Influence of Harvesting on Riparian Stand Structure and Function in Western Oregon

Oregon Department of Forestry
Technical Report #21

September 2020

Adam Coble and Marganne Allen

Table of Contents

Executive Summary

In 2002, the Oregon Department of Forestry initiated an extensive field study, the Riparian Function and Stream Temperature (RipStream) study throughout the Oregon Coast Range to examine the effectiveness of the Oregon Forest Practices Act (FPA) stream protection rules and State Forest's stream management strategies in protecting stream temperature and promoting riparian structure that provides necessary functions for the protection of fish and wildlife habitat. Study sites were established along small and medium fish-bearing streams on private and state forest land in the Coast Range and Interior geographic regions across a latitudinal gradient from Astoria to Coos counties. Data analyzed in this report primarily focuses on measurements made on private land that include metrics associated with overstory and understory riparian vegetation, downed wood in the riparian areas, and large wood in streams. We compared results against the FPA goals for minimum stocking requirements and desired future conditions (DFC) in riparian management areas (RMA).

Our results show that riparian stands were, on average, 38 years old at breast height at the time of the pre-harvest data collection and likely became established from the late 1950s through the early 1970s. Prior to harvesting, most stands were conifer-dominated or mixed conifer-hardwood stands, where red alder was the most common hardwood species and Douglas-fir and western hemlock were the most common conifer species. In the understory, western hemlock, red alder, and bigleaf maple seedlings and saplings, and short stature trees, such as cascara buckthorn, were more common than other species. Shrub species primarily consisted of vine maple, salmonberry, and red huckleberry. The number of downed wood pieces and total downed wood volume inside and outside of the FPA RMAs was dominated by more-decayed logs (e.g., decay classes 3, 4, and 5). In streams, large wood was mostly comprised of small diameter (5-18 in), shorter (5-20 ft) pieces.

The degree of harvesting in the RMA was primarily associated with pre-harvest conifer basal area due to FPA rules (e.g., greater conifer basal area allows for more harvesting). Harvesting tended to target smaller diameter western hemlock and Douglas-fir (6-22 in) near the edges of the RMAs furthest from the stream. There was little evidence for harvesting of large diameter conifers (>36 in) and hardwoods, though the relative proportion of large diameter conifers was low. Seedling density of western hemlock, Douglas-fir, Sitka spruce, and western red cedar decreased from pre-harvest to year 1 post-harvest; however, density returned to pre-harvest values by year 3 post-harvest for these species, except for western red cedar. Due to high variability of seedling density across species, we did not detect changes in total conifer seedling density over time. Vine maple and salmonberry displayed different responses to harvesting. Vine maple experienced large decreases outside of the RMA, likely due to herbicide application or mechanical removal, while salmonberry cover did not change in response to harvesting, which may be associated with its ability to quickly reproduce asexually through rhizomes and aerial shoot sprouting following disturbance. Other shrub species, such as red huckleberry, also experienced decreases in cover following harvesting.

As a result of harvesting and subsequent generation of slash, we observed an increase in downed logs per acre for the less-decayed pieces outside of the RMA along small and medium streams. Total volume of the more-decayed wood decreased outside of the RMA along medium streams and inside the RMA along small streams. Large wood in streams increased from pre-harvest to 3 years post-harvest in both control and treatment reaches. While the source of large wood in streams was not explicitly measured in this study, our results show similarities between

wind throw in the RMA and large wood in streams in terms of short-term and similar increases over time in control and treatment reaches. Understanding the effects of additional contributing factors on large wood recruitment such as debris flows, landslides of local hillslopes, streambank erosion (and tree undercutting), and natural mortality requires further study.

Assumptions regarding site index for the Coast Range appear to be valid for conifer species growing in the RMAs. When basal area targets for the FPA rules were originally developed, site index was a key variable used to determine stand growth over time and subsequently, defining average mature conditions. Conifer-dominated and mixed-conifer-hardwood stands appear to be at a good starting point for achieving mature conditions as described in the FPA. However, given the short time span of this study, additional field work and analysis such as modeling stand growth and large wood recruitment will be appropriate for testing FPA assumptions related to long-term changes in riparian stand conditions and large wood recruitment. Furthermore, comprehensive literature reviews of riparian stand structure, regeneration, and large wood recruitment and retention will provide additional insight into the effectiveness of the FPA rules in achieving the goals for DFC and large wood in streams.

Introduction

Riparian forests in the Pacific Northwest provide many valuable functions for both wildlife and fish habitat (Naiman et al. 2000, Sarr et al. 2005). Stand structure and species composition of riparian forests influence important functions for natural resources including aquatic large wood recruitment for fish habitat, shade for regulating stream temperature, downed wood and snags for wildlife habitat, and regeneration of understory shrubs that provide food and nesting resources for bird species. Regulations that promote functional outcomes that are similar to mature forests are desirable for providing many of these benefits into the future.

The Forest Practices Act (FPA) water protection rules[1] on vegetation retention were designed to produce desired future conditions (DFC) for riparian stands along streams in Oregon. Crafted in 1994, the goal of DFC of riparian stands along fish use streams is to grow and retain vegetation so that, over time, average conditions across the landscape become similar to mature streamside stands. In the FPA, mature stands are characterized as often being dominated by conifer trees, 80-200 years of age that provide ample shade over the stream channel, an abundance of large wood in the channel, root masses along edge of channel, snags, and regular inputs of nutrients through litter fall[2].

In 2002, the Oregon Department of Forestry (ODF) initiated the Riparian Function and Stream Temperature (RipStream) study throughout the Oregon Coast Range. The study objectives were to evaluate the effectiveness of FPA rules in protecting stream temperature and promoting riparian structure that provides the necessary functions for the protection of fish and wildlife habitat. . Previous RipStream analyses (e.g., reports, analysis, and peer-reviewed publications) focused on harvesting effects on stream temperature and shade, as well as meeting state water quality standards (e.g., Dent et al. 2008, Groom et al. 2011, Davis et al. 2015, Groom et al. 2018, Arismendi and Groom 2019). This phase of the RipStream analyses will assess riparian stand structure, understory vegetation, downed wood, and large wood in stream. This analysis is one component of the larger project, Western Oregon Streamside Protections Review, which will also include literature reviews on DFC and large wood, as well as modeling analyses that will project stand conditions and large wood recruitment over time. The goal of the Western

---

[1] OAR 629, Division 642

[2] OAR 629-642-0000(2)

Oregon Streamside Protections Review is to evaluate the effectiveness of the FPA rules in achieving the goals for DFC[3] and large wood.

For the RipStream field data analysis, the following questions from the original RipStream proposal (Oregon Department of Forestry 2003) will serve as a guide for the analysis:

- What are the trends in overstory and understory riparian characteristics?
- What are the trends in riparian area regeneration?
- Are the riparian rules and strategies effective in maintaining large wood recruitment to streams, and downed wood in riparian areas?

Since the RipStream study occurred over a period of seven years (e.g., maximum 5 years post-harvest), we recognize that the RipStream analysis is limited in addressing questions related to long-term processes such as large wood recruitment to streams and forest successional pathways. Also, disturbance processes such as landslides, debris torrents, or beaver dams are not included and are out of scope for this analysis. Windthrow that occurred during the study will be described as necessary to provide full transparency, as well as understanding potential sources of large wood recruitment to streams.

Oregon Administrative Rules on Vegetation Retention and Assumptions

FPA rules[4] require vegetation retention prescriptions that include widths of riparian management areas (RMAs) and basal area (BA) targets. Briefly, RMA widths are 50 and 70 feet (slope distance) for small and medium fish-bearing (Type F) streams, respectively, with a 20-foot no cut zone adjacent to the stream (Fig. 1a). Due to the timing of this study (e.g., early to mid-2000s), this study does not include Type SSBT[5] (i.e., salmon, steelhead, and bull trout) streams that have RMA widths of 60-80 feet. Based on current prescriptive rules on vegetation retention in the FPA, the amount and size of conifers in the riparian management area (RMA) ultimately determines what can be harvested[6]. For example, if the conifer basal area within the RMA is above the standard target prior to harvesting, the landowner can harvest conifers, while keeping the basal area at or above the standard target (Rule 6a; Fig. 1b). Ten percent of the basal area can include snags (> 30 ft in height) and hardwoods (> 24 in DBH), not including red alder.

If the conifer basal area within the RMA is below the standard target and above ½ the standard target, the landowner shall retain all conifers greater than 6 inches DBH (Rule 6b). If below ½ the standard target, the landowner shall retain all conifers in the RMA and hardwoods within 20 feet of small streams and 30 feet of medium streams (Rule 6c). An underlying assumption of these prescriptions is that managing riparian forests consistent with the prescriptive rules will result in the beneficial outcomes of providing ample shade to streams and maintaining an abundance of large wood in streams.

---

[3] OAR 629-642-0000(2)

[4] OAR 629-635-0310 & 629-642-0100; Effectiveness of rules related to salmon, steelhead, and bull trout (SSBT) were not evaluated in this study since these rules were not in place during the study.

[5] OAR 629-642-0105

[6] OAR 629-642-0100 (6a, 6b, & 6c)

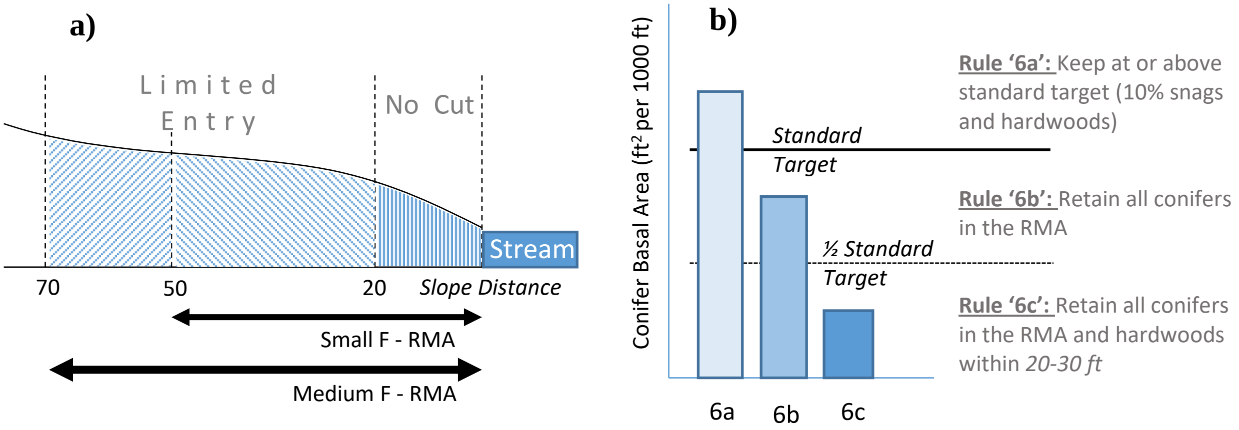

Figure 1. Diagrams of current prescriptive rules on riparian buffer widths (a) and vegetation retention (b) for small and medium fish-bearing streams.

The basis for the current FPA basal area targets is described in Lorensen et al. (1994). The basal area of 'average mature conditions' (e.g., upper red line in Fig. 2) is based on a fully-stocked, unmanaged Douglas-fir stand at age 120 with an assumed site index, while also accounting for reductions in stand basal area due to disturbance, mortality, and limitations to stocking associated with areas of limited tree growth (i.e., rocky or wet soils). For example, Figure 2 shows as assumed conifer basal area of ~256 ft^2 per 1000 ft of stream for average mature conditions along medium, fish-bearing streams. Lorensen et al. (1994) assumed that the average basal area of mature stand conditions (Fig. 2) could be achieved across the landscape if stands were on a 50 year rotation and the stand basal area was reduced to the standard target at the end of each rotation. In theory, conifer basal area increases following each harvest throughout the rotation. Average mature conditions are achieved at the midpoint of the rotation (Fig. 2), and over the course of the 50-year rotation, the average basal area is equal to the basal area of average mature conditions. Lorensen et al. (1994) did not specify large wood targets, but laid out a framework by which average basal area of conifer species over time mimics those associated with mature stands. They hypothesize that this approach will produce similar outcomes for large wood, water quality and other parameters. Neither current FPA rules nor Lorensen et al. (1994) explicitly describe or define 'across the landscape'. Lorensen et al. (1994) stated that a large proportion of streamside areas historically supported stands of mature age classes across the landscape, but were predominantly in younger age classes at the time the report was completed (e.g., 1994). Lorensen et al. (1994) also noted that the average landscape conditions is composed of riparian stands with a variety of conifer basal area with an average basal area that equals the average mature conditions.

In estimating an appropriate standard target, Lorensen et al. (1994) first estimated the average mature conditions for unmanaged, mature stands and then used stand growth rates derived from the Stand Projection System model (Arney 1985) to estimate a basal area at the start of the rotation. Basal area at the start of the rotation, or BA target, would be a necessary starting point to achieve mature stand conditions at mid-rotation. Finally, Lorensen et al. (1994) also assumed that ingrowth (e.g., basal area of reproduction during the next rotation) would contribute up to 25% of the large wood delivery to medium streams during the rotation. Therefore, the conifer basal area targets for medium streams was further reduced by 25%. For small streams, greater credit (75%) was given to ingrowth for large wood recruitment.

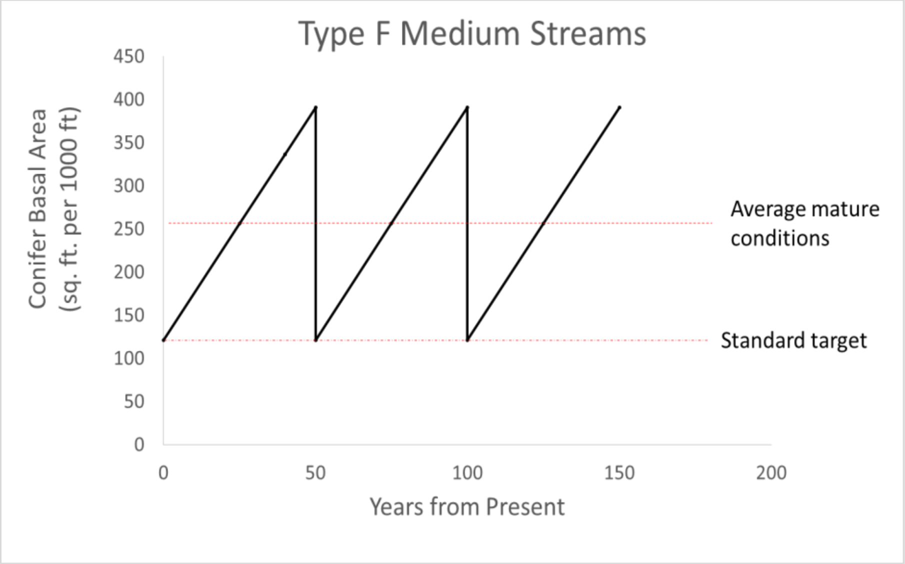

Figure 2. Conceptual diagram as adapted from Lorensen et al. (1994) that shows the conifer basal for a fully stocked, upland Douglas fir stand at the start, midpoint, and end of a 50-year rotation. This is repeated three times in this diagram.

