RipStream Data Analysis and Preliminary Results

Background

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 necessary for providing many of these functions into the future.

The Forest Practices Act (FPA) water protection rules on vegetation retention along streams were designed to produce desired future conditions (DFC) for riparian stands along streams in Oregon. The concept of DFC of riparian stands along fish use streams, crafted in 1994, 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 [OAR 629-642-0000(2)]. Vegetation retention prescriptions that include minimum basal area (BA), conifer species, and widths of riparian management areas (RMAs) are outlined in the FPA rules (OAR 629-642-0100). An underlying assumption of these prescriptions is that managing riparian forests consistent with the prescriptive rules will result in the outcomes described above (e.g., shade and large wood).

In 2002, the Oregon Department of Forestry (ODF) initiated the Riparian Function and Stream Temperature (RipStream) study throughout the Oregon Coast Range. The study objective was to evaluate the effectiveness of FPA rules in protecting stream temperature, and meeting DFC. 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. This phase of the RipStream analyses will assess the effectiveness of FPA rules at meeting large wood and DFC objectives (per OAR 629-642-0000). This analysis is one component of the larger project, the Western Oregon Streamside Protections Review, which will include data analysis of Ripstream data, systematic literature review, and modeling analyses.

For the RipStream field data analysis, the following questions from the original RipStream protocol 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?

Furthermore, the analysis will evaluate how current rules and landowner and operator behavior influence riparian stand characteristics. 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 recruitment of large wood 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. In addition to the RipStream data analysis, this project will include a systematic literature review addressing DFC and large wood recruitment in streams. We are also exploring modeling streamside stand growth, mortality, regeneration, and large wood recruitment into the future to assess whether the FPA rules will achieve DFC for stands at 120 years of age. Modeling large wood recruitment using the RipStream data will better address the third question above.

Methods

Study Sites

The RipStream study occurred from 2002 to 2010 at 33 sites in the Oregon Coast Range (Dent et al. 2008, Groom et al. 2011). Study sites were along small and medium fish-bearing streams on privately-owned and state forests sites (18 and 15 sites, respectively). Riparian forests at the study sites (i.e., state and private) were typically between 50 and 70 years old, fire- or harvest-regenerated, and 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 an upstream 'control' reach and a downstream 'treatment' reach. The control reach was not harvested throughout the study period, and the treatment reach surrounding the RMA was thinned or clear-cut no sooner than two years following the start of the study. Based on previous analysis (Groom et al. 2018), harvesting occurred within the (RMA) at most sites, excluding a few sites on state land. Both treatment and control reaches contained at least one vegetation plot each, and most had two plots located on opposing sides of the streams. Thus, each site had a total of two to four plots and always had at least one control and one treatment plot.

Vegetation plot measurements

Control and treatment plots were used to survey pre- and post-harvest overstory and understory vegetation (Fig. 1). Each plot (500' x 170') included five transects running perpendicular to the valley azimuth spaced 100 feet apart. Six equally-spaced circular subplots ($1/100^{th}$ acre) were established along each transect at 25' intervals for understory vegetation measurements (Fig. 1). 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 to stream was converted to slope distance.

We observed measurement error associated with slope distance to stream, which was evident in a preliminary analysis that observed positive and negative changes within 20' 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' and there appeared to be a general trend of more trees lumped at 25' intervals (i.e., 25', 50', 75', etc.). The binning of slope distance may have explained the measurement error described above. Our analysis indicated that field technicians were having some difficulty assigning an exact distance value to individual trees.

Tree height was measured for at least 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 within each plot. Measurements for overstory trees were made on all plots during pre-harvest year 1 and post-harvest year 1. Additionally, overstory measurements were made for a few plots during post-harvest year 5. Starting in post-harvest year 1 and for a few 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.

Understory vegetation included small trees (<6 in 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. 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, though budget reductions associated with the 2008 recession resulted in fewer plots with the full suite of measurements five years after harvest.

