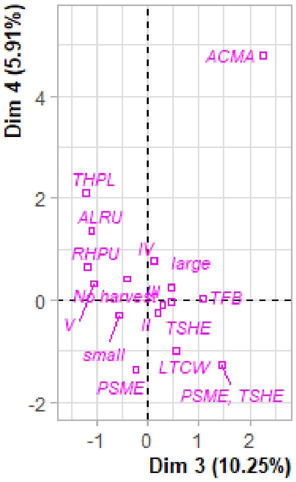


Figure C4.4 - Qualitative factor map (PCA) *The labeled factors are those the best shown on the plane.*

The **dimension 3** opposes sites such as *55* and *33* (to the right of the graph, characterized by a strongly positive coordinate on the axis) to sites such as *94*, *14*, *76*, *34*, *40* and *31* (to the left of the graph, characterized by a strongly negative coordinate on the axis).

The group in which the sites *55* and *33* stand (characterized by a positive coordinate on the axis) is sharing :

- high values for variables like *IPH.Live.BAPA*, *IPH.Live.BA*, *YR3.Live.BAPA*, *YR3.Live.BA*, *IPH.PctTSHE*, *Fallen.Mean_DBH*, *Mortality.QMD*, *IPH.Live.QMD*, *YR3.Live.QMD* and *Fallen.BAPA* (variables are sorted from the strongest).
- low values for the variable *IPH.PctPSME*.

The group in which the sites *94*, *14*, *76*, *34*, *40* and *31* stand (characterized by a negative coordinate on the axis) is sharing :

- high values for the variables *IPH.PctAlru*, *IPH.Richness* and *IPH.PctTHPL* (variables are sorted from the strongest).
- low values for variables like *IPH.PctConfier*, *IPH.Live.BA*, *YR3.Live.BA*, *YR3.Live.QMD*, *IPH.Live.QMD*, *IPH.Live.BAPA*, *YR3.Live.BAPA*, *IPH.PctPSME*, *IPH.PctTSHE* and *Mortality.BA* (variables are sorted from the weakest).

The **dimension 4** opposes sites such as *94*, *14*, *76*, *34*, *40* and *31* (to the top of the graph, characterized by a strongly positive coordinate on the axis) to sites such as *59*, *87*, *88* and *100* (to the bottom of the graph, characterized by a strongly negative coordinate on the axis).

The group in which the sites *94*, *14*, *76*, *34*, *40* and *31* stand (characterized by a positive coordinate on the axis) is sharing :

- high values for the variables *IPH.PctAlru*, *IPH.Richness* and *IPH.PctTHPL* (variables are sorted from the strongest).
- low values for variables like *IPH.PctConfier*, *IPH.Live.BA*, *YR3.Live.BA*, *YR3.Live.QMD*, *IPH.Live.QMD*, *IPH.Live.BAPA*, *YR3.Live.BAPA*, *IPH.PctPSME*, *IPH.PctTSHE* and *Mortality.BA* (variables are sorted from the weakest).

The group in which the sites *59*, *87*, *88* and *100* stand (characterized by a negative coordinate on the axis) is sharing :

- high values for the variables *IPH.PctPSME* and *IPH.PctConfier* (variables are sorted from the strongest).
- low values for the variables *IPH.Richness*, *IPH.PctAlru*, *YR3.Live.TPA*, *YR3.Live.Trees* and *IPH.Live.TPA* (variables are sorted from the weakest).