Methods

Study Sites

The RipStream study occurred from 2002 to 2010 at 33 sites in the Oregon Coast Range and Interior geographic region (Fig. 3; Dent et al. 2008, Groom et al. 2011). Dent et al. (2008) described the site selection process and criteria used to select stream reaches. Briefly, all private and state forest managers in the Oregon Coast Range were asked to provide a list of stream reaches that were to be harvested based on a list of criteria (Dent al. 2008). A total of 36 sites were selected from an initial list of 130 sites based on design constraints. Due to the study design constraints, a random sample of sites was not possible. Three sites were later excluded due to a lack of harvesting that occurred during the post-harvest period. All participating landowners and forest managers were asked to harvest to the minimum basal area targets in the RMA as described in the section above. Study sites were along small and medium fish-bearing streams on privately-owned and state forests sites (18 and 15 sites, respectively). In this report, the analysis primarily includes data analysis of privately-owned sites with a few exceptions that included

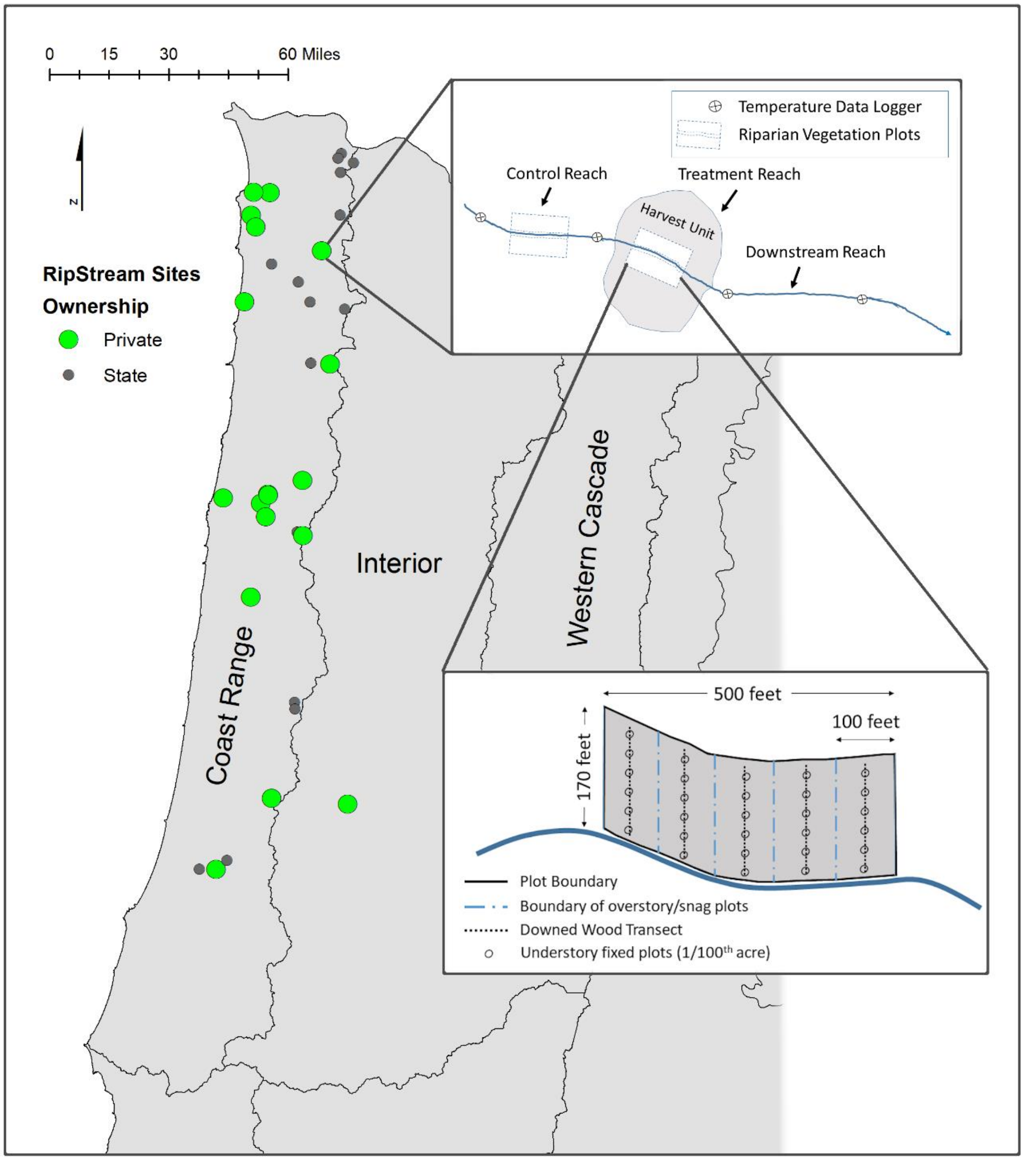

Figure 3. Study sites for private and state forest land in the Oregon Coast Range and Interior geographic regions (left panel). Reach delineation and riparian plot layout are also shown (upper right panel). Temperature data loggers are the endpoints of each reach (e.g., control, treatment, and downstream). At most sites, the harvest unit surrounded the riparian plots on both sides of the stream as shown in the upper right panel. At sites where the harvest unit surrounded riparian plots on only one side, the treatment plot outside the harvest unit was not be sampled. Details of plot boundary, boundary of overstory and snag plots, downed wood transect, and understory fixed plots (1/100th acre) are shown in the lower right panel.

state forest land (e.g., analysis on site index). Riparian forests at the study sites (i.e., state and private) were mostly dominated by Douglas-fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) (Dent et al. 2008). Other common species included western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), bigleaf maple (*Acer macrophyllum*), pacific silver fir (*Abies amabilis*), western red cedar (*Thuja plicata*), and noble fir (*Abies procera*).

Each study site contained three reaches: 1) an upstream, control reach; 2) a treatment reach adjacent to the harvest unit; and 3) a reach immediately downstream of the treatment reach (Fig. 3). Reach lengths across all sites ranged from 1722 to 5801 feet with a mean reach length of 1340 feet. Vegetation data collection occurred along the control and treatment reaches, and large wood and channel data collection occurred along the three reaches. RMAs and upland forests along the control reaches were not harvested throughout the study period, and the harvest unit surrounding the treatment reach RMA was thinned or clear-cut no sooner than two years following the start of the study. Both treatment and control reaches contained at least one vegetation plot each, and most reaches had two plots located on opposing sides of the streams. Each site had a total of two to four plots and always had at least one control and one treatment plot.

Vegetation plot measurements

Plots along the treatment reach were used to survey pre- and post-harvest overstory and understory vegetation (Fig. 3). All plots along the control reach were used to survey pre-harvest overstory and understory conditions, but not for post-harvest years (details described below). The harvest unit surrounded plots on both sides of the stream at 14 sites. The harvest unit occurred on one side of stream at the remaining 4 sites. In this case, data were collected at the one treatment plot that was adjacent to the harvest. Thus, there were 32 vegetation plots in total. Each plot (500 x 170 feet) included five transects running perpendicular to the valley azimuth spaced 100 feet apart. Six equally-spaced circular subplots (1/100th acre) were established along each transect at 25-foot intervals (horizontal distance) for understory vegetation measurements (Fig. 3).

For overstory trees, a 100% cruise was conducted for all trees greater than 6 inches in diameter at breast height (DBH) within each plot. Measurements included horizontal distance to stream, DBH, species, and live tree vs. snag. Horizontal distance was converted to slope distance for overstory trees. Measurements for all overstory trees were made on all 32 treatment and control plots during pre-harvest and all 32 treatment plots post-harvest year 1. Overstory measurements were made on 22 control plots post-harvest year 1. Overstory measurements were also made for 12 plots (e.g., 6 sites) during post-harvest year 5. In post-harvest year 1 and for 12 plots in post-harvest year 5, the presence of blowdown trees were recorded as well as the DBH, species, and horizontal distance from streams of the blowdown trees. For a subset of trees, tree height was measured for three trees per species in each plot. Tree age at breast height, hereinafter referred to as 'age', was also determined for a subset of trees using an increment borer and visually estimating age in the field. Tree height and age were measured during pre-harvest.

We observed measurement error associated with slope distance to stream, which was evident in a preliminary analysis that observed positive and negative changes in stand density within 20 feet of the stream (i.e., no-cut zone) from pre- to post-harvest. In a separate analysis, we examined potential reasons why this may be occurring. It was clear that the field technicians binned slope distance in increments of 5 feet and there appeared to be a general trend of a greater number of trees binned at 25-foot intervals. The binning of trees into intervals of slope distances may explain the measurement error described above. Our analysis indicated that field technicians were having some difficulty assigning an exact distance value to individual trees.

Understory vegetation included small trees (<6 inches DBH), shrubs, and forbs. Tree height, DBH, species, and live crown ratio was measured for all small trees in the circular subplots. Number of layers, species, percent cover, and average height was recorded for shrubs and forbs. Percent cover is a measure of the percentage of the ground covered by a species. Measurements for understory vegetation were made on all plots during pre-harvest year 1 and post-harvest year 1. Additionally, understory measurements were made for most sites during post-harvest year 3 and a few plots for post-harvest year 5. Budget reductions associated with the 2008 recession resulted in fewer plots with the full suite of measurements five years after harvest.

Terrestrial Downed Wood and Aquatic Large Wood Measurements

Along each transect (Fig. 3), measurements were made on downed wood that crossed the transect line with a diameter greater than 6 inches and a length greater than 3 feet. Species were recorded for downed wood when possible, or ‘unknown conifer’ or ‘unknown hardwood’ were recorded. The intercept diameter (e.g., diameter where log crossed transect line), small end diameter (D_S), large end diameter (D_L), length (l), decay class, and distance from channel were recorded for each piece of downed wood. Decay classes (1-5) that represent the physical decomposition characteristics for each downed wood piece are described in more detail in Table 1. In our analysis, we group decay classes 1 and 2 (herein referred to as ‘less decayed’) and decay classes 3, 4 and 5 (herein referred to as ‘more decayed’).

The volume (ft^3) of each downed log was calculated using the equation (Waddell 2002):

$$\boldsymbol{Log\ volume = \frac{(\pi/_8)(D_S^2 + D_L^2)l}{144}} \qquad (1)$$

For each plot, we estimated the number of logs per acre and wood volume ($ft^3\ acre^{-1}$) of downed wood in the RMA and outside of the RMA using the equations (after Waddell 2002):

$$\boldsymbol{Logs\ per\ acre = (\pi/_{2L})(1/_l)f} \qquad (2)$$

$$\boldsymbol{Wood\ volume\ per\ acre = (\pi/_{2L})(V_{log}/_l)f} \qquad (3)$$

where L is the total transect length (horizontal distance) and f is a factor to convert to a per-acre value ($f = 43{,}560$). Wood volume per acre was calculated for each piece of downed wood and summed within the RMA and outside the RMA for each plot. Since RMA widths are a slope distance on private land, we converted slope distance to a horizontal distance for each transect in the study to estimate L (horizontal distance) within and outside of the RMA.

Table 1. Description of wood decay classes and descriptions from the RipStream field study protocol (Oregon Department of Forestry 2002).

Decay class	Bark	Twigs	Texture	Shape	Wood Color	Portion of log on the ground
1	Intact	Present	Intact	Round	Original	None, elevated on supporting points
2	Intact	Absent	Intact to soft	Round	Original	Parts touch, still elevated
3	Trace	Absent	Hard large pieces	Round	Original to faded	Bole on ground
4	Absent	Absent	Soft blocky pieces	Round to oval	Light to faded brown	Partially below ground
5	Absent	Absent	Soft, powdery	Oval	Faded light yellow or gray	Most below ground

Aquatic large wood measurements occurred at all sites pre-harvest, post-harvest year 1, and post-harvest year 3 within the control, treatment, and downstream reaches (Fig. 3). Reaches were further divided into segments. Most (95%) segments were 200 feet in length, and the range of segment-length was 50 to 400 feet. At each segment, large wood within and above the channel were tallied for 5 diameter classes (5-10, 11-18, 19-24, 25-36, and >36 inches) and 4 length classes (5-10, 11-20, 21-30, and >30 feet). The zone of each piece of aquatic large wood was also recorded. Zone 1 included the bottom of the stream channel to the bankfull stage, and Zone 2 included bankfull stage to 6 feet above the bankfull stage. For log jams, the length, width, and height of each wood jam was measured and multiplied to calculate the total wood jam volume. It is worth noting that wood jam volume is not the same as wood volume since the former includes air space.

Statistical Analysis

Statistical analyses were conducted using R 3.5.2 statistical software (R Core Team 2019) and consisted of both descriptive statistics (e.g., percentages and means) and statistical tests. Relationships between tree age and height (e.g., site index) were examined using non-linear regression. The primary statistical analysis included linear mixed-effects models to test treatment effects on a number of parameters including stand basal area, tree density, downed wood in the RMA (e.g., log density and volume), and number of large wood pieces in the stream. Mixed models are often used in studies that involve repeated measures on the same unit. The random effect was site, and the fixed effects included treatment (pre- and post-harvest) and other categorical variables. The categorical variables included rule number (6a, 6b, and 6c) for stand basal area, DBH class for tree density, reach (control and treatment) for large wood, and decay class for downed wood in the RMA. Linear mixed-effects modeling and *post hoc* comparison of means were conducted using the R software packages ‘lme4’ (Bates et al. 2015) and ‘lmerTest’ (Kuznetsova et al. 2017). All figures displaying results were developed using the R software package ‘ggplot2’ (Wickham 2016).

While the experiment was designed in such a way that the experimental unit was site, we are evaluating data at the plot-level. As described above, most RipStream sites contain two plots. We are evaluating the data at the plot-level using a mixed-effects model for a few reasons. First, the FPA prescriptive rules on riparian management areas apply to one side of the stream, which correspond with plots at the RipStream sites. Averaging stand-level metrics for two stands on opposite sides of the stream is not an acceptable approach for meeting the prescriptive rules. Secondly, an implicit assumption with the current study design and for calculating means and error at the site level is that the treatments are the same within sites, particularly for sites with two treatment plots. However, the FPA requirements for vegetation retention differ depending on the basal area prior to harvesting. Therefore, the treatments may differ within sites in some cases. The issue with using plot as the experimental unit is that the plots adjacent to each other are not independent, since they are grouped together on opposite sides of the stream. The approach of evaluating the data at the plot-level is a form of ‘sacrificial pseudoreplication’ where two samples (i.e, plots-level data) taken from each experimental unit are treated as independent replicates (Hurlbert 1984). Generally, pseudoreplication does not meet the statistical assumption of independence of errors. Without the use of an appropriate mixed-effects model, the results could lead to spurious significance due to a lower variance of the mean. The mixed-effects model and treating site as a random effect in this study is one approach to handle this form of psuedoreplication, because the variance of the mean accounts for the error associated with the random effect (i.e., site).

Results

The results below mostly focus on riparian stands growing along medium and small fish-bearing (i.e., Type F) streams on private land with a few exceptions. Figures 12 and 13 also include data from sites on ODF State Forest land in order to provide for a more robust analysis of site indices (i.e., height for a given age) across a latitudinal gradient and to evaluate general assumptions of site index across the extent of the Coast Range.

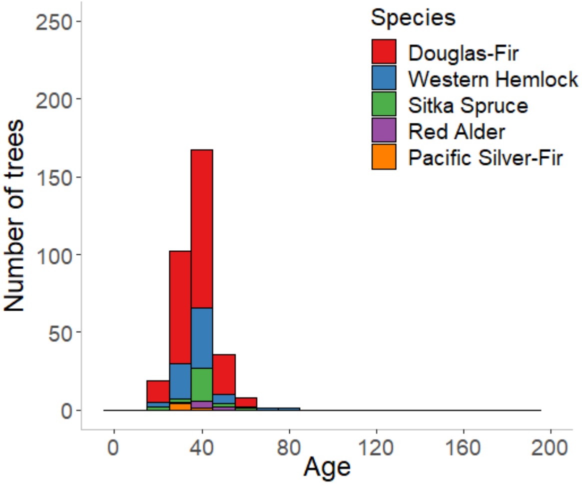

Figure 4. Age distribution for riparian trees growing on private land. The number of trees within each 10-year age class are shown for each species.

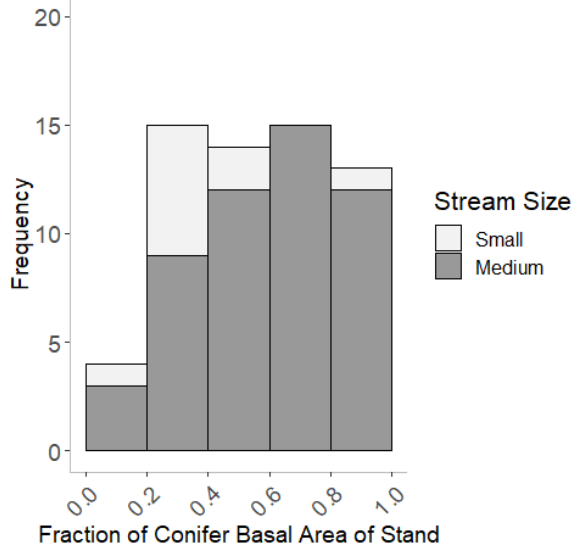

Figure 5. Distribution of the fraction of conifer basal area of riparian stands in all plots (control and treatment) along small and medium streams on private land.

Preharvest stand conditions

Tree ages across RipStream sites along small and medium streams on private land had a range of 16 to 81 years, with a mean age of 38.3 ± 0.5 years at breast height (Fig. 4). The majority of trees sampled for age included Douglas-fir and western hemlock. Tree ages and the normal distribution of those ages (Fig. 4) suggest that these were even-aged stands that established in the late 1950s to early 1970s.

The RipStream stands on private land contained a wide range of conifer basal area. Figure 5 shows the distribution of the proportion of conifer basal area relative to the total stand basal area in the RMA. Values closer to zero would indicate hardwood-dominated stands. At the other end of the spectrum, values closer to 1 indicate conifer-dominated stands. Mixed-conifer-hardwood stands are represented by values closer to 0.5. For medium streams, the distribution is slightly skewed to the right, where the frequency of stands are more distributed near the conifer-dominated end of the spectrum. For small streams, we observed more sites within the 0.2 to 0.4 range, which is likely related to the narrower stream buffers (e.g., 50 ft) and the tendency of hardwoods to dominate near the edges of streams. The median and mean proportion of conifer basal area (all stream types pooled) was 0.61 and 0.57, respectively. These data show that both conifer-dominated and mixed-conifer-hardwood stands were more common, whereas the hardwood-dominated stands were less common.