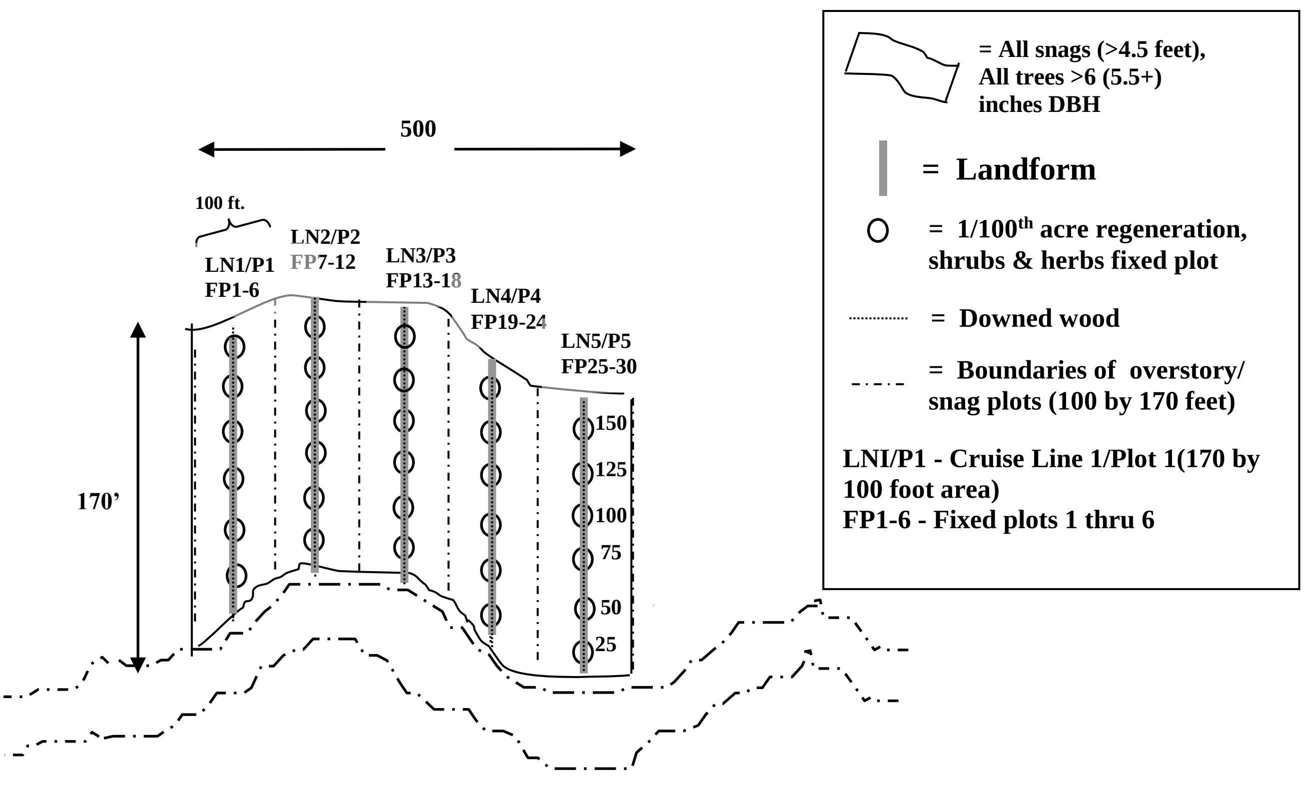

Figure 1. Rectangular plots for riparian vegetation and downed wood measurements.

Statistical Analysis

Statistical analysis consists of both descriptive statistics (e.g., percentages and means) and specific statistical tests as needed and appropriate. We have consulted with the Oregon State University StatNat consulting program in the Statistics Department for developing the appropriate statistical models for testing treatment effects. The primary statistical analysis will include a mixed-effects model to test treatment effects using pre- vs. post-harvest stand parameters, as well as assessing significance of other categorical predictor variables (e.g., dbh-class, species, and FPA rule). The fixed effects will include treatment (pre- and post-harvest) and the other categorical variables described above, and the random effect will be site. While the experiment was designed in a way such 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).

Preliminary Results and Discussion

The preliminary results below mostly focus on riparian stands growing along medium and small type F streams on private land with a few exceptions. Figures 2 and 10 include sites on state forests used primarily for reference.

Stand age and history

Tree ages across all RipStream stands including state and private land along small and medium streams had a wide range of 15 to 260 years, with a mean age of 46.6 ± 1.1 (± std. error) years (Fig. 2a). The majority of trees sampled for age included Douglas-fir and western hemlock. The trees with ages greater than 100 were all on state land (Fig. 2b), which is evident when comparing the age distribution to that of private land (Fig. 2b). Tree ages across stands on private land only for small and medium fish streams had a smaller range of 16 to 81 years, with a mean age of 38.3 ± 0.5 years (Fig. 2b).

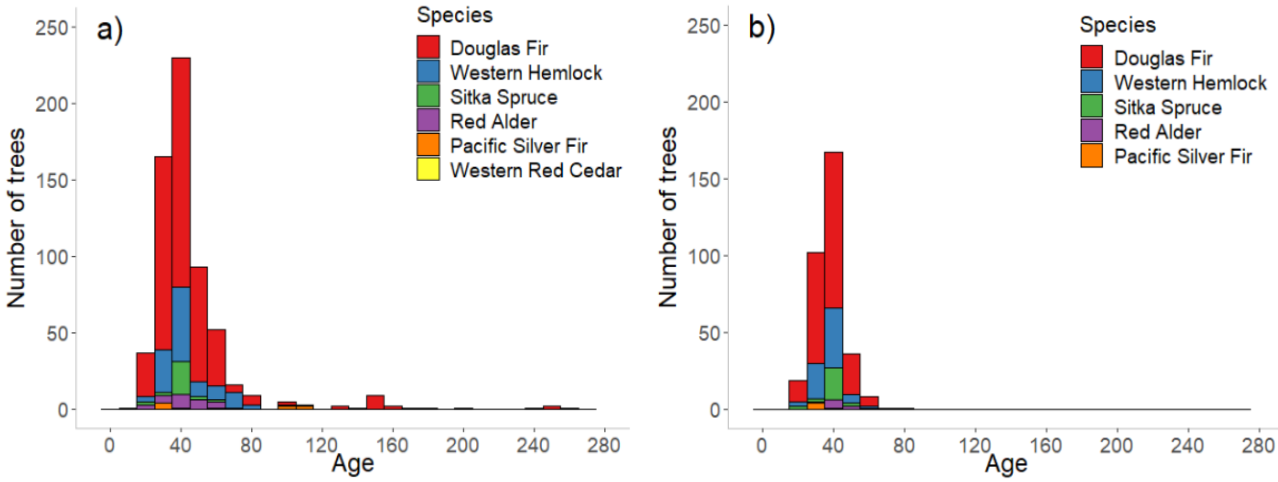

Figure 2. Age distribution for riparian trees growing on Private and State land (a) and on Private land only (b). Both panels include small and medium streams. The number of trees within each 10-year age class are shown for each species.