C-5. Classification

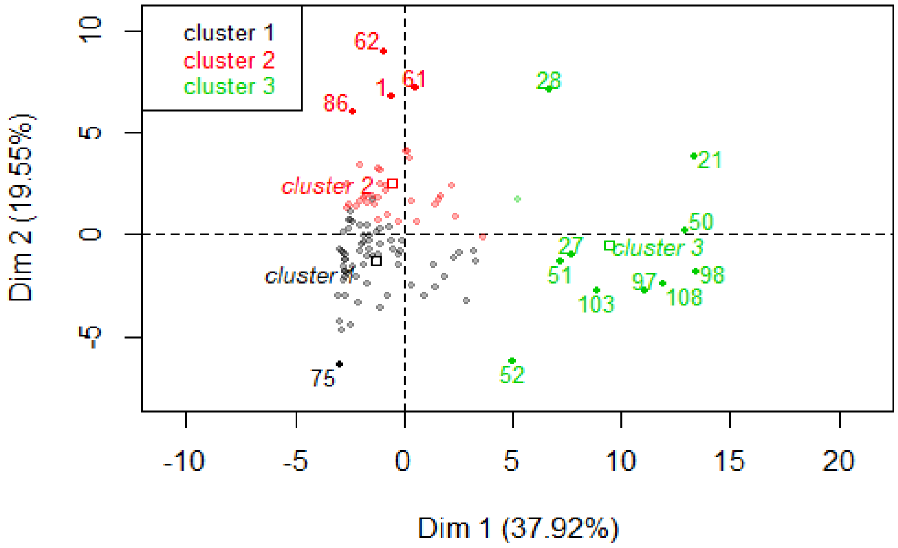


Figure C5-1 - Ascending Hierarchical Classification of the sites. *The classification made on sites reveals 3 clusters.*

The **cluster 1** is made of sites such as *75*. This group is characterized by :

- high values for the variables *IPH.Live.QMD*, *IPH.PctAlru*, *YR3.Live.QMD* and *IPH.Richness* (variables are sorted from the strongest).
- low values for variables like *IPH.Live.TPA*, *IPH.Live.BAPA*, *IPH.Live.Trees*, *Mortality.TPA*, *Mortality.Trees*, *IPH.PctTSHE*, *YR3.Live.TPA*, *Fallen.TPA*, *Fallen.Trees* and *YR3.Live.Trees* (variables are sorted from the weakest).

The **cluster 2** is made of sites such as *1*, *61*, *62* and *86*. This group is characterized by :

- high values for variables like *YR3.Live.Trees*, *IPH.Live.Trees*, *YR3.Live.BAPA*, *YR3.Live.TPA*, *IPH.Live.BAPA*, *IPH.Live.TPA*, *YR3.Live.BA*, *IPH.Live.BA*, *IPH.PctTSHE* and *IPH.PctConfier* (variables are sorted from the strongest).
- low values for the variables *YR3.Live.QMD*, *IPH.Live.QMD*, *IPH.PctAlru* and *Mortality.QMD* (variables are sorted from the weakest).