Pre-harvest conifer basal area in the RMA along small and medium type-F streams displayed a wide range of values (3 – 511 sq. ft. per 1000 ft; Fig. 6). Therefore, the associated prescriptive rules on vegetation retention also varied among plots. More than half (60%) of the treatment and reference plots were above the standard target (‘6a’ stands), 21% of stands were below but greater than ½ the standard target (‘6b’ stands), and 19% were below ½ the standard target (‘6c’ stands). For small streams, the conifer basal area was considerably lower than medium streams, primarily an artifact of the narrower buffer width. A majority of these stands (69%) were above the standard target, 13% of stands were below but greater than ½ the standard target (‘6b’ stands) and 19% of stands were below ½ the standard target. It is worth noting that two sites were in the Interior Region, which has a slightly greater basal area target than the Coast Range Region. However, this does not influence the results shown in Figure 6a. As an example, the basal area in plot 73532 in the Interior Region was between the standard target and ½ the standard target when using the basal area target in either the Interior or Coast Range.

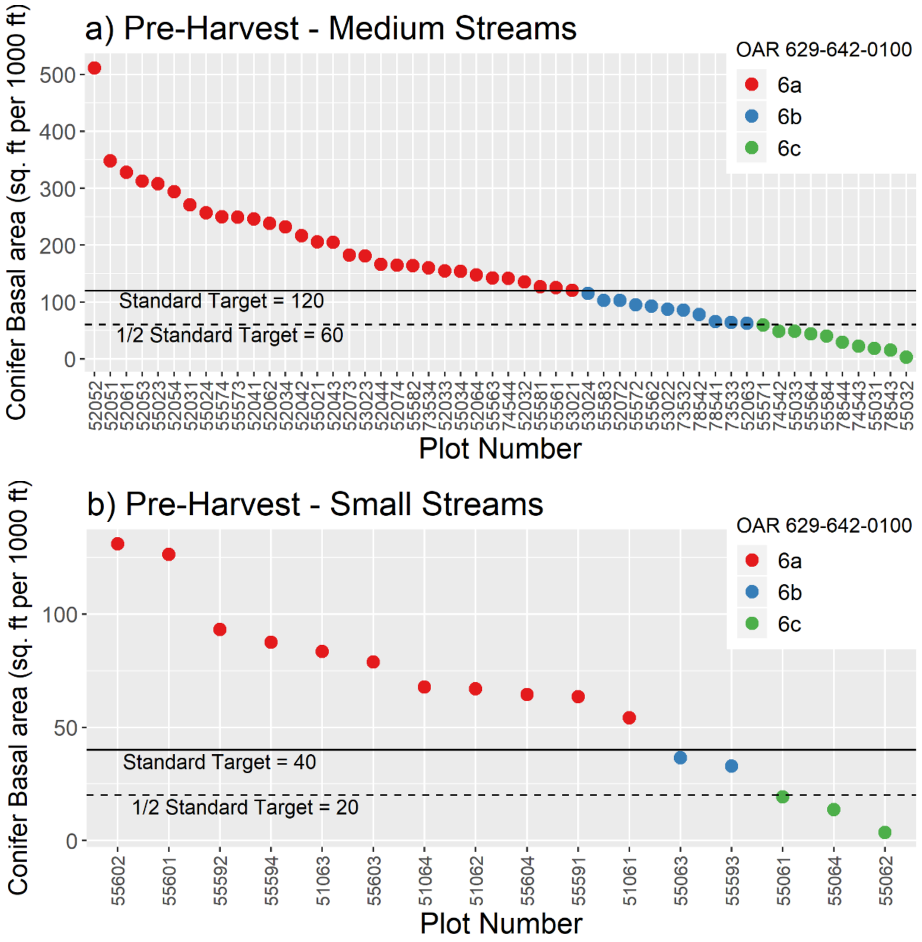

Figure 6. Pre-harvest conifer basal area (sq. ft. per 1000 ft) within the RMA for each plot along medium (a) and small (b) fish-bearing streams on private land including treatment (ending in 1 or 2) and control plots (ending in 3 or 4). Each panel identifies (with colors) whether the plot or stand falls into rule category 6a, 6b, or 6c, which is determined by the basal area relative to the standard target and ½ of the standard target that are shown on the figure.

Harvest effects on riparian stands

Our analysis shows that greater harvesting of conifers occurred for sites that exceeded the basal area target prior to harvest. Due to potential differences in harvesting among plots, plots were grouped into rule categories (6a, 6b, and 6c) when evaluating the harvest effect on conifer basal area (Fig. 7a, 7b). These categories reflect what prescriptions could be applied based on pre-harvest conditions. Sites that fall into rule category 6a showed larger decreases in conifer basal area from pre- to post-harvest for both small and medium streams. The mixed-effects analysis showed that mean basal area for 6a stands was significantly lower during post-harvest than pre-harvest (Table 2), indicating a significant decrease in conifer basal area due to harvesting in the RMA along small and medium, fish-bearing streams. Sites that fell into rule category 6b and 6c did not experience detectable changes in basal area, and no statistical differences were detected pre- and post-harvest, which suggests that landowners did not harvest or harvested very little in the RMAs for these sites. In Figure 7b, we show that no treatment plots along small streams fell into category 6b. The analysis described above (Fig. 6b) included a few sites that fell into rule category 6b along small streams because the analysis in Fig. 6b included pre-harvest data at both treatment and control pots. Stand density (trees per 1000 ft) displayed consistent trends with basal area for small and medium streams, where the 6a stands displayed greater decreases after harvesting occurred (data not shown).

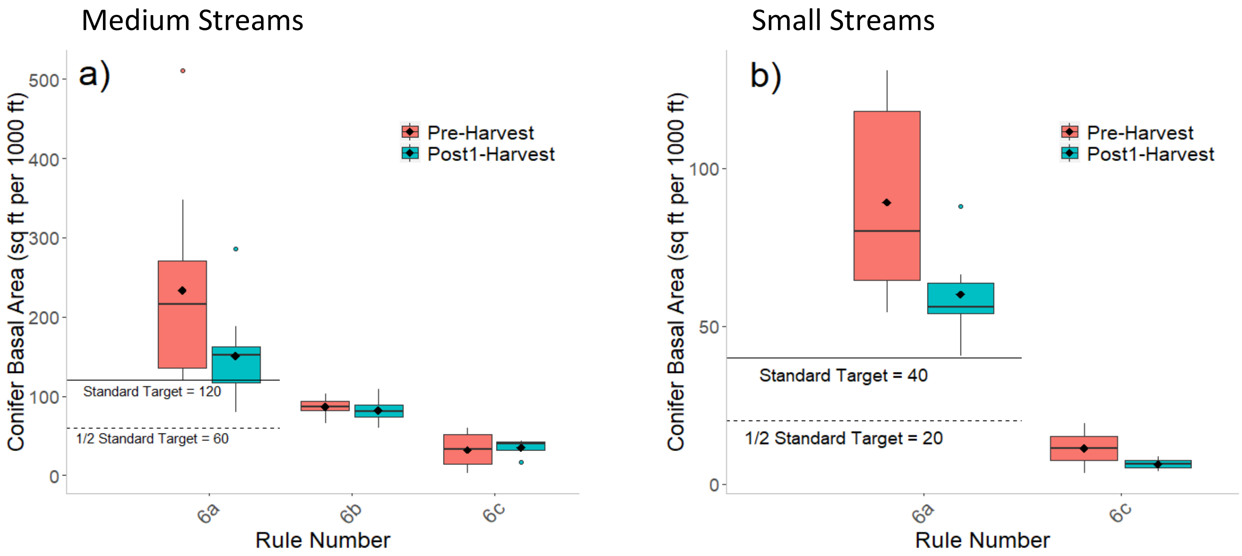

Figure 7. Conifer basal area within RMAs along medium (a) and small (b) streams on private land for pre- and post1-harvest. The plots were grouped by the rule category (described above). Each box shows the interquartile range from the 25th to 75th percentile represented by the bottom and top, respectively, of the box. The median is the horizontal line near the center of the boxes and the mean is the point within the box. The maximum and minimum are the ends of each vertical line, and outliers are points above or below the maximum and minimum. Note the difference in scale between panels a and b.

Table 2. Mean conifer basal area (ft^2 1000 ft^{-1}) pre- and post-harvest for medium and small type-F streams on private land for sites within each rule category. Different capital letters within each column indicate significant differences pre- and post-harvest.

Stream size	Species group	Time	Basal area (±SE)		
			6a	**6b**	**6c**
Medium	Conifers	Pre-harvest	233.6 ±31.2^A	86.8 ±4.6^A	32.5 ±13.1^A
		Post-harvest	150.5 ±14.2^B	82.2 ±6.0^A	35.1 ±6.4^A
	Number of plots		*13*	*7*	*4*
Small	Conifers	Pre-harvest	89.3 ±13.6^A	-	11.4 ±7.8^A
		Post-harvest	60.1 ±6.5^B	-	6.3 ±2.3^A
	Number of plots		*6*	*0*	*2*

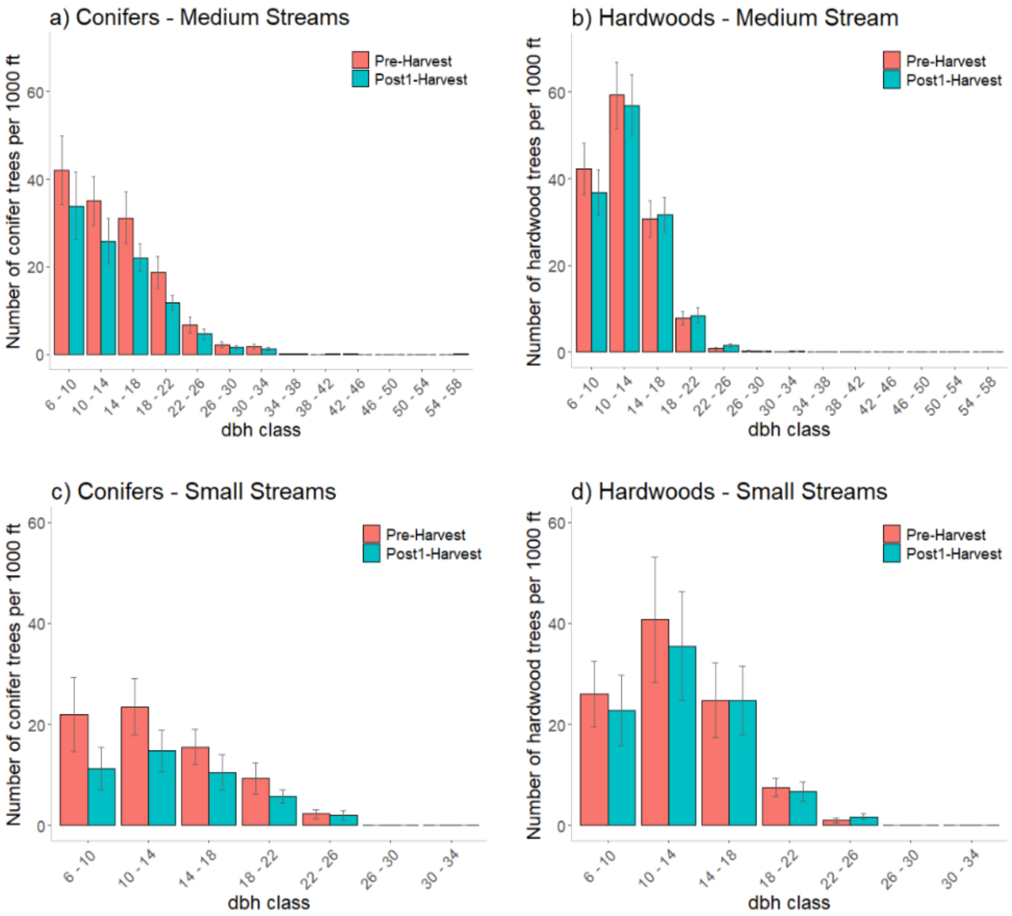

Figure 8. Diameter at breast height (DBH) distributions pre- and post1-harvest for number of conifers per 1,000 ft in RMAs on private land. Figure panels include distributions along medium streams (a), hardwoods along medium streams (b), conifers along small streams (c), and hardwoods along small streams. DBH bins were set at 4 in. Error bars represent the standard error of the mean.

In comparing, pre- and post1-harvest diameter distributions, harvesting appeared to target conifers in the smaller diameter classes along both medium and small streams (Fig. 8a-d). The mixed effects model results (Table 3) showed that the number of conifer trees (per 1000 ft of stream in the RMA) decreased for smaller trees (6-18 inch DBH class) along small and medium streams, but not for trees greater than 18 inches in DBH. For medium streams, there were a few trees greater than 36 inches in DBH, however, there was no detectable change. For hardwoods, there was no evidence of a change in the number of trees in any DBH class (Table 3).

Table 3. Mean conifer and hardwood tree density (trees 1000 ft^{-1}) for medium and small streams on private land pre- and post-harvest within three DBH classes (6-18, 18-36 , >36 in). Different capital letters within each column indicate significant differences pre- and post-harvest, and different lowercase letters within each row indicate significant differences among DBH classes.

Stream size	**Species group**	**Time**	**Trees per 1000 ft of stream** (±SE)		
			6 – 18 in	**18 – 36 in**	**>36 in**
Medium	Conifers	Pre-harvest	108.2 ±16.1^{Aa}	29.3 ±5.8^{Ab}	0.1 ±0.1^{Ac}
		Post1-harvest	81.7 ±14.1^{Ba}	19.1 ±2.8^{Ab}	0.2 ±0.1^{Ab}
	Hardwoods	Pre-harvest	132.3 ±15.0^{Aa}	8.9 ±1.8^{Ab}	0.2 ±0.1^{Ab}
		Post1-harvest	125.3 ±13.2^{Aa}	10.3 ±2.1^{Ab}	0.0 ±0.0^{Ab}
Small	Conifers	Pre-harvest	98.3 ±22.2^{Aa}	17.5 ±5.0^{Ab}	-
		Post1-harvest	45.5 ±12.4^{Ba}	8.8 ±2.0^{Ab}	-
	Hardwoods	Pre-harvest	115.5 ±26.0^{Aa}	11.8 ±3.4^{Ab}	-
		Post1-harvest	95.0 ±26.8^{Aa}	10.8 ±3.2^{Ab}	-

Along medium streams, harvesting tended to target western hemlock and to some extent, Sitka Spruce, which is surprising given the higher monetary value of Douglas-fir than other species (Fig. 9a). Sitka spruce was restricted to 5 sites (10 plots) that were all located within 10 miles of the Oregon Coast. At these sites, there was evidence of greater harvesting of Sitka Spruce in the RMA at plots that had a greater pre-harvest Sitka spruce density (data not shown). Along small streams, Douglas-fir was a targeted species for harvesting (Fig. 9b). It was clear that red alder comprises nearly all of the hardwoods present and was more common than Douglas-fir, western hemlock, bigleaf maple, and other species along both small and medium streams.

Prior to harvesting, conifer and hardwood basal area displayed an increasing and decreasing trend, respectively, with distance from stream (data not shown). In both cases, gradients in basal area were most apparent within the RMA. Within the RMA, harvesting of conifer trees mostly occurred near the outer portion of the RMA (i.e., furthest away from the stream). This generally includes 50-70 feet away from stream along medium streams and 40-50 feet for small streams (Fig. 10a-d). Outside of the RMA, the large decrease in conifer basal area was associated with the adjacent clearcut. For hardwoods, there was little evidence for harvesting in the RMA, consistent with our results as described above. Outside of RMAs, hardwood basal area did not change much along medium streams, but significantly along small streams.

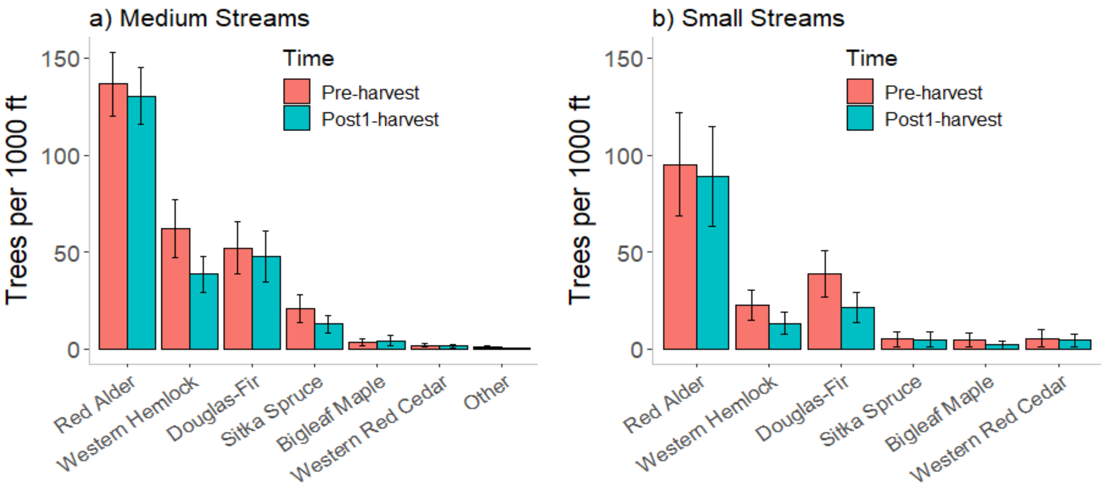

Figure 9. Mean number of trees per 1000 ft of stream within the RMAs along medium (a) and small (b) streams on private land for pre- and post1-harvest for each species. The error bars represent the standard error of the mean.