Given that these data were collected in 2002-2003, as well as the age distribution displayed in Figure 2b, suggests that these riparian stands were even-aged and became established 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. The Oregon Conservation Act, passed in 1941, required reforestation after harvesting.

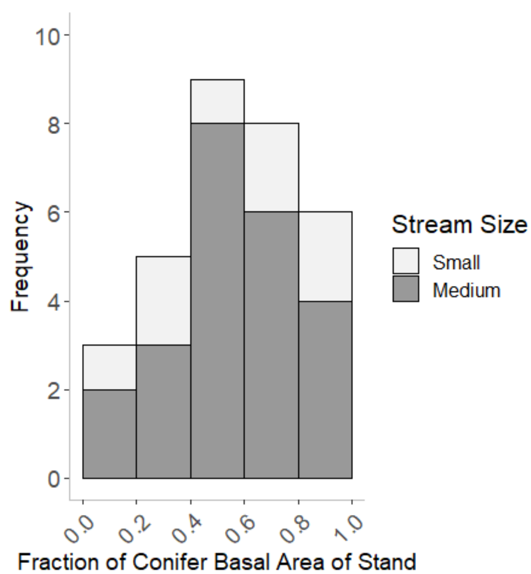

Figure 3. Distribution of the fraction of conifer basal area of riparian stands along small and medium stream on private land.

Pre-harvest stand conditions

After ~40 years of growth, the RipStream stands on private land contained a wide range in the relative amount of conifer vs. hardwood presence. Figure 3 shows the distribution of the proportion of conifer basal area relative to the total stand basal area. 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-stands would be represented by values closer to 0.5. The distribution is slightly skewed to the right, where the frequency of stands are more distributed near the conifer-dominated end of the spectrum. The median and mean proportion of conifer basal area was 0.50 and 0.56, respectively. These data show that both conifer-dominated and mixed-conifer-hardwood stands were more common, whereas the hardwood-dominated stands were less common.

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 (OAR 629-642-0100). 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). If the conifer basal area within the RMA is below the standard target and above ½ the standard target, the landowner should retain all conifers greater than 6” dbh (Rule 6b). If below ½ the standard target, the landowner should retain all conifers in the RMA and hardwoods within 50 ft of the stream (Rule 6c).

Pre-harvest conifer harvest basal area in the RMA along medium type-F streams displayed a wide range of values (3 – 511 sq. ft. per 1000 ft; Fig. 4a). Therefore, the associated prescriptive rules on vegetation retention differed among stands (i.e, plots). More than half (54%) of the stands were above the standard target (‘6a’ stands), 29% of stands were below but greater than ½ the standard target (‘6b’ stands), and 17% were below ½ the standard target (‘6c’ stands). For small streams, the conifer basal area per 1000 feet was considerably lower than medium streams, primarily an artifact of the narrower buffer width (Fig. 4b). A majority of stands (75%) were above the standard target, and 25% 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 4a. 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.

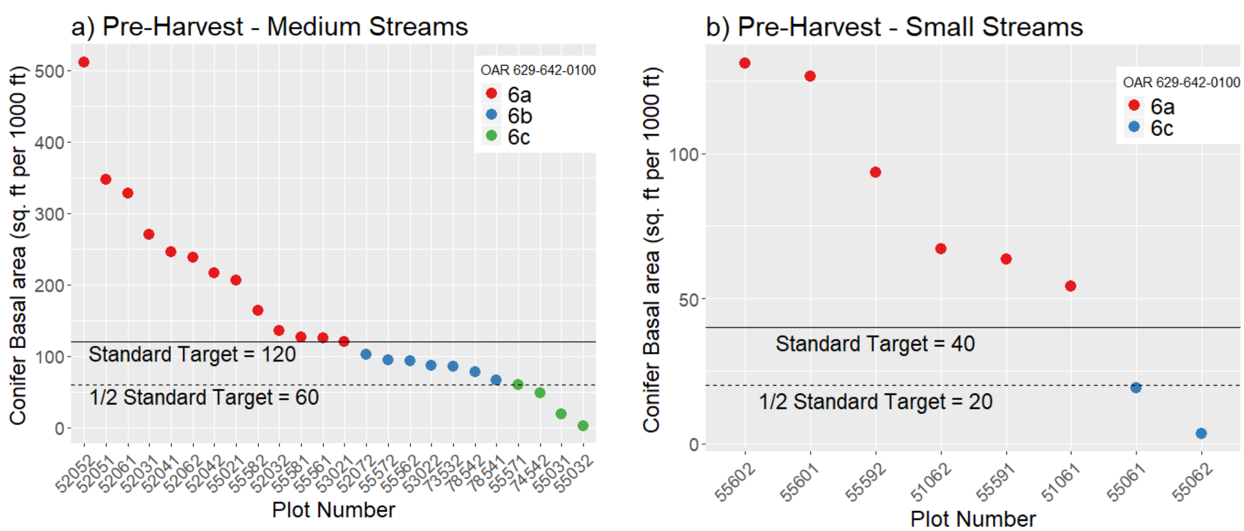

Figure 4. Pre-harvest conifer basal area (sq. ft. per 1000 ft) for each plot along medium (a) and small (b) type F streams on private land. Each panel identifies (with colors) whether the plot or stand falls into rule category 6a, 6b, or 6c, which is determined by the basal area relative to the standard target and ½ of the standard target that are shown on the figure.