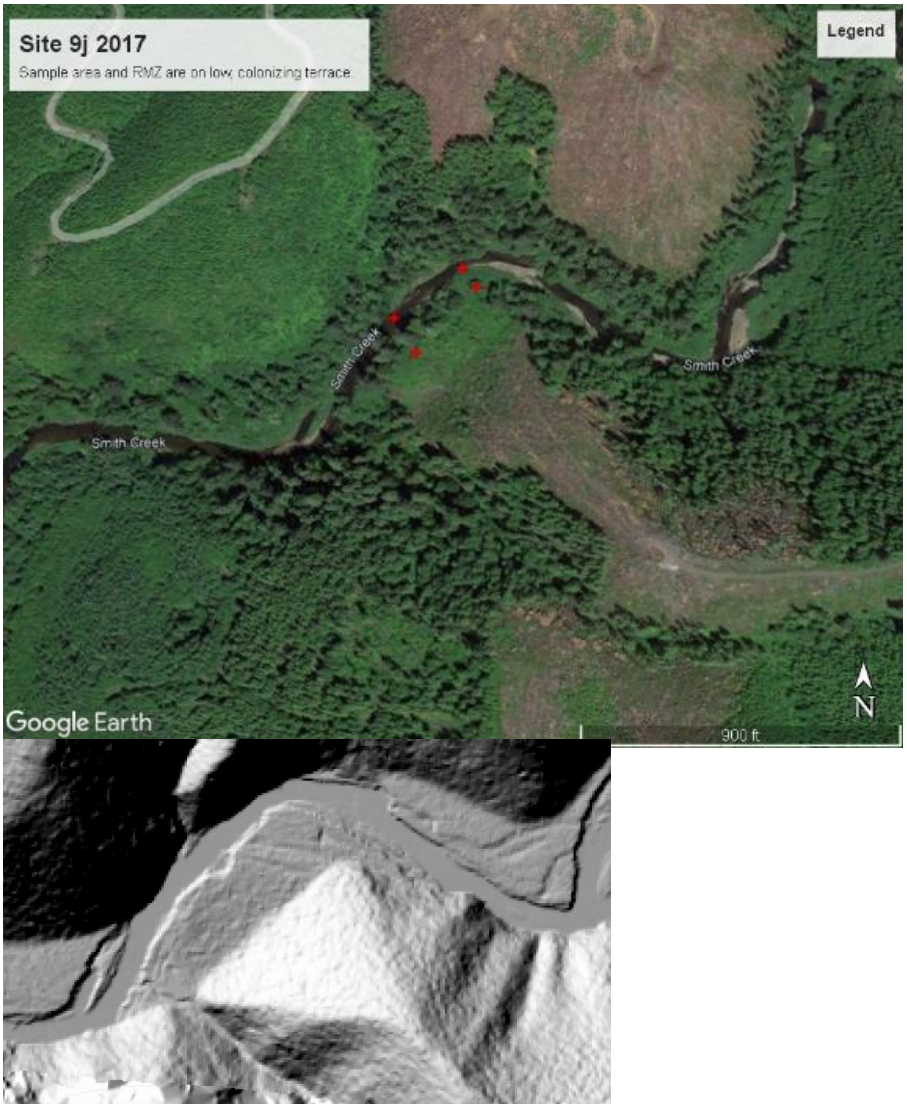
The **cluster 3** is made of sites such as *21*, *27*, *28*, *50*, *51*, *52*, *97*, *98*, *103* and *108*. This group is characterized by :

- high values for variables like *Fall.Recruit.BAPA*, *Fall.Recruit.BA*, *Fall.Recruit.Trees*, *Site_Pieces*, *Fall.Recruit.TPA*, *Mortality.BAPA*, *Pct_Mort_BA*, *Fallen.BAPA*, *Fallen.TPA* and *Pct_Mort* (variables are sorted from the strongest).
- low values for the variables *YR3.Live.BA*, *YR3.Live.BAPA*, *YR3.Live.Trees* and *IPH.PctAlru* (variables are sorted from the weakest).