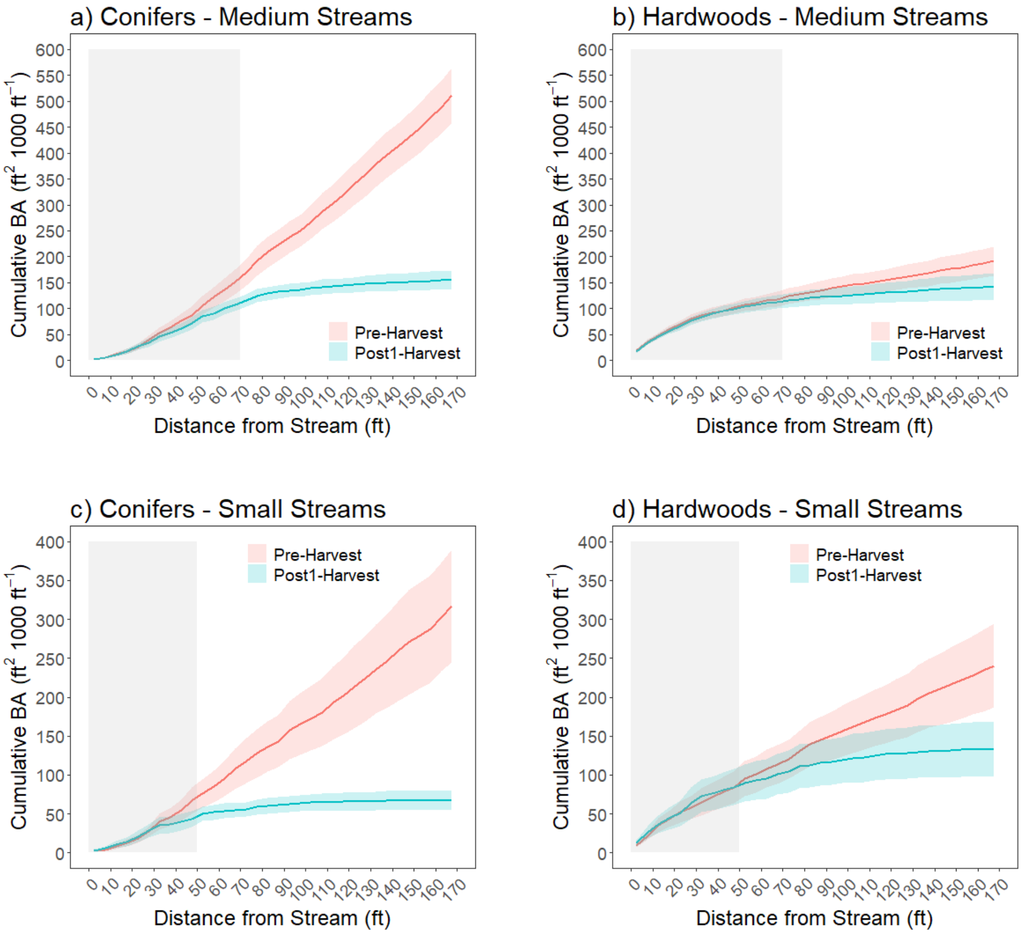

Figure 10. Cumulative basal area (BA) as a function of distance from stream for pre- and post1-harvest for conifers along medium streams (a), hardwoods along medium streams (b), conifers along small streams (c), and hardwoods along small streams (d) on private land. The shaded grey area represents the buffer width of the RMA widths. The shaded colors flanking the red and blue lines (i.e., mean cumulative BA) represent the standard error of the mean.

Assumptions for Basal Area Targets

Using the RipStream data, we overlaid the trajectories of RipStream stands that fell into rule category 6a (i.e, conifer-dominate stands) with the conceptual diagram (Fig. 11). Within the ‘6a’ category, stands with the maximum and minimum conifer basal are shown (i.e, Max and Min), as well as the average conifer basal area across stands. Figure 11 displays the wide range of trajectories for these stands where the maximum exceeds the average mature conditions and minimum achieves the standard target. On average, these stands exceeded the standard target during the first 40 years of initial growth and was maintained above the standard target after harvest. While these stands were at a desirable starting point (i.e., above the standard target), there is not sufficient information to identify whether the stands are on track to achieve desired future conditions. Additional analysis, such as modeling stand growth, would be required to project increases in stand basal area over time and to test the assumption regarding the change in basal area over time. The analysis up to this point does provide fundamental information about the extent of harvesting in the RMA, which can be used to develop modeling and harvest scenarios.

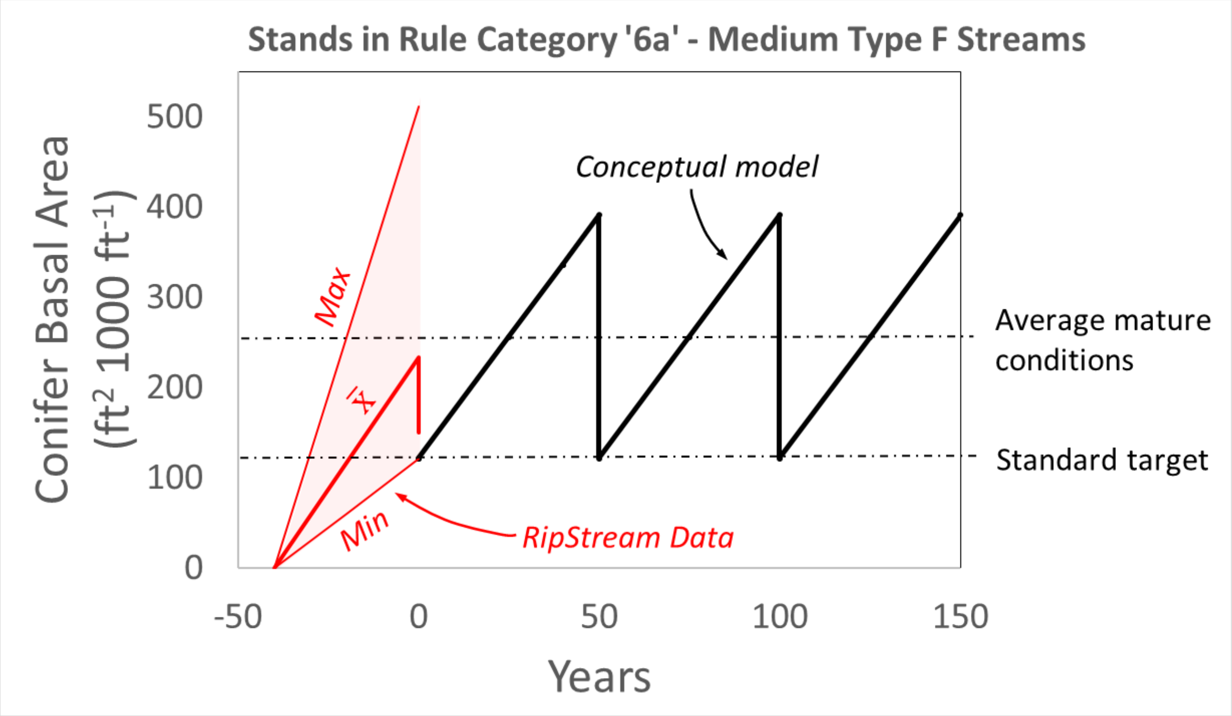

Figure 11. Conceptual diagram (Figure 2) overlaid by the RipStream pre- and post1-harvest data. These data show the maximum, minimum, and mean trajectories of stand basal area over a period of 40 years. We assumed a basal area of 0 at 40 years prior to data collection of pre-harvest data (i.e., year 0). The maximum trajectory (‘Max’) represents the RipStream plot with the greatest conifer basal area, whereas the minimum (‘Min’) is the plot with the lowest conifer basal area (e.g., similar to the standard target). The mean ($\bar{X}$) is the average basal area of all plots. The vertical line of the mean at year 0 reflects the mean change in basal area following harvesting.

For the Coast Range, Lorensen et al. (1994) assumed a site index of 119, which was based on upland sites. The site index in this case is the mean tree height (ft) of the stand at 50 years, and site index curves are used to describe the increase in height with stand age. Site index is often used to assess what the basal area of a stand is at full stocking. Figure 12a shows the non-linear relationship between height and age at breast height (i.e., site index curve) for Douglas-fir. The points represent tree ages across all RipStream plots. The blue line is fit to the data points, while the red line is the site index curve of 119 (King 1966). The nearly identical increase in height with age between the two lines suggest that the site index of 119 is valid for Douglas-fir. For other species such as Sitka spruce and western hemlock, most points fall along or near the site index curve of 119 (Fig. 12b). However, there are a number of points that deviate from the line, where the growth trajectory does not reflect a site index of 119. Points that deviate from the curve (e.g., below the line) likely reflect the shade tolerance of western hemlock and ability to persist in the understory for a longer period of time prior to reaching the overstory.

We also evaluated the mean residuals of the data presented in Figure 12a. The mean residuals presented in Figure 13 are the vertical distances [+/-] from the curve (i.e., blue line) in Figure 12a averaged by site. The mean residuals by site is one approach to evaluate whether sites have a relatively low or high site index (i.e., shorter or taller trees for a given age). A majority of sites in the two most northern counties of Oregon, Clatsop (67%) and Tillamook (75%) counties, had negative mean residuals (Fig. 13). Similarly, three sites at the most southern county, Coos County, all had negative residuals. In contrast, all but one site in Lincoln County had positive residuals, suggesting relatively greater site index as compared with other counties.

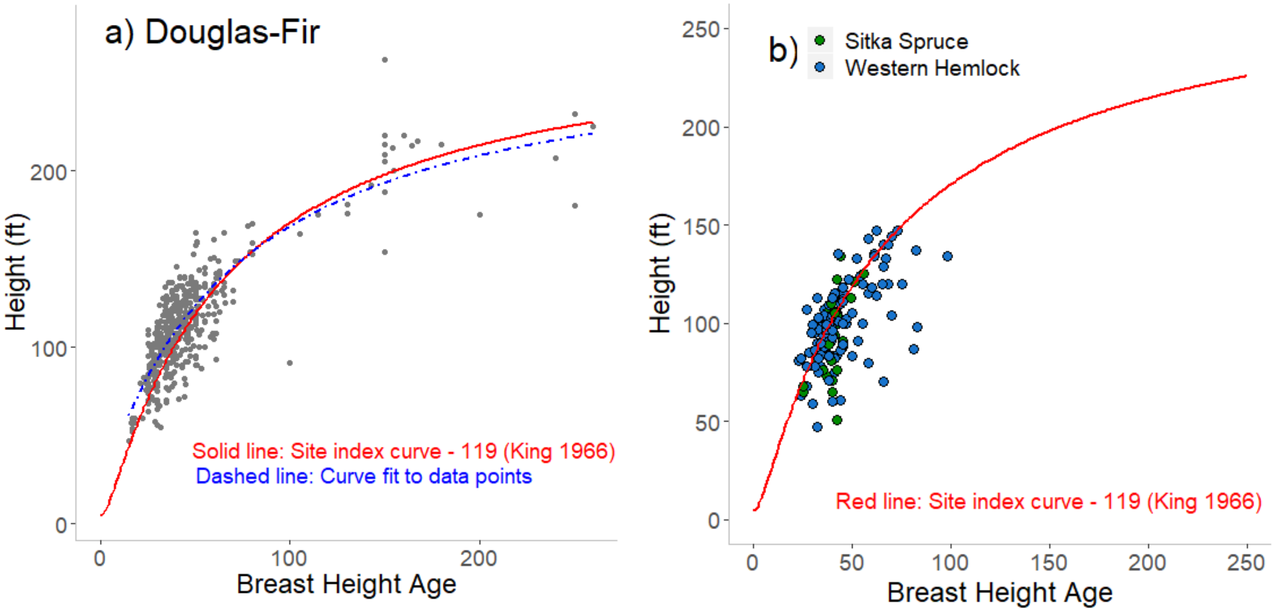

Figure 12. Site index curves (height vs. age) for Douglas fir (a) and Sitka spruce and western hemlock (b) on private and ODF State Forest land. In panel (a), a curve is fit to the RipStream data (blue line) and a site index curve of 119 is also plotted for reference (red line). In panel (b), only the site index curve of 119 is shown for reference. A curve was not fit to the data due to the lack of points greater than 100 years.

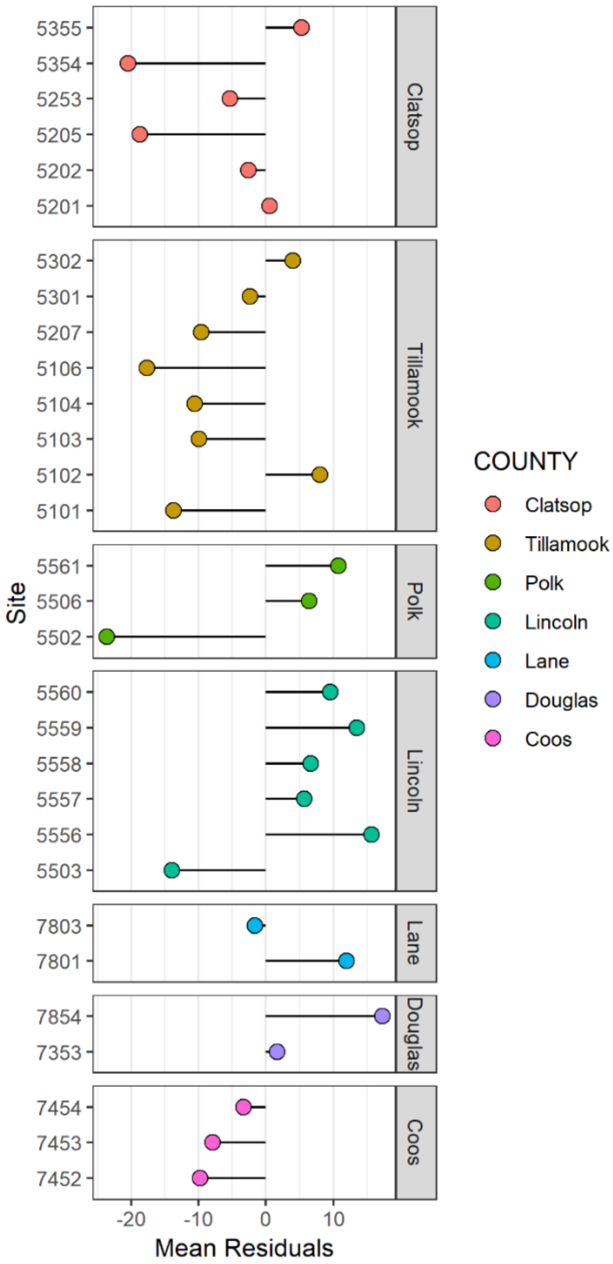

Figure 13. Mean residuals (i.e., vertical distance from blue line Figure 12a) by site grouped by county. From top to bottom, counties are ordered along a north to south gradient. Negative residuals indicate a lower site index (e.g., shorter tree height for a given age), whereas positive residuals indicate a greater site index. Sites include private and ODF State Forest land.

Blowdown

The analysis up to this point has included blowdown trees (e.g., post-harvest) as part of the basal area and tree density values, because this was the best approach to understanding the extent of harvesting in the RMA. We did, however, assess the effects of blowdown relative to harvesting effects on conifer basal area and stand density across sites along medium and small streams. Figure 14 shows the mean, median, and confidence intervals for basal area and stand density in the RMA for pre-harvest, post1-harvest (including blowdown trees in analysis), and post1-harvest (not including blowdown trees in analysis). Our results show that harvesting had a greater effect on basal area and stand density as compared with blowdown. For medium streams, stand BA decreased 30% and 35% from pre- to post-harvest when blowdown trees were included and not included, respectively, in the analysis as part of the stand BA. Stand density decreased 27% and 33% from pre- to post-harvest when blowdown trees were included and not included, respectively, in the analysis. For small streams, stand BA decreased 34% and 41% from pre- to post-harvest when blowdown trees were included and not included, respectively, in the analysis as part of the stand BA. Stand density decreased 39% and 46% from pre- to post-harvest when blowdown trees were included and not included, respectively, in the analysis. Our results suggest that while blowdown did occur at sites, harvesting appeared to have a greater effect than blowdown on basal area and tree density within the RMA.