Harvest effects on riparian stands

As expected, our preliminary analysis suggests that greater harvesting of conifers occurred for sites that exceeded the basal area 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. 5a, 5b). Sites that fall into rule category 6a showed larger decreases in conifer basal area from pre- to post-harvest. Sites that fell into rule category 6b and 6c did not experience noticeable changes in basal area. Additional statistical analysis will test treatment effects in this analysis. Stand density (trees per 1000 ft) displayed consistent trends with basal area, where the 6a stands displayed greater decreases after harvesting occurred (data not shown).

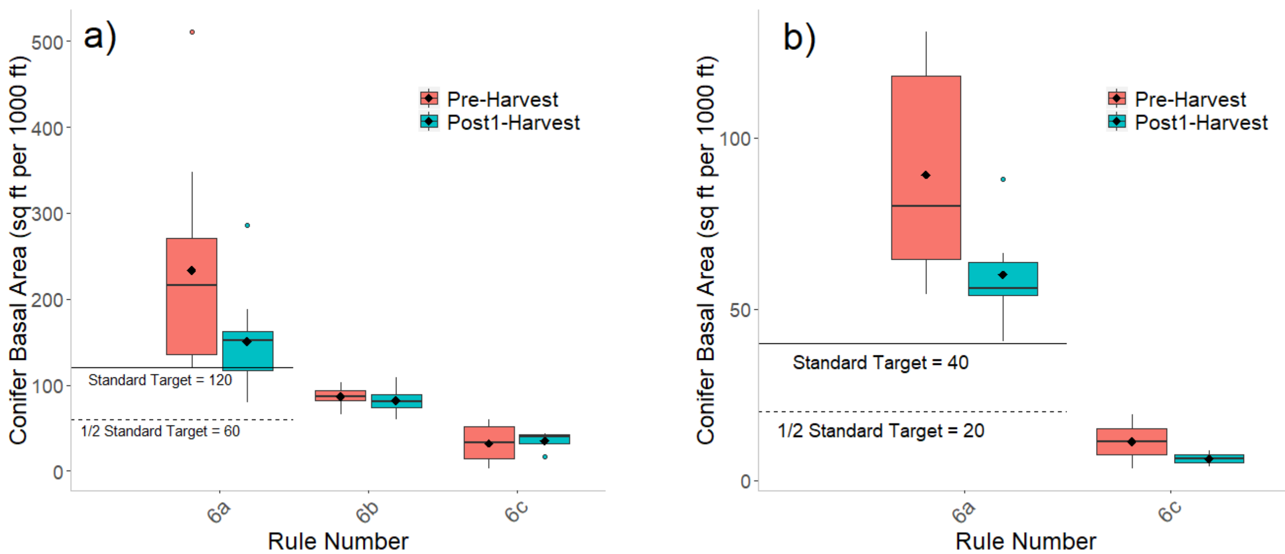

Figure 5. Conifer basal area along medium (a) and small (b) streams for pre- and post1-harvest. The plots were grouped by the rule category (described above). Each box shows the interquartile range from the 25th to 75th percentile represented by the bottom and top, respectively, of the box. The median 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.

In comparing, pre- and post-harvest diameter distributions, harvesting appeared to target conifers in the smaller diameter classes along both medium and small streams (Figs. 6a-d). The mean number of conifer trees within 4” dbh classes across plots decreased in most diameter classes, with the most noticeable decreases occurring for trees ranging from 6” to 22” dbh for both medium (Fig. 6a) and small streams (Fig. 6c). For medium streams, there were a few conifer trees greater than 34” dbh; however, there was not a detectable change. For hardwoods, there was some evidence for a decrease in number of trees in the 6-10” and 10-14” dbh classes (Figs. 6b-c); however, further statistical analysis will identify whether these differences are significant.

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, the 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.