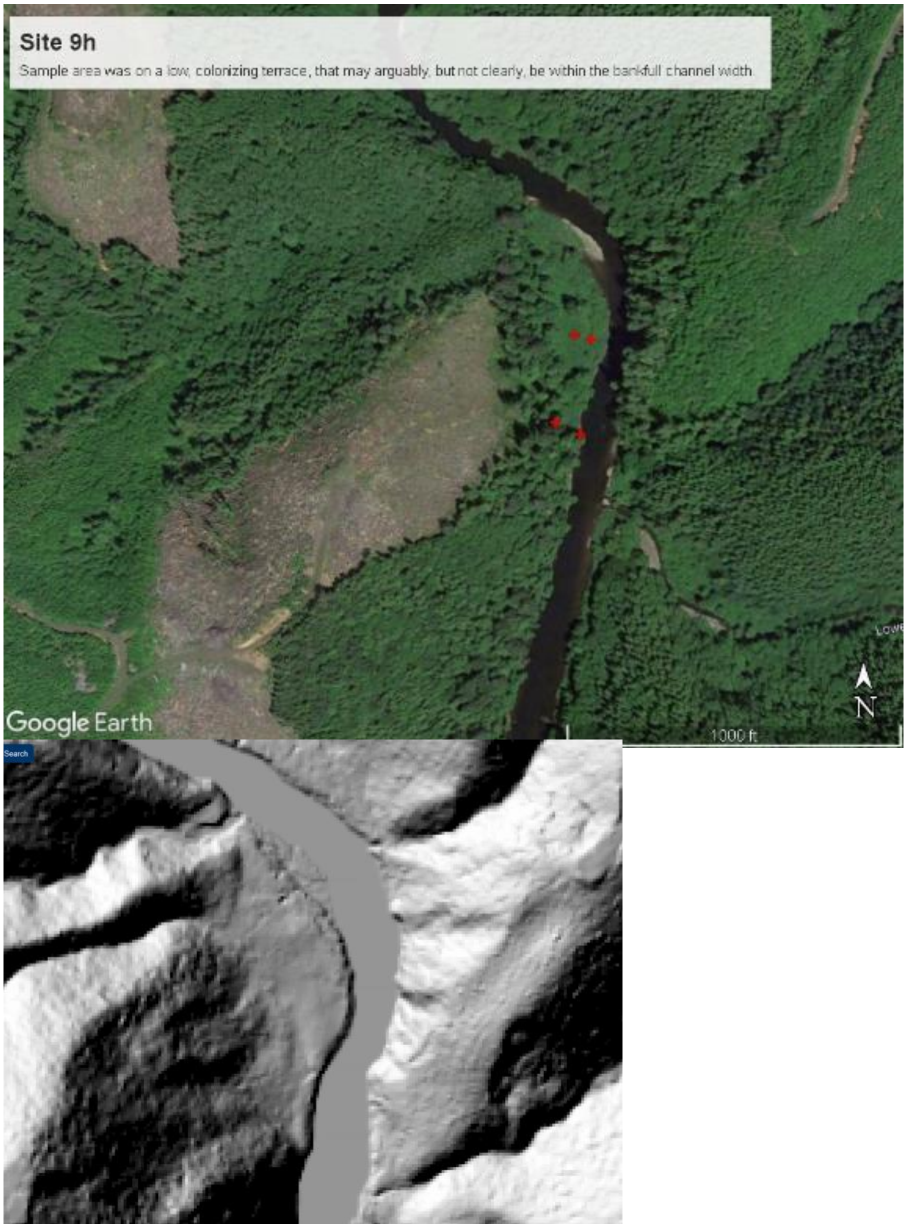
Appendix D. Aerial Photos of Sites on Type S Streams

The three sites on large (>35m) Type S streams. The first two have low shade values and poor DFC projections. However, the second site, 9h, has a more functional RMZ harvest buffer behind the sampled area. The difference in the layouts is likely the result of differing methods of determining the edge of the bankfull channel. The third large Type S site has an effective buffer that consists of mixed conifer and deciduous species. Our randomly-selected sample locations happened to be on portions that has little or no conifers.

The last photo is of a Type S site on a smaller Type S channel of approximately 20m wide. This buffer meets all functional targets, had no mortality, and appears likely to be a long-term source for stream shade and effective large wood recruitment as the RMZ trees continue to grow. Note that shade functionality was assessed in this study using canopy cover measured at stream bank edge and looking into buffer. Therefore, it does not evaluate the total stream shading at those locations and does not account for stream width.


Site 9j 2017
Sample area and RMZ are on low, colonizing terrace
Legend
Smith Creek
Smith Creek
Smith Creek
Google Earth
900 ft
N

Site 9j


Site 9h

Sample area was on a low, colonizing terrace, that may arguably, but not clearly, be within the bankfull channel width

Site 9h – The FPA map shows the entire area between channel streamline and harvest area as RMZ. However, the harvest plan indicates only a 110’ RMZ buffer, which appears to be upslope of the sampled area. This suggests a discrepancy between this study’s channel edge determination and that of the harvest layout forester.

Site 6c – Buffer on large (50m) channel that meets targets.

Site 10i - Example of Type S site on smaller Type S channel (~20m)