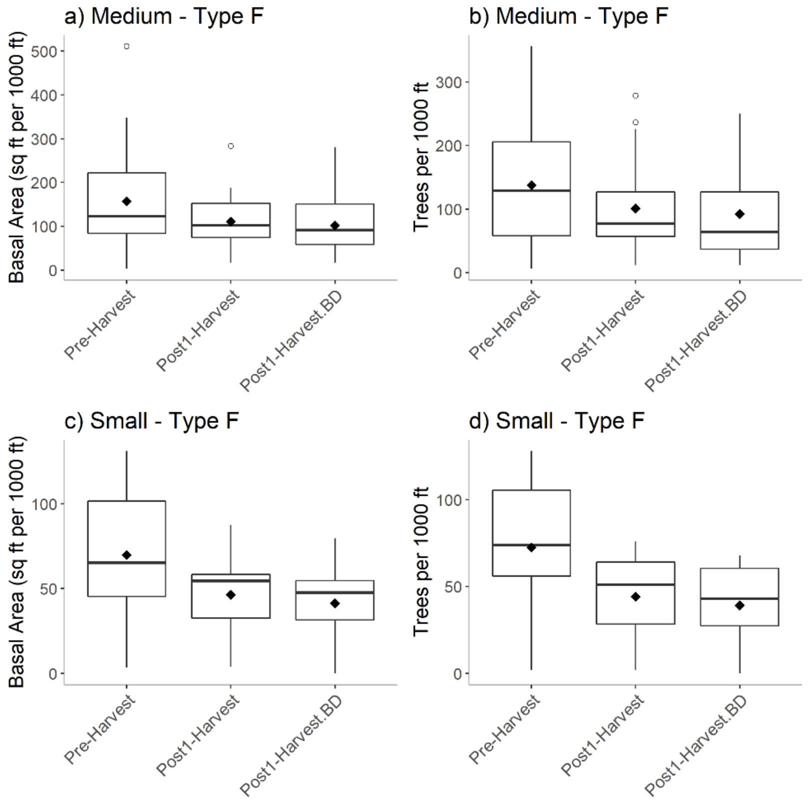

Figure 14. Conifer basal area and trees per 1000 ft of stream along medium (a, b) and small (c, d) streams on private land for pre-harvest, post1-harvest including blowdown trees, and post1-harvest excluding blowdown trees (i.e., Post1-Harvest.BD).

We also compared the number of blowdown trees in the RMA between control and treatment plots during years 1 and 5 post-harvest. Since the study was not specifically designed to address questions about wind throw, the number of plots used in this analysis is considerably lower than what has been used to this point. For example, cruise data at the control plots were limited in the post-harvest years. Regardless, we did not detect a significant difference in the number of blowdown trees per 1000 feet of stream in the RMA between control and treatment plots during year 1 (paired t-test: $p = 0.15$, df = 12) and year 5 ($p = 0.28$, df = 8). Plots along small and medium streams were pooled for this analysis since stream size did not have a significant effect on number of wind thrown trees. For plots that included measurements of blowdown trees during years 1 and 5 post-harvest, we observed an average increase of 7.1 blowdown trees per 1000 feet of stream in the RMA over the four year post-harvest period.

Tree Regeneration and Understory Vegetation

Pre-harvest conifer seedlings/saplings per acre (< 6 in DBH) was positively and significantly correlated with overstory conifer trees per acre (> 6 in DBH), although the relationship was weak ($R^2 = 0.30$, $p < 0.001$; Fig. 15). Our pre-harvest results highlight the importance of a seed source for natural regeneration of conifer seedlings and potential constraints to conifer regeneration in hardwood-dominated stands.

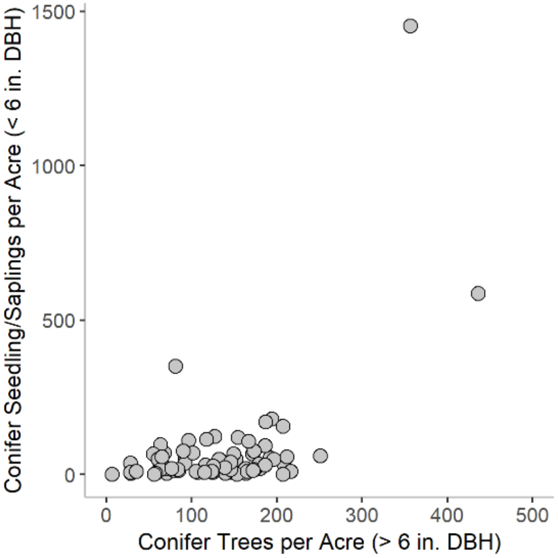

Figure 15. Relationship between overstory and understory trees per acre for all pre-harvest plots (e.g., treatment and control reaches) along small and medium streams on private land.

Our results also highlight considerable variability in seedlings/saplings per acre across plots for both conifers and hardwoods during pre-, post1-, and post3-harvest as shown by the wide range of values and outliers (Fig. 16). We did not detect significant changes in conifer seedlings/saplings per acre from pre- to post-harvest along the control or treatment reaches. We did, however, observe consistently greater conifer seedlings/saplings per acre in the control reach than the treatment reach during pre-, post1-, and post3-harvest ($p < 0.05$, mixed-effects model). Differences between the control and treatment reaches were similar during all three time periods. Overall, harvesting of overstory trees outside and inside of the RMA do not appear to influence conifer seedling/saplings per acre three years following harvest.

From pre- to post3-harvest, western hemlock was the most common conifer species less than 6-in DBH, followed by Douglas-fir, western red cedar,

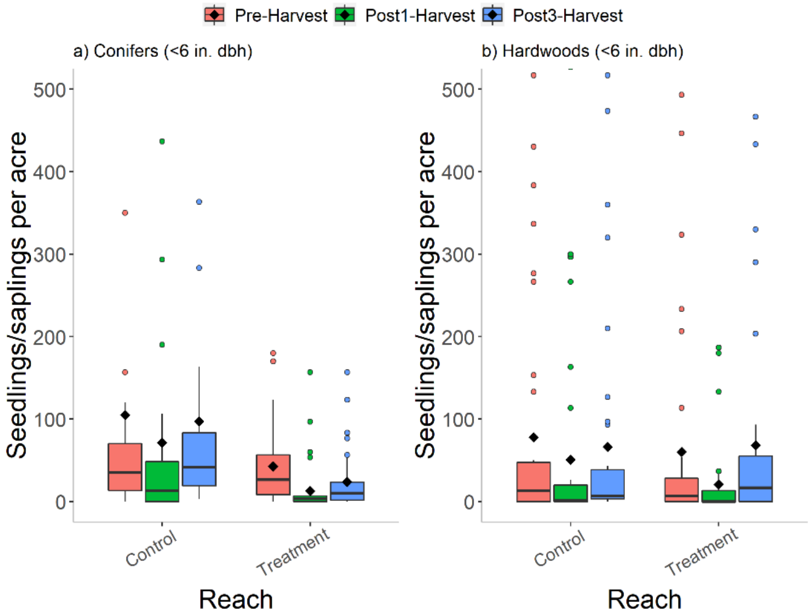

Figure 16. Boxplots of trees per acre by reach (control and treatment) for conifer (a) and hardwood (b) seedlings and saplings for pre-, post1-, and post3-harvest along small and medium streams on private land. Note that seven outliers greater than 500 trees per acre are not shown. Four outliers are not shown for conifers (control reach; range of 587 to 1453 trees per acre), and three outliers were not shown for hardwoods (control reach; range of 517 to 527 trees per acre).

and Sitka spruce along small and medium streams (Fig. 17). Other conifer species were recorded; however, the number of trees per acre were fairly low for the other species. Bigleaf maple and red alder were the most common hardwood seedlings. Other broadleaf deciduous trees (sometimes shrubs) included cascara buckthorn and *Salix* species (e.g., willow). While cascara buckthorn was quite common and contained the greatest number of trees per acre prior to harvest, this species does not grow as tall as bigleaf maple or red alder and does not contribute to the overstory tree species composition in riparian forests. Based on the methodology of this study, it was not possible to group cascara buckthorn or willow with other shrubs in the data analysis. No distinction was made among *Salix* species in the data collection.

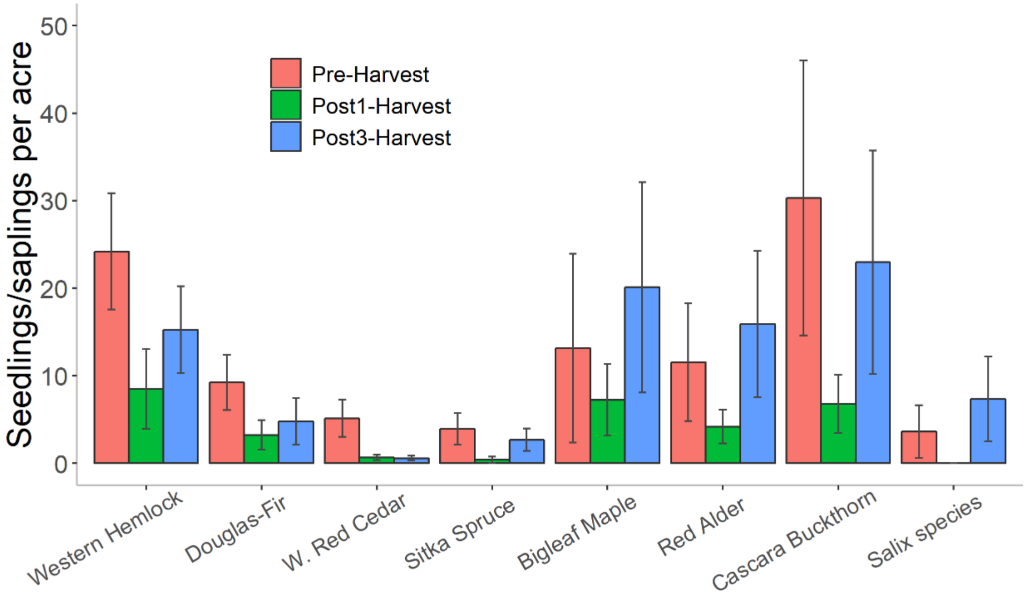

Figure 17. Mean seedlings and saplings per acre (< 6-in DBH) along treatment reaches for the most common species including Cascara buckthorn and Salix species (i.e., willow), which also tend to display a shrub-like form. These results include data collected from sites on private land along both medium and small streams, which include all circular subplots within the larger riparian plots (500 x 170 ft).

We observed a consistent trend of decreasing seedling/sapling trees per acre from pre- to post1-harvest across all species (Fig. 17). For western hemlock, Douglas-fir, and Sitka spruce seedlings and saplings, pre-harvest trees per acre were greater than post1-harvest ($p < 0.05$, mixed-effects model), but similar to post3-harvest. For western red cedar seedlings and saplings, pre-harvest trees per acre was greater than post1- and post3-harvest ($p < 0.05$, mixed-effects model). No differences in trees per acre among the time periods were observed for bigleaf maple, red alder, cascara buckthorn, or *Salix* species seedlings and saplings.

Following harvest, decreases in trees per acre for conifer seedlings/saplings were generally more apparent in the 75 to 125 feet from the stream (horizontal distance) and extending out to 150 feet for Douglas-fir (Fig. 18). With the exception of western red cedar, conifer seedling/sapling density did not display much change at 25 feet, the closest subplots to the streams. There was evidence of an increase in trees per acre for western hemlock, Douglas-fir, and Sitka spruce seedlings/sapling, resulting in no difference between pre- and post3-harvest trees per acre as described above.

For understory shrubs prior to harvest, vine maple was the most common species with respect to percent cover followed by salmonberry, red huckleberry, salal, red elderberry, cascade barberry, and California hazelnut (Fig. 19). Decreases in percent cover following harvest were most apparent for vine maple and red huckleberry (Fig. 19). For vine maple, decreases in percent cover were greatest further away from the stream and likely occurring mostly outside of the RMA, whereas decreases in red huckleberry cover were fairly consistent within and outside of the RMA (Fig. 20).

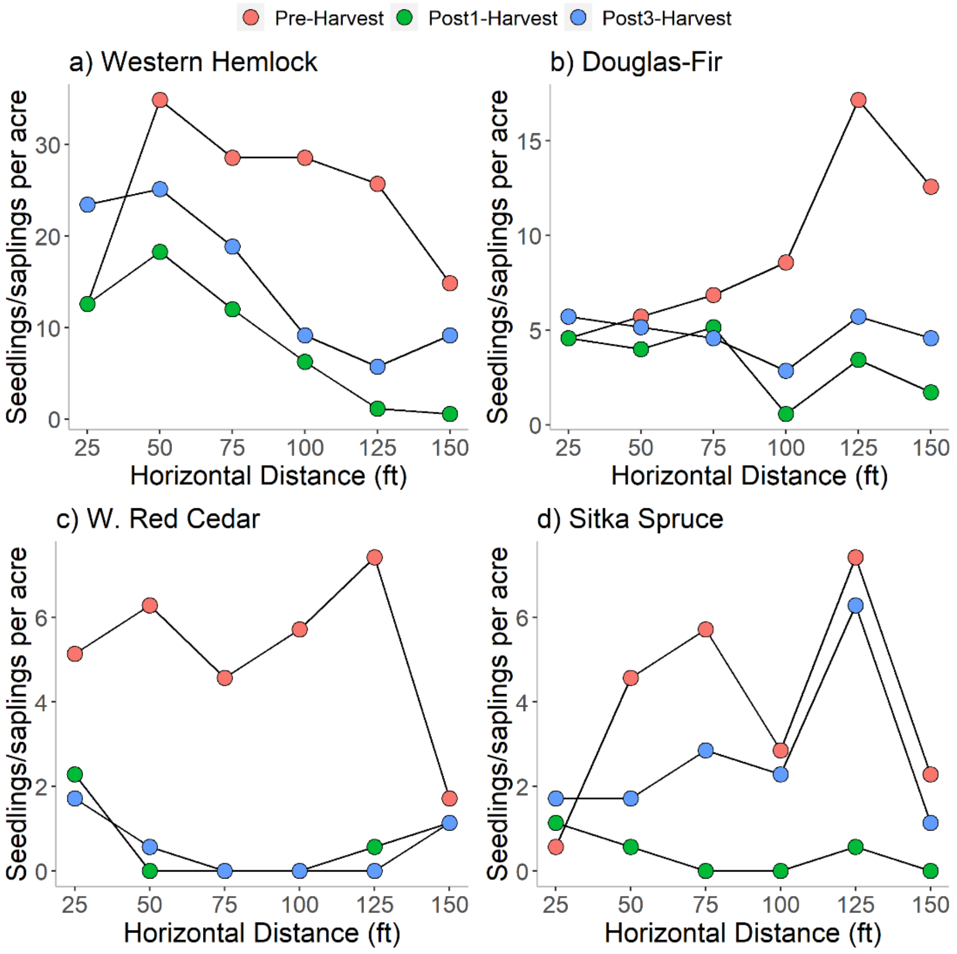

Figure 18. Seedlings/saplings per acre for western hemlock (a), Douglas-fir (b), Western red cedar (c), and Sitka spruce (d) as a function of horizontal distance from the stream. These results include data collected from sites on private land along both medium and small streams, which include all circular subplots within the larger riparian plots (500 x 170 ft). Horizontal distance, as opposed to slope distance, is used here because an equal number of subplots within each plot were established at 25-foot intervals using horizontal distance from stream.

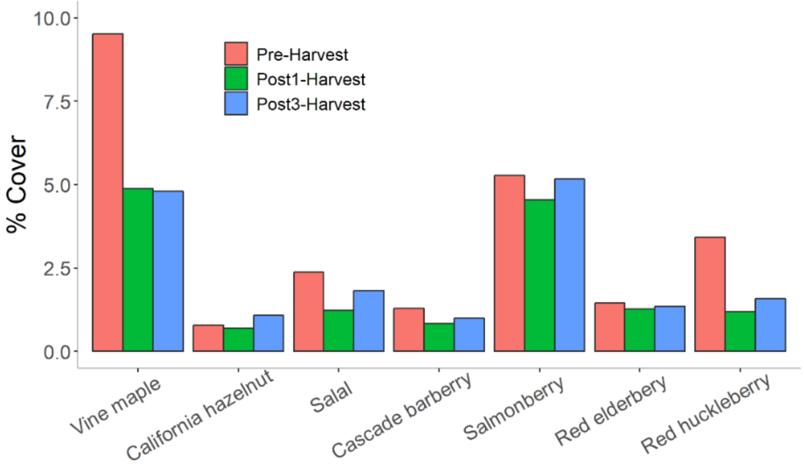

Figure 19. Mean percent cover for most the common shrub species (>1% cover during all collection periods). These results include data collected from sites on private land along both medium and small streams, which include all circular subplots within the larger riparian plots (500 x 170 ft).