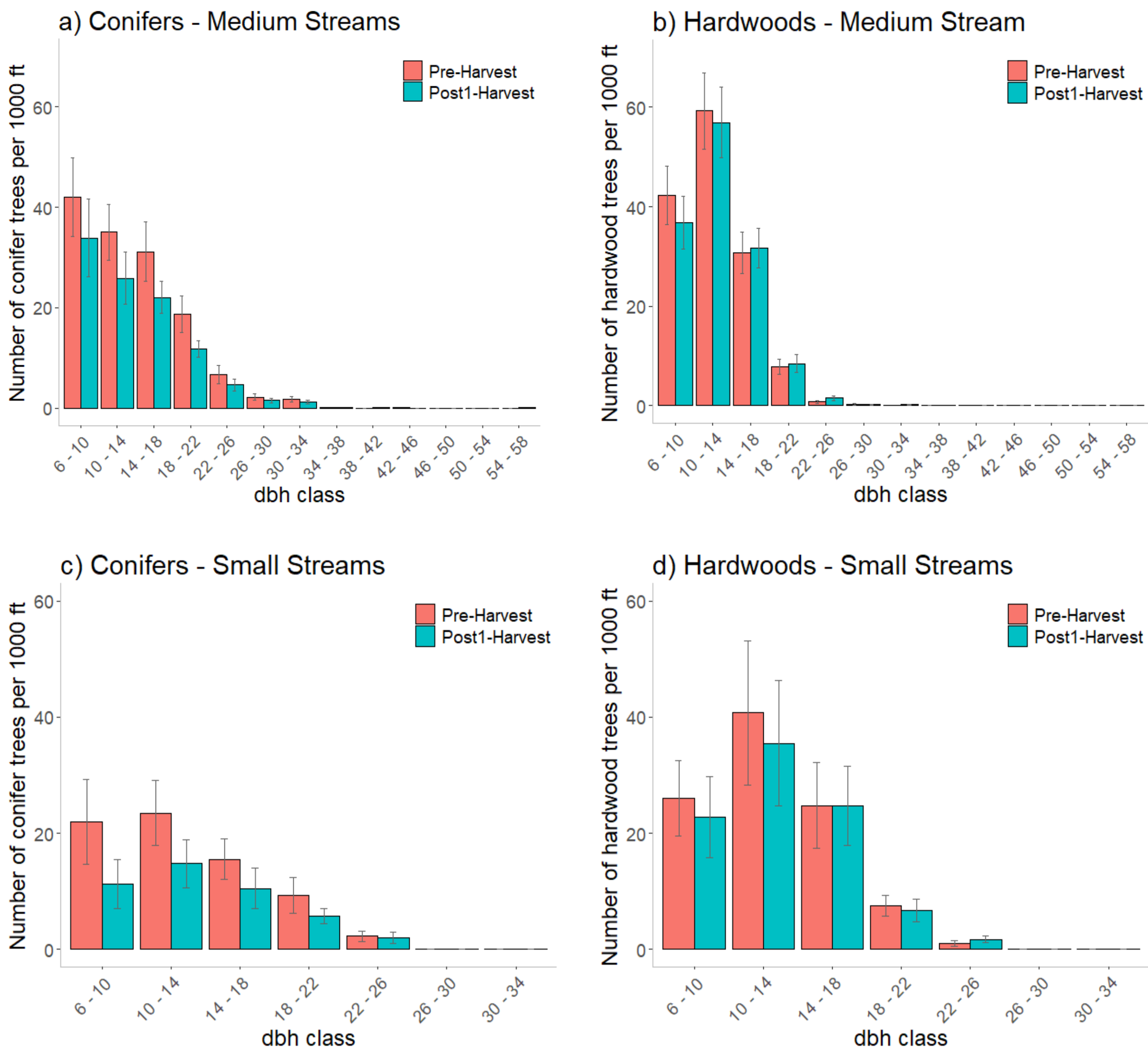

Figure 6. Diameter at breast height (dbh) distributions pre- and post1-harvest for conifers along medium streams (a), hardwoods along medium streams (b), conifers along small streams (c), and hardwoods along small streams. Dbh bins were set at 4”. Error bars represent the standard error of the mean.

Harvesting tended to target western hemlock and to some extent, Sitka Spruce, which is surprising given the higher value of Douglas-fir than other species (Fig. 7a). 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. Douglas-fir was a targeted species for harvesting along small streams. Red alder was also more common than other species along small streams.

Within the RMA, harvesting of conifer trees mostly occurred near the outer portion of the RMA away from the stream. This generally includes 50-70' away from stream along medium streams and 40-50' for small streams (Fig. 8a-d). Outside of the RMA, the large decrease in 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.

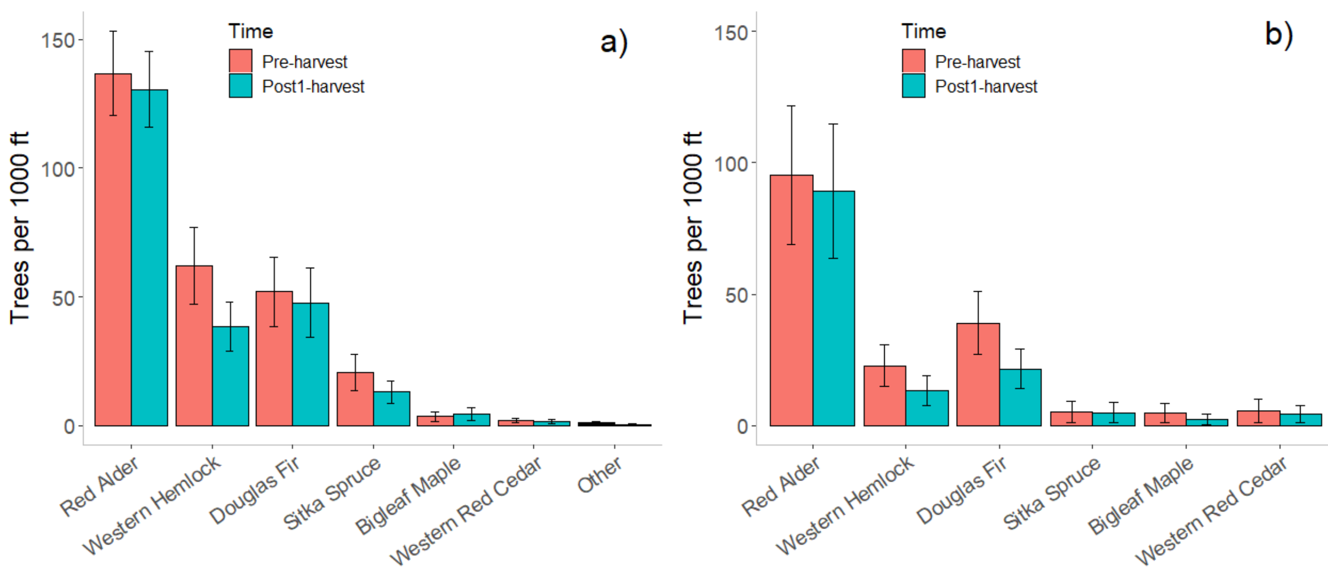

Figure 7. Mean number of trees per 1000 ft of stream pre- and post1-harvest for each species along medium (a) and small (b) streams. The error bars represent the standard error of the mean.