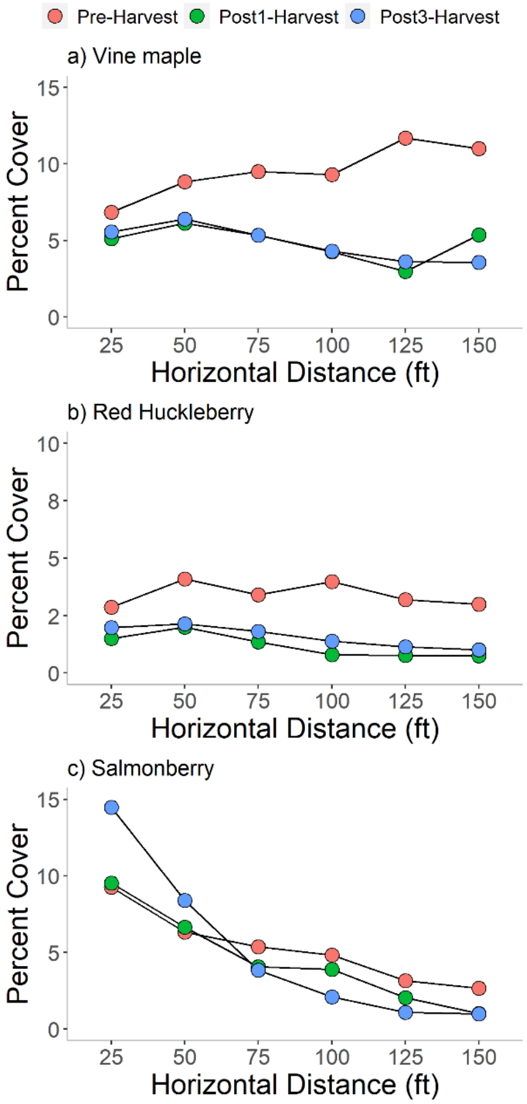

Figure 20. Percent cover of vine maple (a), red huckleberry (b), and salmonberry (c) as a function of distance from the stream. These results include data collected from sites on private land along both medium and small streams, which include all circular subplots within the larger riparian plots (500 x 170 ft). Horizontal distance, as opposed to slope distance, is used here because an equal number of subplots within each plot were established at 25-foot intervals using horizontal distance.

Downed Wood in the RMA

Within the RMA, we did not detect a statistically significant change in the total number of downed logs (>6-in diameter, >3-ft length) per acre from pre- to post-harvest along small and medium streams (Fig. 21, Table 4). Rather, we observed a significant increase in logs per acre outside of the RMA along medium and small streams (Table 4, Fig. 21). Outside of the RMA comprises 50-170 feet from the stream for small streams and 70-170 feet for medium streams. The increase in downed logs per acre outside of the RMA were primarily a result of an increase in the less decayed wood (decay class 1 and 2; Table 4, Fig. 21). This suggests that small logs, or pieces of logs, from the harvest likely resulted in an increase in downed wood. We also detected an increase in downed logs in the less decayed classes inside of the RMA for small streams.

Along small and medium streams within and outside of the RMA, we did not detect a statistically significant change in the total volume of downed logs per acre from pre- to post-harvest (Table 4, Fig. 22). Within the more decayed classes, we observed a significant decrease in the volume of downed logs outside of the RMA along medium streams and inside the RMA for small streams (Table 4, Fig. 22). Also, the total volume of downed wood was mostly comprised of the more decayed classes (Classes 3-5) inside and outside of the RMA along both small and medium streams.

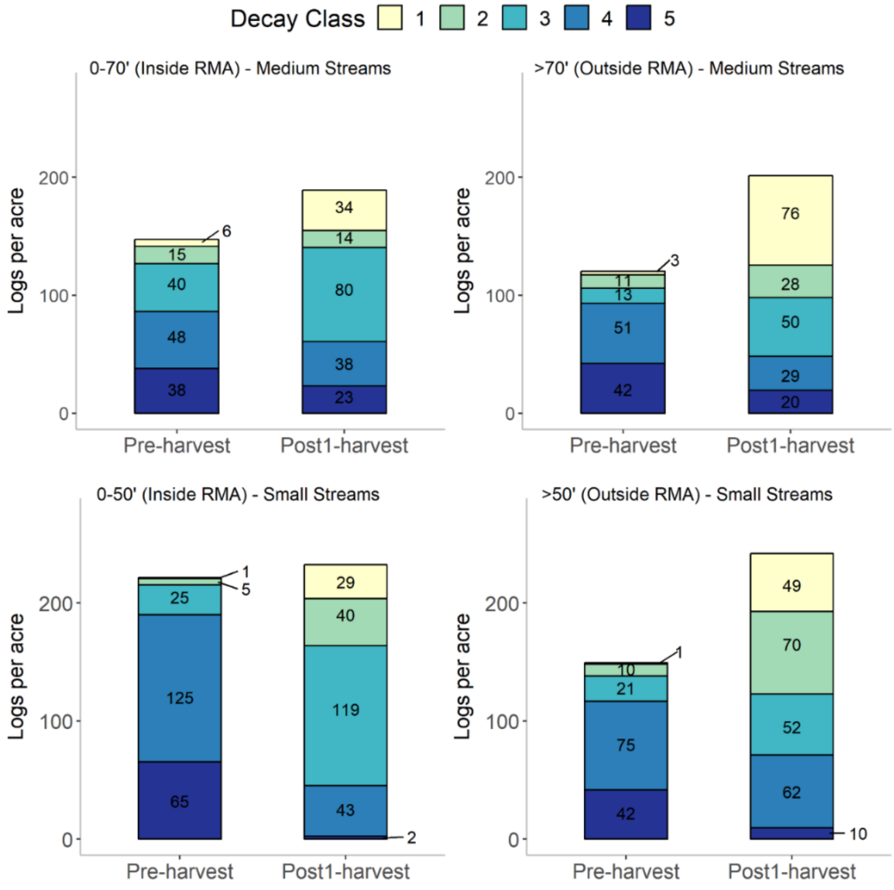

Figure 21. Logs per acre by decay class for medium streams inside (a) and outside of the RMA, as well as small streams inside (c) and outside of the RMA on private land.

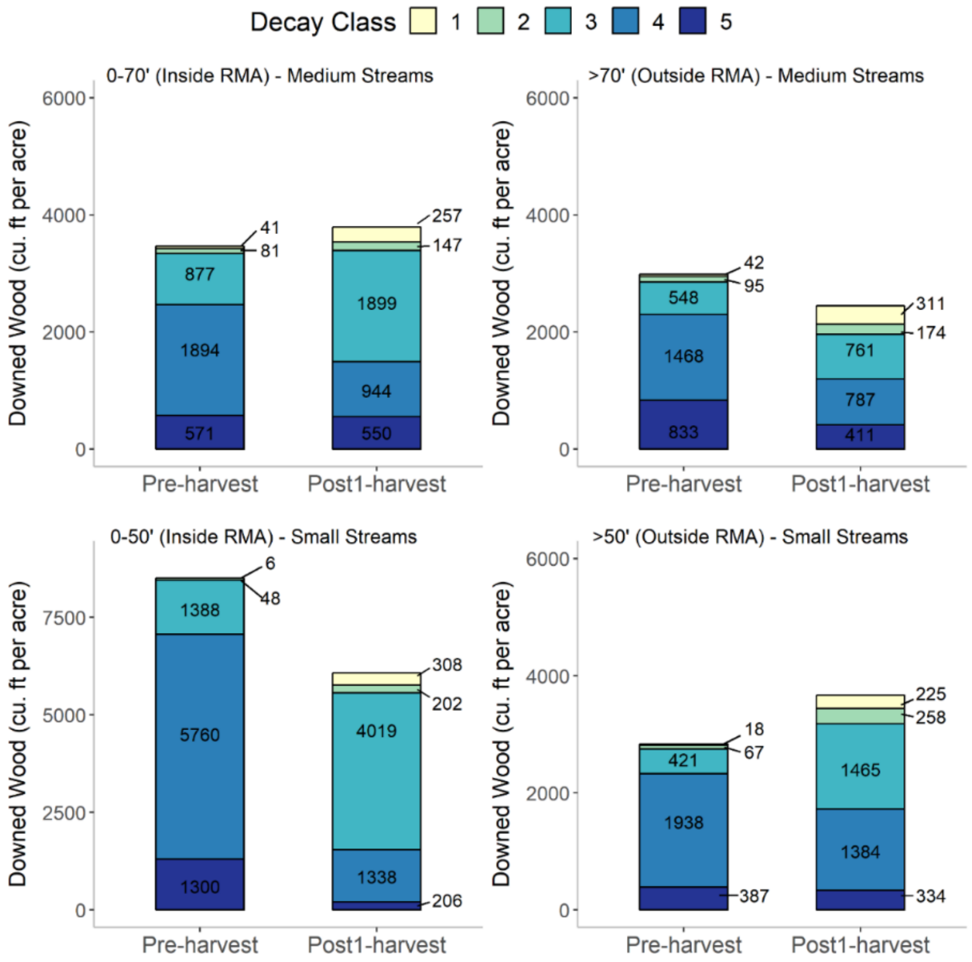

Figure 22. Volume of downed wood (cu. ft per acre) by decay class for medium streams inside (a) and outside of the RMA, as well as small streams inside (c) and outside of the RMA on private land.

Table 4. Change (Δ) in total logs per acre, logs per acre by decay class, volume per acre, and volume per acre by decay class from pre- to post-harvest along small and medium streams on private land. Bold numbers indicate a significant increase or decrease (negative numbers).

Metric	**Stream Size**	**Location**	**Decay Class Group**[§]	**Δ Pre-harvest to Post-harvest *(95% CI)***
Total logs per acre	Medium	In RMA	-	41.8 *(-8.0, 91.7)*
		Out of RMA	-	**80.9**** ***(31.9, 129.7)***
	Small	In RMA	-	11.0 *(-57.7, 79.8)*
		Out of RMA	-	**92.7*** ***(14.2, 171.3)***
Logs per acre by decay classes	Medium	In RMA	Less Decayed (1, 2)	28.1 *(-8.9, 65.0)*
			More Decayed (3, 4, 5)	13.8 *(-23.2, 50.7)*
		Out of RMA	Less Decayed (1, 2)	**88.7***** ***(50.6, 126.8)***
			More Decayed (3, 4, 5)	-7.9 *(-46.0, 30.2)*
	Small	In RMA	Less Decayed (1, 2)	**62.7*** ***(12.2, 113.1)***
			More Decayed (3, 4, 5)	-51.6 *(-102.0, -1.2)*
		Out of RMA	Less Decayed (1, 2)	**107.9***** ***(59.3, 156.4)***
			More Decayed (3, 4, 5)	-15.2 *(-63.7, 33.4)*
Volume per acre	Medium	In RMA	-	329.8 *(-935.4, 1595.1)*
		Out of RMA	-	-543.5 *(-1192.7, 105.7)*
	Small	In RMA	-	-2428.9 *(-5300.6, 442.9)*
		Out of RMA	-	835.6 *(-893.8, 2565.0)*
Volume per acre by decay classes	Medium	In RMA	Less Decayed (1, 2)	280.3 *(-686.6, 1247.2)*
			More Decayed (3, 4, 5)	49.5 *(-917.4, 1016.5)*
		Out of RMA	Less Decayed (1, 2)	347.7 *(-215.6, 911.0)*
			More Decayed (3, 4, 5)	**-891.2**** ***(-1454.4, -327.9)***
	Small	In RMA	Less Decayed (1, 2)	455.4 *(-1688.4, 2599.3)*
			More Decayed (3, 4, 5)	**-2884.3*** ***(-5028.2, -740.4)***
		Out of RMA	Less Decayed (1, 2)	398.3 *(-872.6, 1669.3)*
			More Decayed (3, 4, 5)	437.3 *(-833.7, 1708.2)*

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

[§] In order to avoid model overfitting, downed wood decay classes (1 – 5) were further grouped into 2 categories (e.g., less decayed and more decayed). Less decayed group included decay classes 1 and 2, and more decayed group included decay classes 3, 4, and 5. See Table 1 for a description of each decay class. The total number of logs or volume of logs were pooled into decay class groups within each plot.

Large Wood in the Stream Channel

Our results suggest that harvesting adjacent to and within the RMA did not affect the number of large wood pieces and key pieces (> 25-in diameter, > 30-ft length) in the stream channel. Within medium streams, we observed an increasing trend in large wood pieces over time, prior to harvest through the 3rd year post harvest (i.e., post3-harvest) (Table 5, Fig. 23). This trend was observed in both the control and treatment reach, suggesting that the increase in large wood was a result of other factors such as natural disturbance or delivery of wood from upstream reaches. We did not detect a change in large wood pieces over time in small streams in either control or treatment reach (Table 5). For key large wood pieces, we observed a significant increase from pre- to post1-harvest (Table 5) in the control and treatment reaches in small and medium streams, although values returned to pre-harvest levels by post3-harvest. Unlike downed wood in the RMA, decay classes for large wood in the channel were not recorded.

Our results also indicate that the increase in large wood pieces from pre- to post3-harvest were comprised of smaller diameter pieces (Fig. 24). Large wood pieces in the 5-10 inch diameter class (i.e., smallest diameter class) displayed the most dramatic increase from pre- to post3-harvest. The increase in large wood pieces appear to represent a broad range of length classes. Although, the largest length class (> 30 ft) appear to contribute most to the increasing large wood pieces over time. Finally, wood jams were also tallied and their dimensions were measured in the field. From pre- to post1-harvest, there was a large increase in the frequency of small wood jams (Fig. 25). By post3-harvest, the distribution of wood jam size was similar to the pre-harvest distribution.

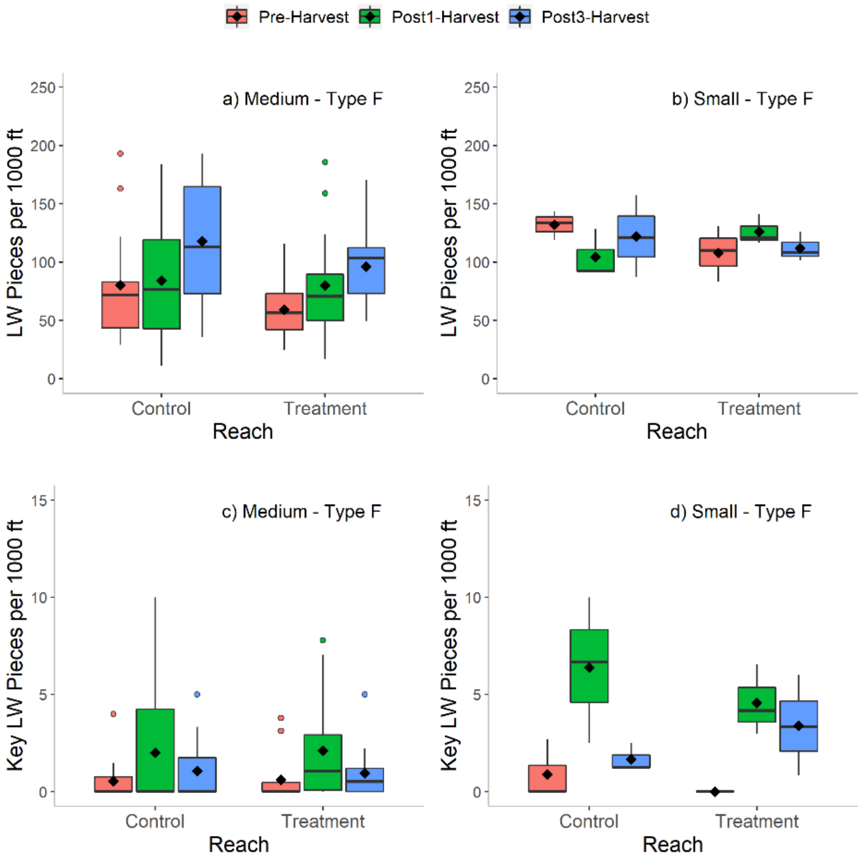

Figure 23. Boxplots of large wood pieces per 1000 ft of stream pre-, post1-, and post3-harvest for medium (a) and small (b) streams, and boxplots for key pieces for medium (c) and small (d) streams on private land. Large wood pieces had a diameter >6 in and length > 5ft, whereas key large wood pieces had a diameter >25 in and length >30 ft.

Table 5. Mean large wood (LW) pieces and key pieces per 1000 ft of stream pre-, post1-, and post3-harvest for medium and small streams within the control and treatment reaches on private land. Different capital letters within each column indicate significant differences pre- and post-harvest, and different lowercase letters within each row indicate significant differences among DBH classes.