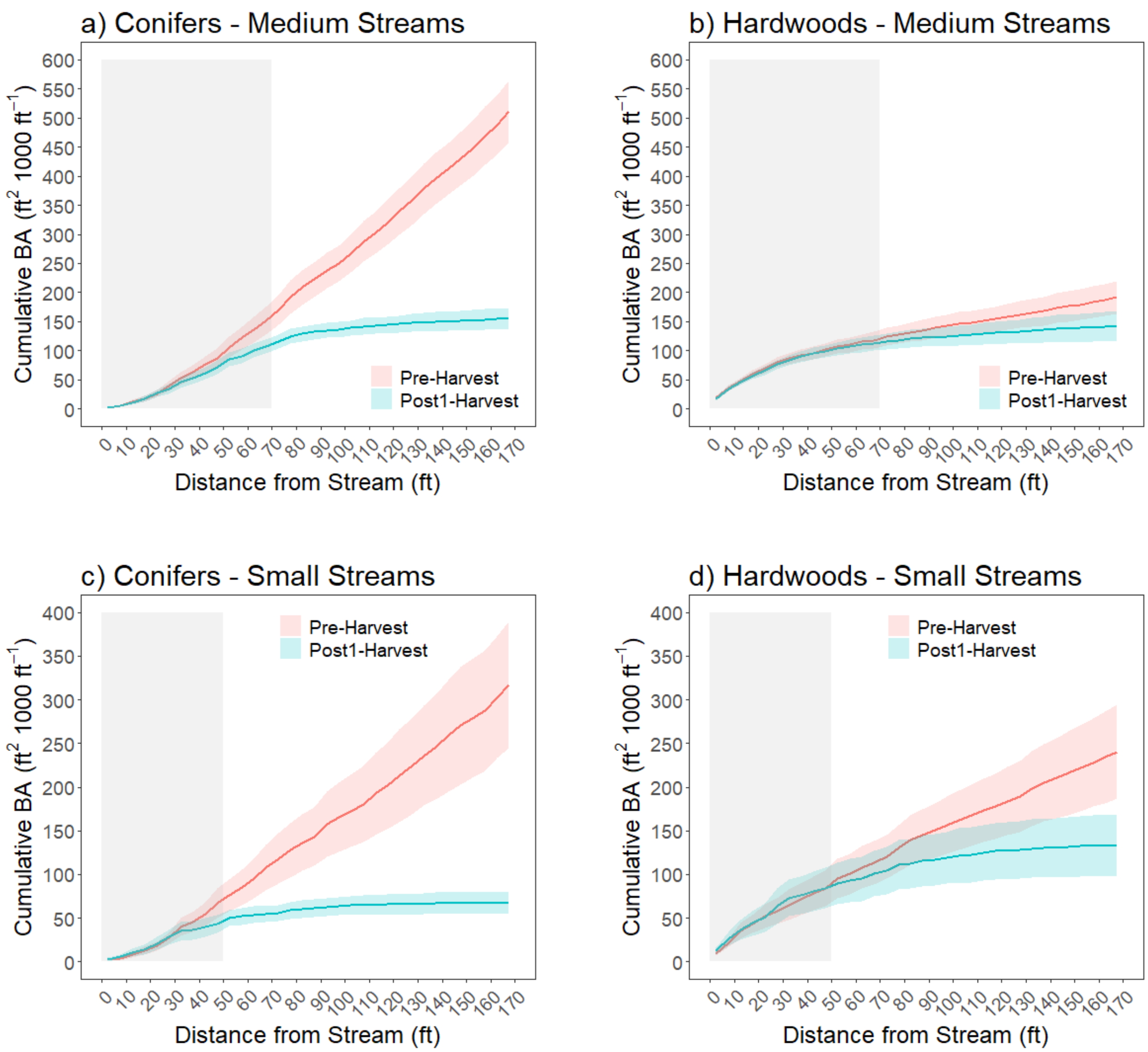

Figure 8. Cumulative basal area as a function of distance from stream for pre- and post1-harvest for conifers along medium streams (a), hardwoods along medium streams (b), conifers along small streams (c), and hardwoods along small streams (d). The red and blue shaded areas represent the standard error of the mean at 5 ft intervals. The gray shaded box represents the RMA.

Assumptions for Basal Area Targets

The basis for the current FPA basal area targets is described in Lorensen et al. (1994). The 'average mature conditions' are based on a fully stocked 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., stream-associated wetlands). Lorensen et al. (1994) assumed that the average mature stand conditions could be achieved across the landscape if stands were on a 50 year rotation and the stand basal area was brought down to the standard target at the end of each rotation. Figure 9a is a conceptual diagram that illustrates the theoretical conifer basal at the beginning, midpoint, and end of each rotation period for an individual stand along a medium type-F stream. The diagram repeats the rotation three times. Lorensen et al. (1994) calculated the basal area target required to achieve mature stand conditions at mid-rotation, which corresponds with the average basal area over time. However, the starting point at year 0 with respect to the stand age is unclear.