Metric	**Stream Size**	**Time**	**Reach**	
			Control	**Treatment**
Number of LW pieces per 1000 ft stream *Diameter > 6 in; Length > 5 ft*	Medium	Pre-harvest	80.4 ±13.0^{Aa}	59.3 ± 6.8^{Aa}
		Post1-harvest	84.2 ±14.0^{Aa}	80.0 ±12.9^{Aa}
		Post3-harvest	118.0 ±14.5^{Ba}	107.9 ±14.4^{Ba}
	Small	Pre-harvest	132.0 ±7.2^{Aa}	108.0 ±13.8^{Aa}
		Post1-harvest	104.3 ±12.2^{Aa}	126.2 ±7.5^{Aa}
		Post3-harvest	122.1 ±20.2^{Aa}	112.0 ±7.3^{Aa}
Number of Key LW pieces per 1000 ft stream *Diameter > 25 in; Length > 30 ft*	Medium	Pre-harvest	0.5 ±0.3^{Aa}	0.6 ±0.3^{Aa}
		Post1-harvest	2.0 ±0.8^{Ba}	2.1 ±0.7^{Ba}
		Post3-harvest	1.1 ±0.4^{ABa}	0.9 ±0.4^{Aa}
	Small	Pre-harvest	0.9 ±0.9^{Aa}	0.0 ±0.0^{Aa}
		Post1-harvest	6.4 ±2.2^{Ba}	4.6 ±1.0^{Ba}
		Post3-harvest	1.7 ±0.4^{Aa}	3.4 ±1.5^{Aa}

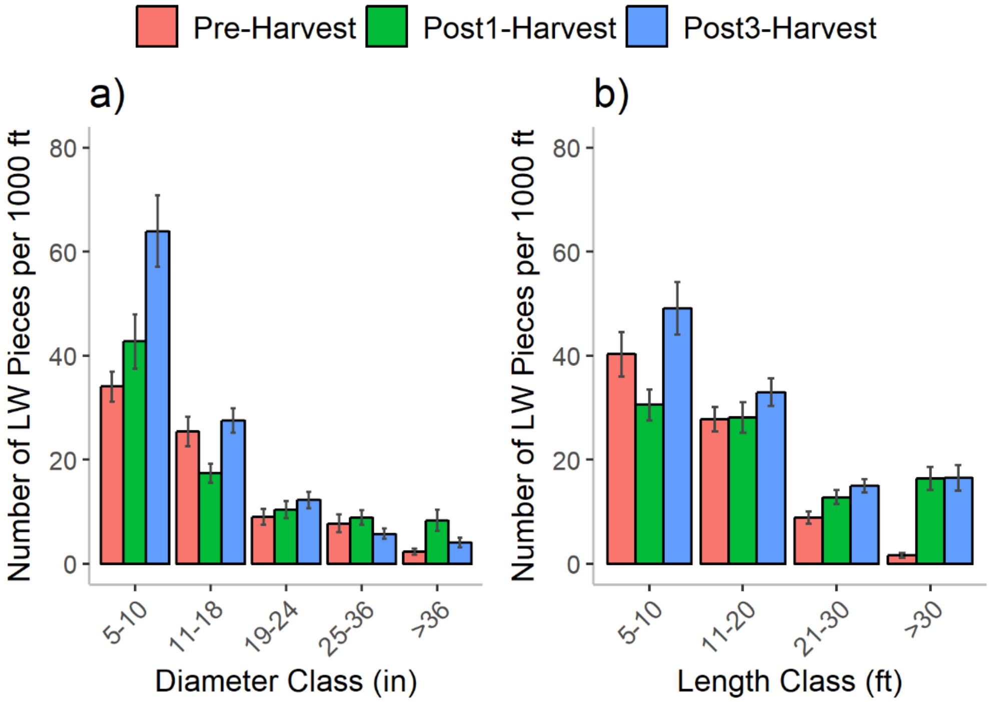

Figure 24. Diameter (a) and length (b) distributions of large wood pieces pre-, post1-, and post3-harvest in control and treatment reaches within small and medium streams on private land.

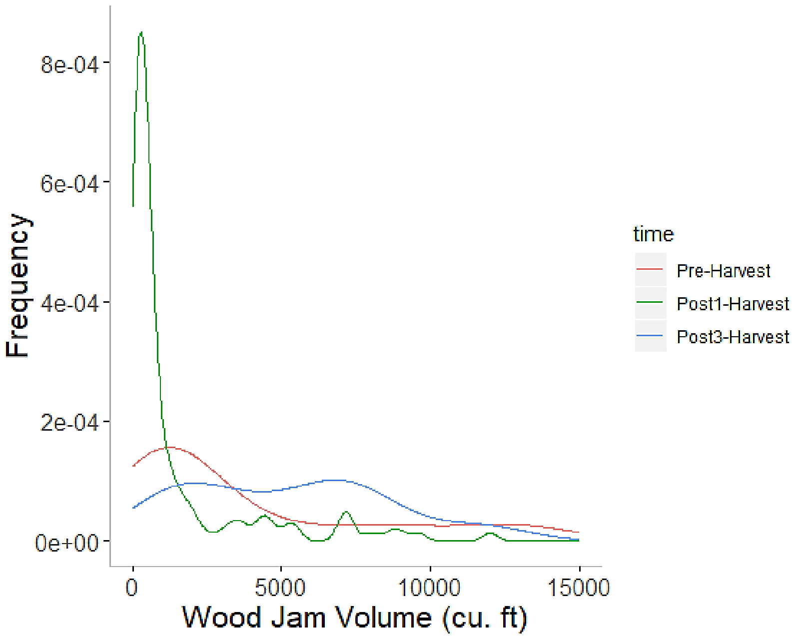

Figure 25. Density curves of wood jam volume (ft^3) for pre-, post1-, and post3-harvest time periods in control and treatment reaches along small and medium streams on private land.

Discussion

Pre-Harvest Overstory Trees

Our results show that riparian stands along small and medium fish-bearing streams in this study were even-aged and became established following timber harvests in the late 1950s to early 1970s. This time predates the FPA, which was passed by the Oregon legislature in 1971. Prior to the FPA, it was common practice to clearcut to the stream. Following clearcutting, regeneration of conifers likely occurred through planting or seed trees, and red alder likely established naturally as a result of this disturbance. The Oregon Conservation Act, passed in 1941, required reforestation after harvesting.

After 40 years of growth, riparian stands in this study displayed a wide range of conifer and hardwood basal areas. Conifers mostly consisted of western hemlock, Douglas-fir, and Sitka spruce, while hardwoods primarily consisted of red alder. Mixed-conifer-hardwood and conifer-dominated stands were more common than hardwood-dominated stands prior to harvest. In addition to seed trees and tree planting of conifers, landform and channel morphology may also explain the broad range of forest types that developed since clearcutting in 1950s to early 1970s at these sites. Landform plays an important role in determining overstory species composition of riparian forests (Villarin et al. 2009). For example, valley landforms that are fluvially disturbed promote deciduous regeneration and overstory, whereas upland landforms (e.g., hillslopes and terraces) promote conifer overstory (Villarin et al. 2009). Our findings are generally consistent with those of Villarin et al. (2009) given that red alder in this study tended to occupy areas that were more prone to fluvial disturbance (i.e., close to the stream).

Conifer basal area increased with distance from the stream, whereas hardwood basal area decreased with distance from stream (data not shown). Our results are generally consistent with a number of other studies that have observed increasing conifer basal area or density with distance from streams in the Pacific Northwest, including the Coast Range in Oregon (Minore and Weatherly 1994, Pabst and Spies 1999, Dent 2001, D'Souza et al. 2012). Regarding hardwoods, a number of studies have reported no trends in hardwood basal area with distance from the stream (Minore and Weatherly 1994, Pabst and Spies 1999, D'Souza et al. 2012), although hardwood tree density has been found to decrease with distance from the stream (D'Souza et al. 2012). Differences in stand age, stream size, and geographic region may explain a few of the inconsistencies between this study and other studies regarding hardwoods (Minore and Weatherly 1994, Pabst and Spies 1999, D'Souza et al. 2012). The studies mentioned above included older stands than stands in this study.

Post-Harvest Overstory Trees

The extent of conifers in riparian stands prior to harvest determined how many conifers were harvested from the stand. Stands that consisted of conifer basal area above the standard target prior to harvest experienced greater reductions (36%) in basal area due to harvesting in the RMA. In contrast, stands with lower conifer basal area with greater harvesting restrictions experienced little to no change in conifer basal area following harvesting. Hardwoods did not appear to be harvested by landowners. In this study, landowners were requested to harvest down the minimum basal area as required by FPA rules. While many sites were close to the minimum basal area, there were sites that had a basal area well above the minimum (Fig. 7; Groom et al. 2018), likely due to operational and topographic constraints.

Harvesting tended to target smaller diameter conifer trees near the outer edge of the RMA along small and medium fish-bearing streams. There are a few possible explanations as to why harvesting targeted smaller diameter conifer trees. First, conifers such as Douglas-fir have a higher timber value than hardwoods, such as red alder. Second, smaller diameter conifers were more abundant than larger diameter conifers and likely had a greater probability of being harvested in certain situations where the clearcut extended into the RMA. Third, there are very few mills in western Oregon that can process larger diameter trees. Finally, the larger diameter trees, when left as part of the residual stand, can account for a greater portion of the total stand basal area as compared with smaller diameter trees. Consequently, this may provide some incentive for retaining large-diameter conifer trees. Harvesting likely targeted trees near the outer edge of the RMA due to the logistics of harvesting immediately adjacent to the harvest unit. While there is evidence that harvesting targeted conifer species such as Douglas-fir, western hemlock, and Sitka spruce, it appears that species diversity of standing RMA trees was maintained.

Based on diameter distributions, it was clear that larger diameter trees were less common than smaller diameter trees, which is not surprising considering the age of these stands. While large diameter trees were scarce, our results are generally consistent with other studies in the Pacific Northwest that have examined the relative proportion of larger diameter trees in riparian stands with a similar age (Dent 2001, D'Souza et al. 2012). For example, D'Souza et al. (2012) found that large trees (> 20 in) contributed 10% to stand density for stands 31-51 yrs, 18% for stands 52-70 yrs., and 21% for stands >100 yrs. In this study, trees > 20-inch DBH, on average, contributed to 15 and 16% to stand density during pre- and post1-harvest, respectively.

For stands that exceeded the standard target for conifer basal area (i.e., '6a' sites), trajectories of stand growth displayed a wide range in basal area increases over time. On average, these stands were above the standard target after harvest, placing them at a good starting point for maintaining average mature conditions. The change in basal area over time appeared to be similar to that predicted by Lorensen et al. (1994). An important consideration in future trajectories of riparian stands is the lifespan of hardwoods. Red alder matures at an earlier age (60-70 yrs) and has a shorter lifespan (~100 yrs) than conifer species like Douglas-fir and western hemlock (Burns and Honkala 1990a, 1990b). Thus, young stands as observed in this study will likely experience a shift toward conifer dominance, potentially reducing competition by hardwoods. However, future disturbance events (e.g., localized landslides, debris-flows) will promote red alder regeneration. Long term studies in Oregon riparian stands will be valuable in understanding changes in species composition over time, which cannot be evaluated within the timeframe of this study.

Site index, a key variable in predicting changes in basal area over time, appears to be consistent with the values used by Lorensen et al. (1994). Further analysis of site index showed that certain areas within Western Oregon including Clatsop, Tillamook, and Coos counties tended to have lower site indices. This suggests that stands in these areas may require more time to achieve average mature conditions, while other areas such as Lincoln Country are likely to achieve mature conditions sooner. One possible explanation of lower site indices is Swiss Needle Cast, which is specific to Douglas-fir and primarily restricted to the Coast Range ranging from Coos Bay to Astoria in Oregon, and extending into coastal Washington (Shaw et al. 2011). A common symptom of Swiss Needle Cast is reduced tree height growth (Shaw et al. 2011), which would result in a lower site index if site index is based on tree measurements.

Past research in managed riparian forests and upland Douglas-fir unmanaged stands have shown that stand basal area increases with stand age (Spies and Franklin 1991, D'Souza et al. 2012), which is likely to occur during the next rotation for stands in this study. However, further work such as additional field measurements (e.g., DBH, height, basal area increment) and modeling stand growth and mortality over time could be important steps to identify a range of growth trajectories over time for these stands. It is important to reiterate that these results reflect the first 40 years of stand growth, and growth trajectories displayed here may not necessarily apply to older stands. Modeling stand growth or field measurements for stands in this study will also allow us to assess the relative effects of harvesting on growth trajectories. Additional field work in these stands will aid in validating model projections, which will be important in identifying responses to harvesting. Past research in riparian stands have shown that the type of harvesting or thinning can have different effects on riparian tree growth (Ruzicka et al. 2014). Overall, modeling stand growth using stand level inventory data from this study will provide further insight into the potential to achieve mature stand conditions and the effectiveness of the prescriptive rules on vegetation retention in achieving mature stand conditions.

Regeneration and Understory Vegetation

Species composition and quantity of seedlings and saplings play an important role in determining future overstory species composition and stand structure. In this study, stands with a higher conifer density of overstory trees supported a greater density of conifer seedlings and saplings prior to harvesting, highlighting the importance of seed trees in natural regeneration. Our results are consistent with other studies in the Oregon Coast Range that have observed greater conifer seedling density in riparian stands with a greater conifer basal area (Minore and

Weatherly 1994, Pabst and Spies 1999, Hibbs and Bower 2001). Hardwood-dominated stands were associated with low conifer seedling density and low conifer basal area of overstory trees. For shade-tolerant conifer species that are capable of establishing in shadier conditions of the understory, the lack of a seed source may explain the low conifer seedling density in hardwood-dominated stands. For shade-intolerant species such as Douglas fir, seedling recruitment was likely inhibited by shade produced by red alder stands. Other site-specific conditions not measured in this study (e.g., wet soils, past disturbance events) may also explain the lack of conifer seedling recruitment in hardwood-dominated stands. Current FPA rules include alternative riparian prescriptions[7] (e.g., hardwood conversion) that permit harvesting of hardwoods closer to the stream.

For conifers and hardwoods, we observed considerable variation in seedlings/saplings per acre among the vegetation plots. Conifer regeneration on average was fairly low, which is consistent with other riparian studies in the Oregon Coast Range (Minore and Weatherly 1994, Pabst and Spies 1999). Due to the high variation in seedling/sapling density among plots, we did not detect a change in conifer or hardwood seedlings after harvesting, which suggests that harvesting does not affect seedling recruitment in riparian areas 1 to 3 years after harvest.

When accounting for species, we detected an initial decrease in seedlings/saplings per acre for western hemlock, Douglas-fir, and Sitka spruce after 1 year post-harvest. However, after 3 years following harvest, there was no difference in seedlings/saplings relative to pre-harvest values. A number of factors could have caused a decrease in seedlings and saplings following harvest such as slash covering smaller seedlings, mortality from disturbance from harvesting or site prep, or a combination of both. The slight increase from post1- to post3-harvest may have been a result of seedlings outgrowing slash that covered them during post1-harvest, planted seedlings within the harvest unit, or both.

Vine maple and salmonberry were the most common shrubs prior to and following harvest. Vine maple experienced declines in percent cover further away from the stream, likely in the harvest unit where harvest was more common and where herbicide applications likely occurred. In contrast, salmonberry cover did not appear to change after harvesting. Shrub cover, particularly salmonberry, can outcompete or impede growth of conifer seedlings in early stages of development (Hyatt 1992, Newton et al. 1993, Minore and Weatherly 1994, Pabst and Spies 1999). There was evidence of an increase in salmonberry cover in subplots closest to the stream (25 ft) with little change outside of the RMA (100-150 ft), although we did not conduct statistical tests for understory shrubs. In undisturbed areas, salmonberry can sustain cover through rhizome extension, subsequent vegetative reproduction of new plants, and bud sprouting from old stems (Tappeiner et al. 1991). Clonal reproduction also tends be more prolific in red alder stands (Tappeiner et al. 1991). Salmonberry is capable of a quick recovery (within ~2 years) in response to disturbance, which may explain the lack of change outside of RMA despite equipment disturbance during harvesting and/or herbicide application during site prep. Red huckleberry, and salal to some extent, also experienced a decrease in percent cover following harvesting of overstory conifers. Red huckleberry in particular holds economic, medicinal, and cultural significance for tribes in the Pacific Northwest (U.S. Forest Service 2012, Whereat-Phillips et al. 2016).

---

[7] OAR 629-642-0600 (4)

Downed Wood in the RMA

In western Oregon, coarse woody debris is fundamental to conifer regeneration, as well as providing necessary habitat for salamanders and small mammals in riparian forests. Shade-tolerant conifer species, western hemlock and Sitka spruce, heavily rely on woody substrate for regeneration, particularly in the central and northern regions of the Oregon Coast Range (Pabst and Spies 1999, Hibbs and Bower 2001, Sarr et al. 2011). Conifer seedlings have been found growing on logs as quickly as 2 years after logs fall to the ground, and seedling density on logs peaks at 15-40 years after logs fall to the ground, depending on the conifer species of seedlings (Harmon 1986). Regeneration success is partially explained by the amount of bryophytes (e.g., moss) on logs. For example, initial colonization of logs by bryophytes facilitates conifer recruitment, but seedling survival tends to decrease with time due to increasing bryophyte depth (Harmon and Franklin 1987). As logs decay, exposure of wood through breakage or disturbance, provides additional opportunities for conifer regeneration (Harmon and Franklin 1989).