Using the RipStream data, we overlaid the trajectories of RipStream stands where basal area was greater than the standard target rule category 6a with the conceptual diagram (Fig. 9b). 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 9b 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 landowner behavior with respect to harvesting in the RMA, which can be used to develop modeling and harvest scenarios.

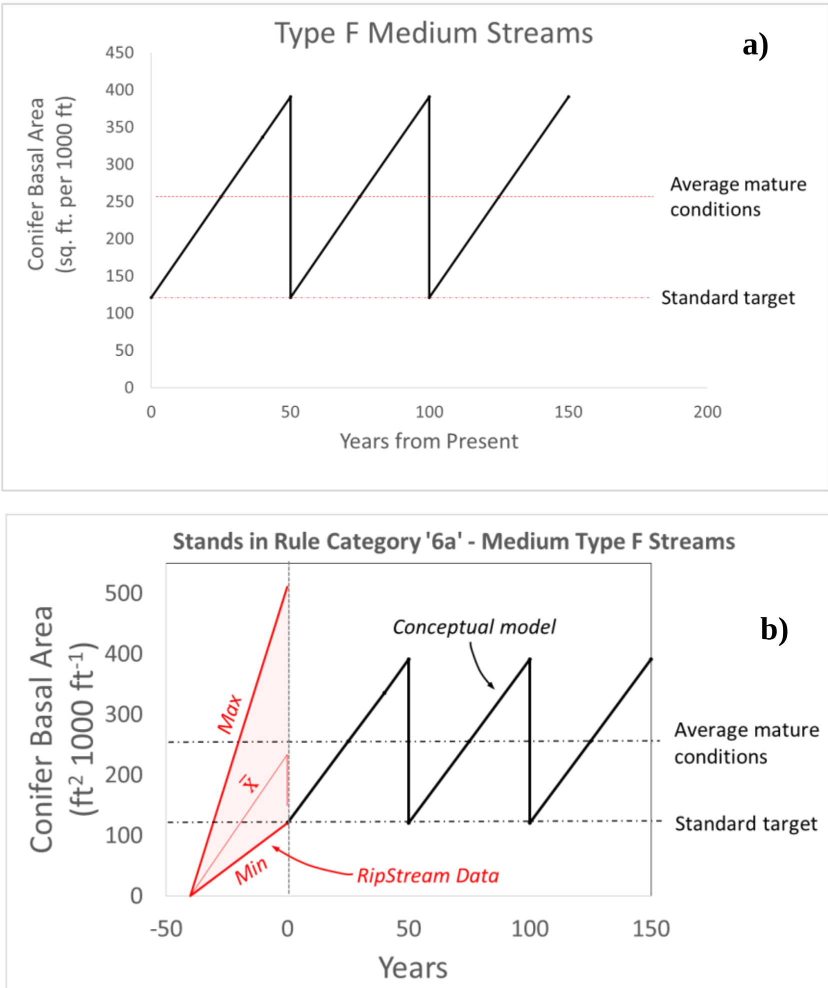

Figure 9. Panel (a) shows a conceptual diagram as adapted from Lorensen et al. (1994) that shows the conifer basal for a fully stocked, upland Douglas fir stand at the start, midpoint, and end of a 50-year rotation. This is repeated three times in this diagram. The average mature conditions and standard target for medium type-F streams are also shown. Panel (b) shows the same conceptual diagram overlaid by the RipStream data. These data show the maximum, minimum, and mean trajectories of stand basal area over a period of 40 years, assuming that riparian areas adjacent to the stream were clear cut.

For the Coast Range, Lorensen et al. (1994) assumed a site index of 119. The site index in this case is the mean tree height of the stand at 50 years and site index curves are used to describe the increase in height with stand age. The site index is often used to assess what the basal area of a stand is at full stocking. Our results suggest that that a site index of 119 is valid for Douglas-fir and other conifers. Figure 10 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). Given the nearly identical increase in height with age between the two lines suggest that the site index of 119 is valid. For other species such as Sitka spruce and western hemlock, a number of points fall along or near the site index curve of 119. However, there are a number of points that deviate from the line. 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.