In this study, the number of downed wood pieces (i.e., less decayed logs) increased after harvesting outside of the RMA for small and medium streams, likely due to slash generated from harvesting and/or blowdown. The lack of change in total volume of downed wood outside of the RMA, as well as the diameter distributions of these stands, suggests that the increase in number of logs after harvesting was likely comprised of smaller diameter pieces. One hypothesis, supported in the literature (Harmon and Franklin 1989), suggests that conifer regeneration in the Oregon Coast Range is more successful on nurse logs due to reduced competition. Nurse logs provides an elevated position above the forest floor, free from competition of light and nutrient resources by herbs, mosses, and shrubs. Therefore, contribution to downed wood by larger diameter trees or maintaining higher stumps may improve survivorship of future seedlings by reducing the risk of competition from understory vegetation, providing greater surface area of rooting substrate and bryophyte colonization, and reducing decomposition rates of potential rooting substrate.

Our results are consistent with Spies et al. (1988) and Weikel et al. (2014) who found that downed wood was mostly comprised of moderately decayed logs for young stands (< 80 yrs). Moderately decayed logs as described in Spies et al. (1988) and Weikel et al. (2014) would fall into the more decayed class (e.g., decay classes 3 to 5) used in this report. Within the more decayed class, we detected a significant decrease in the volume of downed wood outside of the RMA along medium streams, which may be a result of heavy equipment breaking downed wood into smaller pieces that didn’t meet the size requirements (e.g., 6-in diameter, 3-foot length) for including in the data collection. Although, it isn’t clear why the volume of downed wood decreased inside of the RMA along small streams, while no changes were observed outside of the RMA. Decayed logs tend to support a higher plant species diversity, as well as greater plant cover (McDonald 2013). Large, decayed logs also provide critical habitat for Plethodontid salamanders in the Oregon Coast Range and western Cascades (Corn and Bury 1991, Butts and McComb 2000, Kluber et al. 2009).

Large Wood in Streams

Large wood in streams is important for creating and maintaining pools, as well as increasing sediment storage and structural complexity of streams (Bilby and Ward 1989, Naiman et al. 2000). Pools are a key component to salmonid habitat, especially during low flow conditions in the summer (Bisson et al. 1988, Nickelson et al. 1992, Reeves et al. 2011). There is strong evidence in the literature that the frequency and size of large wood pieces influences pool size, volume, or spacing (Andrus et al. 1988, Bilby and Ward 1989, Beechie and Sibley 1997). The presence of large wood is particularly important for sustaining pools in streams with steeper gradients (which tends to be the case for small and medium streams), as compared with low-slope channels (Beechie and Sibley 1997). Maintaining a continuous supply of large wood pieces to streams from adjacent riparian forests is critical for protecting fish habitat in Oregon.

While the source of large wood was not identified for large wood pieces in this study, the trend of increasing large wood over time does not appear to be associated with harvesting next to and within the RMA since this trend was observed in both the control and treatment reaches. Fundamental processes that lead to recruitment of large wood in small streams from adjacent riparian areas include slope instability (e.g., streamside landslides) and wind throw (May and Gresswell 2003). The relative importance of each of these processes is largely dependent on stream gradient and steepness of adjacent hillslopes. Flooding along unconstrained reaches also leads to greater large wood recruitment (Acker et al. 2003). Long distance transport via debris flows can contribute considerable amounts of large wood pieces to low gradient, downstream reaches (May 2002). Given that the greatest increase in large wood pieces over time occurred for largest length class (> 30 ft; Fig. 24b), windthrow and/or undercutting of trees along the bank via bank erosion are likely important sources of large wood for these streams.

While we would expect a greater frequency of blowdown trees in RMAs adjacent to clear cuts, we found that the number of blowdown trees per 1000 feet of stream were similar between control and treatment plots during years 1 and 5 post-harvest for small and medium streams. Furthermore, we observed an increasing trend in blowdown trees from year 1 to year 5 post-harvest. Our results suggests that during the post-harvest period in this study, harvesting did not necessarily result in a greater number of blowdown trees. This may partially explain the similar number of large wood pieces observed in the control and treatment reaches.

The size of large wood pieces (e.g., diameter and length) is an important consideration in large wood recruitment and additional outcomes including the creation of pools and more complex channel structure. First, the effectiveness of large wood in creating pools is dependent on the diameter of large pieces and stream size. Beechie and Sibley (1997) found that the smallest single piece that formed a pool within a reach was positively correlated with bankfull channel width. A 5-inch diameter piece, for example, is an approximation of the minimum size required to create a pool in a stream with a bankfull width of 13 feet. Thus, larger diameter pieces are likely more effective in creating pools, particularly in wider streams. Second, larger diamater pieces have a longer legacy effect due to greater volume and low decay rates as compared with smaller diameter pieces (McHenry et al. 1998, Benda et al. 2002). Third, shorter large wood pieces are more likely to be exported downstream (Lienkaemper and Swanson 1987). For example, Lienkaemper and Swanson (1987) found that during a high flow event, all pieces that moved 10 to 110 m downstream were shorter than the bankfull width of the stream. In this study, the average bankfull width of streams for all sites was 14 ft. Thus, smaller-diameter pieces in the smallest length (5-10 feet) class are more likely to be exported during high flows. Relative to pre-harvest conditions, the increase in large wood pieces consisted of a broad range of lengths (5 to >30 feet), although the largest increase was observed in the largest length class (>30 feet).

Long-term benefits of large wood in streams will likely be achieved through greater contributions by larger diameter, key pieces than what was observed in this study. As mentioned above, these stands are relatively young stands (~40 yrs) that established after clearcutting, so the contribution of larger diameter pieces will require time, well beyond the timespan of this study. Thus, modeling large wood recruitment is one approach to better understand the overall trajectories of managed riparian stands relative to unmanaged stands. Furthermore, a number of studies have evaluated the effects of harvesting on large wood recruitment (Hairstan-Strang and Adams 1988, Meleason et al. 2003, Czarnomski et al. 2008, Pollock and Beechie 2014, Benda et al. 2016, Burton et al. 2016), as well as stand age and temporal effects on large wood (Bilby and Ward 1991, Benda et al. 2002, Hassan et al. 2005), so a focused review of this type of literature will provide additional insight into the effectiveness of the FPA in achieving goals for large wood in streams.

Acknowledgements

We would like to thank private forest landowners and the Oregon Department of Forestry State Forests Division for allowing access to study sites. A special thanks to Liz Dent and Kyle Abraham for setting up and designing the study, as well as providing comments on the report. We would like to thank the Oregon Forest and Industries Council, Oregon Small Woodlands Association, Oregon Stream Protection Coalition, Rogue Riverkeeper, Coquille Indian Tribe, and Confederated Tribes of Grande Ronde for providing helpful comments on the report. We would like thank Jon Laine, Mike Thompson, and Kevin Nelson for collecting data and leading field crews. We would also like to thank Jeremy Groom for leading crews and providing data support and Lisa Madsen for providing statistical support. We would also like to thank ODF staff: Terry Frueh, Ariel Cowan, John Hawksworth, Paul Clements, and Jay Walters for their helpful comments on the report, figures, interpretation of the results, and policy implications. Finally, we would like to thank the RipStream External Review Team for providing input and feedback on the study and protocol.

References

Acker SA, Gregory SV, Lienkaemper G, McKee WA, Swanson FJ and SD Miller. 2003. Composition, complexity, and tree mortality in riparian forests in the central Western Cascades of Oregon. Forest Ecology and Management 173:293-308.

Andrus CW, Long BA and HA Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Canadian Journal of Fisheries and Aquatic Sciences 45:2080-2086.

Arismendi I and JD Groom. 2019. A novel approach for examining downstream thermal responses of streams to contemporary forestry. Science of the Total Environment 651:736-748.

Arney JD. 1985. A modeling strategy for the growth projection of managed stands. Canadian Journal of Forestry Research 15:511-518.

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1-48.

Beechie TJ and Sibley TH. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Transactions of the American Fisheries Society 126:217-229.

Benda LE, Bigelow P and TM Worsley. 2002. Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, USA. Canadian Journal of Forest Research 32:1460-1477.

Benda LE, Litschert SE, Reeves G and R Pabst. 2016. Thinning and in-stream wood recruitment in riparian second growth forests in coastal Oregon and the use of buffers and tree tipping as mitigation. Journal of Forest Research 27:821-836.

Bilby RE and JW Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in Western Washington. Transactions of the American Fisheries Society 118:368-378.

Bilby RE and JW Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in Southwestern Washington. Canadian Journal of Fisheries and Aquatic Science 48:2499-2508.

Bisson PA, Sullivan K, and JL Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Burns R and BH Honkala [Technical Coordinators]. 1990a. Silvics of North America: Volume 1. Conifers. United States Department of Agriculture (USDA), Forest Service, Agriculture Handbook 654.

Burns R and BH Honkala [Technical Coordinators]. 1990a. Silvics of North America: Volume 2. Hardwoods. United States Department of Agriculture (USDA), Forest Service, Agriculture Handbook 654.

Burton JI, Olson DH, and KJ Puettman. 2016. Effects of riparian buffer width on wood loading in headwater streams after repeated forest thinning. Forest Ecology and Management 372:247-257.

Butts SR and WC McComb. 2000. Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. Journal of Wildlife Management 64:95-104.

Corn PS and RB Bury. 1991. Terrestrial amphibian communities in the Oregon Coast Range. In Ruggerio LF, Aubry KB, Carey AB, and MH Huff, (editors), Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service General Technical Report PNW-285. Pacific Northwest Research Station, Portland, OR. Pp. 305-318.

Czarnomski et al. 2008. Dynamics of wood in stream networks of the western Cascades Range, Oregon. Can J For Res 38:2236-2248.

Davis LJ, Reiter M, and JD Groom. 2015. Modelling temperature change downstream of forest harvest using Newton’s law of cooling. Hydrological Processes 30:959-971.

Dent L. 2001. Harvest effects on riparian function and structure under current Oregon Forest Practice Rules. Oregon Department of Forestry, Technical Report #12.

Dent L, Vick D, Abraham K, Schoenholtz S, Johnson S. 2008. Summer temperature patterns in headwater streams of the Oregon Coast Range. *JAWRA* 44:803-813.

D'Souza LE, Six LJ, Bakker JD and Bilby RE. 2012. Spatial and temporal patterns of plant communities near small mountain streams in managed forests. Canadian Journal of Forest Research 42:260-271.

Groom JD, Dent L, Madsen LJ, and J Fleuret. 2011. Response of western Oregon (USA) stream temperatures to contemporary forest management. Forest Ecology and Management 262:1618-1629.

Groom J, Madsen LJ, Jones JE, Giovanini JN. 2018. Informing changes to riparian forestry rules with a Bayesian hierarchical model. *Forest Ecology and Management* 419-420:17-30**.**

Hairston-Strang AB and PW Adams. 1998. Potential large woody debris sources in riparian buffers after harvesting in Oregon, U.S.A. Forest Ecology and Management 112:67-77.

Harmon ME. 1986. Logs as sites of tree regeneration in *Picea sitchensis-Tsuga heterophylla* forests of coastal Washington and Oregon. Ph.D. Dissertation, Oregon State University.

Harmon ME and JF Franklin. 1989. Tree seedlings on logs in *Picea-Tsuga* forests of Oregon and Washington. Ecology 70:48-59.

Hassan MA et al. 2005. Spatial and temporal dynamics of wood in headwater streams of the Pacific Northwest. JAWRA 41:899-919.

Hibbs DE and AL Bower. 2001. Riparian forests in the Oregon Coast Range. Forest Ecology and Management 154:201-213.

Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Hyatt JM. 1992. Animal damage, vegetative competition and growth of western hemlock seedlings in the Coast Range of Oregon. M.S. Thesis, Oregon State University.

King JE. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper No. 8. Weyerhaeuser Forestry Research Center, Centralia, WA.

Kluber MR, Olson DH, and KJ Puettman. 2009. Downed wood microclimates and their potential impact on Plethodontid salamander habitat in the Oregon Coast Range. Northwest Science 83:25-34.

Kuznetsova A, Brockhoff PB, Christensen RHB. 2017. lmerTest Package: Tests in linear mixed effects models. Journal of Statistical Software 82: 1-26.

Lienkaemper GW and FJ Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Research 17:150-156.

Lorensen T, Andrus C, Runyon J. 1994. The Oregon Forest Practices Act water protection rules: Scientific and policy considerations. Forest Practices Policy Unit, Oregon Department of Forestry, Salem, OR.

McDonald SL. 2013. Understory diversity and succession on coarse woody debris in a coastal, old-growth forest, Oregon. M.S. Thesis. Portland State University.

May CL. 2002. Debris flows through different forest age classes in the central Oregon Coast Range. Journal of the American Water Resources Association 38: 1097-1113.

May CL and RE Gresswell. 2003. Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, U.S.A. Canadian Journal of Forest Research 33:1352-1362.

McHenry ML et al. 1998. Changes in the quantity and characteristics of large woody debris in streams of the Olympic Peninsula, Washington, U.S.A. (1982-1993). Canadian Journal of Fisheries and Aquatic Science 55:1395-1407.

Meleason MA, Gregory SV, and JP Bolte. 2003. Implications of riparian management strategies on wood in streams of the Pacific Northwest. Ecological Applications 13:1212-1221.

Minore D and HG Weatherly. 1994. Riparian trees, shrubs, and forest regeneration in the coastal mountains of Oregon. New Forests 8:249-263.

Naiman RJ, Bilby RE, Bisson PE. 2000. Riparian ecology and management in the Pacific Coastal Rain Forest. *BioScience* 50:996-1011.

Newton M, Cole EC, and DE White. 1993. Tall planting stock for enhanced growth and domination of brush in the Douglas-fir region. New Forest 7:107-121.

Nickelson TE, Rodgers JD, Johnson SL, and MF Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49:783-789.

Oregon Department of Forestry (ODF). 2002. Stand level inventory (SLI) field guide for the Riparian Vegetation Date Collection Project. Version 1.0.

Oregon Department of Forestry (ODF). 2003. Riparian function and stream temperature: Effectiveness of Oregon Department of Forestry's Protection Rules and Strategies. ODF Forest Practices and State Forests Study Approach, version 2.2.

Pabst RJ and TA Spies. 1999. Structure and composition of unmanaged riparian forests in the coastal mountains of Oregon, U.S.A. Canadian Journal of Forest Research 29:1557-1573.

Pollock MM and TJ Beechie. 2014. Does riparian forest restoration thinning enhance biodiversity? The ecological importance of large wood. Journal of the American Water Resources Association 50:543-559.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reeves GH, Sleeper JD, and DW Lang. 2011. Seasonal changes in habitat availability and the distribution and abundance of Salmonids along a stream gradient from headwaters to mouth in coastal Oregon. Transactions of the American Fisheries Society 140:537-548.

Ruzicka Jr. KJ et al. 2014. Management of riparian buffers: upslope thinning with downslope impacts. Forest Science 60:881-892.

Sarr DD, Odion D, Hibbs D, Weikel J, Gresswell R, Bury R, Czarnomski N, Pabst R, Shatford J, Moldenke A (2005) Riparian zone forest management and the protection of biodiversity: A problem analysis. Technical Bulletin No. 908. National Council for Air and Stream Improvement (NCASI), Inc. Research Triangle Park, N.C. 107 pp.

Sarr DA et al. 2011. Influences of life history, environmental gradients, and disturbance on riparian tree regeneration in Western Oregon. Forest Ecology and Management 261:1241-1253.

Shaw DC, Filip GM, Kanaskie A, Maguire DA, and WA Littke. 2011. Managing an epidemic of Swiss Needle Cast in the Douglas-Fir region of Oregon: The role of the Swiss Needle Cast Cooperative. Journal of Forestry 109:109-119.

Spies TA, Franklin JF, and TB Thomas. 1988. Coarse woody debris in Douglas-fir forests of Western Oregon and Washington. Ecology 69:1689-1702.

Spies TA and JF Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington.

Tappeiner J, Zasada J, Ryan P, and M Newton. 1991. Salmonberry clonal and population structure: The basis for a persistent cover. Ecology 72:609-618.

U.S. Forest Service. 2012. Terrestrial restoration and conservation strategy. Region 6, Pacific Northwest Region.

Villarin LA, Chapin DM, and JE Jones III. 2009. Riparian forest structure and succession in second-growth stands of the central Cascade Mountains, Washington, USA. Forest Ecology and Management 257:1375-1385.

Waddell KL. 2002. Sampling coarse woody debris for multiple attributes in extensive resource inventories. Ecological Indicators 1:139-153.

Weikel J, Krahmer R, and J Cathcart. 2014. Compliance with leave tree and downed wood Forest Practices Act regulations. Oregon Department of Forestry, Technical Report #20.

Whereat-Philips P. 2016. Ethnobotany of the Coos, Lower Umpqua, and Siuslaw Indians. Oregon State University Press.

Wickham H. 2016. ggplot2: Elegant graphics for data analysis. Springer-Verlag, New York.