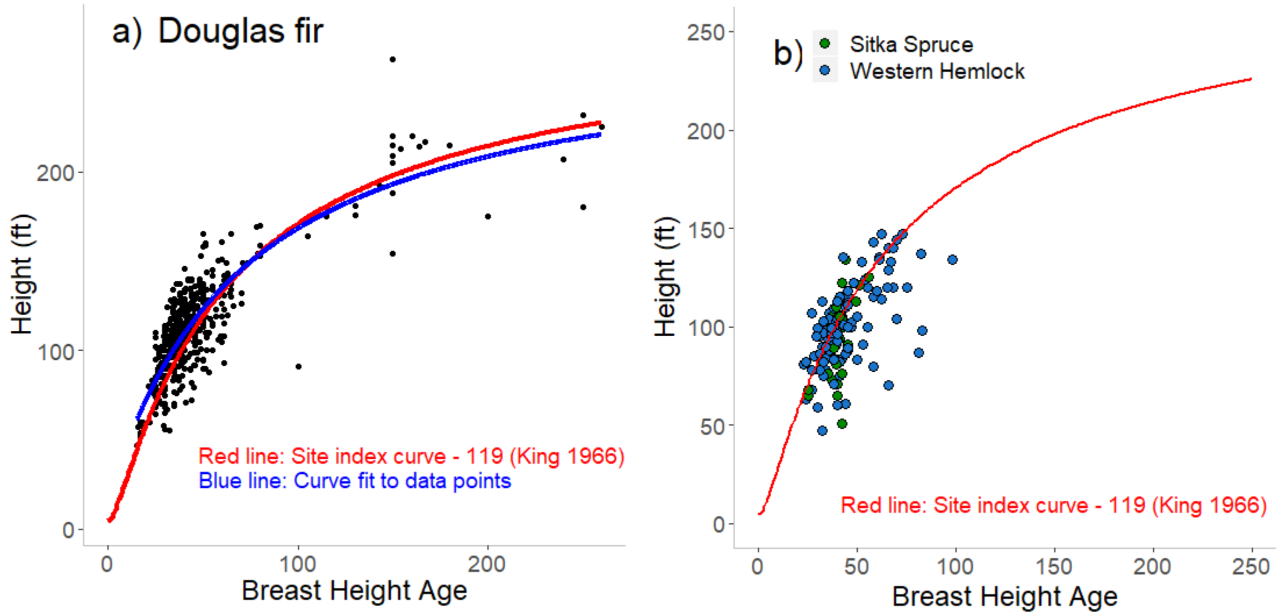

Figure 10. Site index curves (height vs. age) for Douglas fir (a) and Sitka spruce and western hemlock (b). In panel (a), a curve is fit to the RipStream data (blue line) and a site index curve of 119 is also plotted for reference (red line). In panel (b), only the site index curve of 119 is shown for reference. A curve was not fit to the data due to the lack of points greater than 100 years.

Blowdown

The analysis up to this point has included blowdown trees (e.g., post-harvest), because this was the best approach to understanding landowner behavior. We did, however, assess the effects of blowdown relative to harvesting effects on basal area and stand density across sites along medium streams. Figure 11 shows the mean, median, and confidence intervals for basal area and stand density for pre-harvest, post1-harvest (including blowdown trees in post-harvest basal area), and post1-harvest (not including blowdown trees in post-harvest basal area). Our results show that harvesting had a greater effect on basal area and stand density as compared with blowdown. 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. While this suggests that including blowdown trees as part of our analysis would not have strongly influenced the preliminary findings thus far, we will compare treatment effects (e.g, with and without blowdown trees) using statistical analysis to further validate this conclusion.

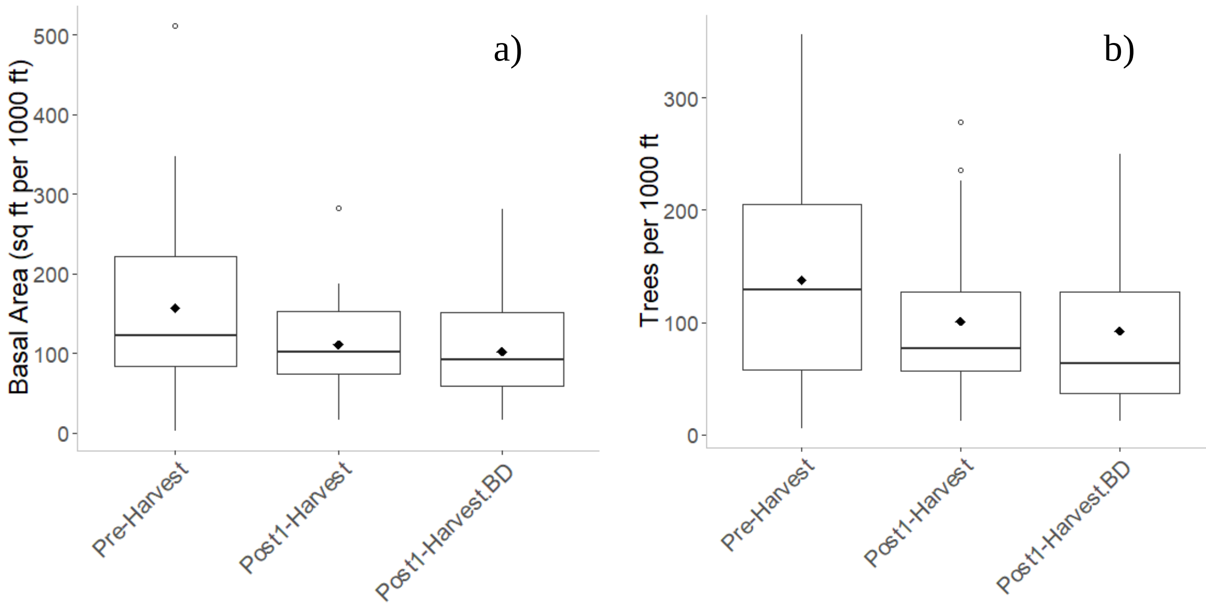

Figure 11. Basal area (a) and trees per 1000 ft of stream (b) for pre-harvest, post1-harvest including blowdown trees, and post1-harvest excluding blowdown trees ('Post1-Harvest.BD). See Figure 5 caption for an interpretation of the box-plot lines and symbols.

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