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Accuracy and suitability of selected sampling methods within conifer dominated riparian zones

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ABSTRACT

Sixteen sampling alternatives were examined for their performance to quantify selected attributes of overstory conifers in riparian areas of western Oregon. Each alternative was examined at eight headwater forest locations based on a 0.52 ha square stem maps. The alternatives were evaluated for selected stand attributes (trees per hectare, basal area per hectare and height to diameter ratio), using root mean square error, absolute percent bias, and mean absolute deviation as criteria. In general, rectangular strip designs outperformed fixed area circular or radial plots and variable area plots. Sampling 3.6 m wide strips perpendicular to the stream outperformed all other alternatives.

1. Introduction

This study examines the accuracy and suitability of a variety of sampling methods to quantify stand attributes of conifer dominated riparian forests of western Oregon. Forest structure can be described in a variety of ways such as species composition (Aguirre et al., 2003; Nierenberg and Hibbs, 2000; Harper and Macdonald, 2001; Coroi et al., 2004; Pabst and Spies, 1999) or measures of tree density (Coroi et al., 2004; Lhotka and Loewenstein, 2006), basal area per hectare (Pabst and Spies, 1999), diameter distribution (Chen and Bradshaw, 1999; Mason et al., 2007), height distribution (Chen and Bradshaw, 1999), crown diameter (Chen and Bradshaw, 1999), canopy characteristics (Nierenberg and Hibbs, 2000; Harper and Macdonald, 2001; Pabst and Spies, 1999; Lhotka and Loewenstein, 2006), snag density (Harper and Macdonald, 2001; Pabst and Spies, 1999), or downed wood (Harper and Macdonald, 2001). The best sampling alternative is that which most accurately quantifies the attributes of interest in typically diverse riparian forests.

Quantifying stand attributes within riparian areas can be extremely difficult. Riparian areas rank among the most complex, variable and dynamic terrestrial habitats in the world (Coroi et al., 2004). This is no different in the Pacific Northwest (Acker et al., 2003). Horizontal and vertical structure are all highly variable within riparian areas of headwater streams (Richardson and Danehy, 2007). For example, stand-level variations in density, diameter and total tree height occur for both conifer and hardwood components. Snags within riparian areas add to the variety of vertical structure. This study focused on stand attributes of trees per hectare, basal area per hectare, and average height to diameter ratio. The objective was to assess sampling alternatives to identify those that best account for the complexities of riparian areas and therefore are appropriate to monitoring riparian forest structure.

The riparian areas of interest in this study were associated with headwater streams. Headwater streams, typically first- or second-order streams, are different than larger streams (Richardson and Danehy, 2007) and serve as important habitat for amphibians and other non-fish vertebrates (Olson and Weaver, 2007). They make up a high percentage of total stream length (Richardson and Danehy, 2007) and drain much of the overall watershed area (Anderson et al., 2007). An accurate sampling methodology is important to characterizing those forest attributes that provide habitat and contribute to species diversity within these stream systems.

Spatial structure is typical for many riparian forest attributes. Stream to upslope gradients often exist for microclimate (Anderson et al., 2007), understory vegetation (Pabst and Spies, 1999), and tree species composition and density (Minore and Weatherly,

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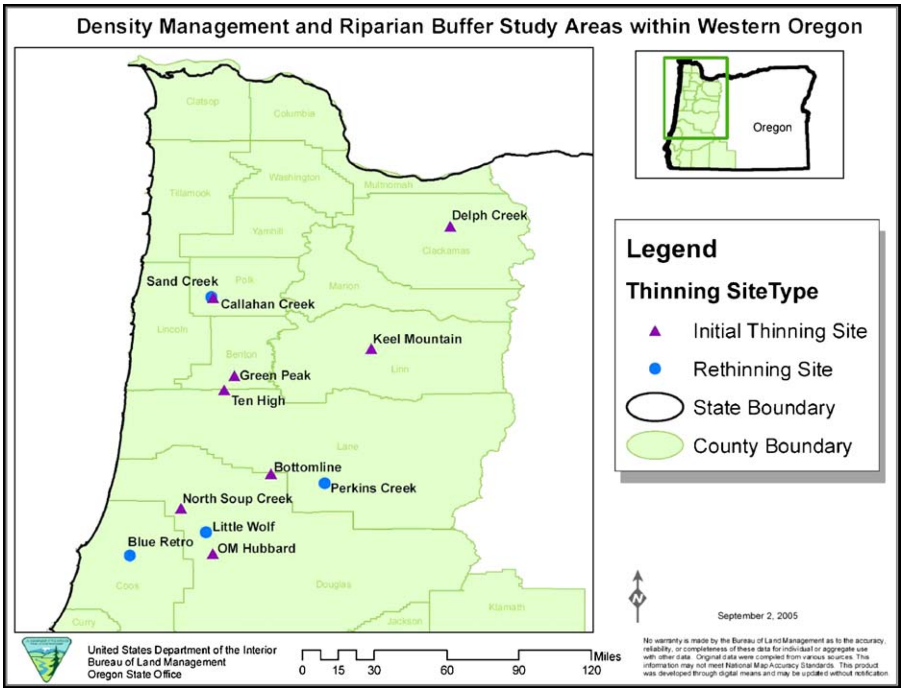

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Fig. 1. Map of DMS site locations (Cissel et al., 2006).

1994). The relative performance of different sampling methods provides information about sources of spatial variation within riparian zones. Some sampling methods mainly capture variation perpendicular to the stream, while others focus on sampling attributes parallel to the stream.

In this study we compared the performance of sixteen sampling methods representing variations of six general design types: simple random sampling (SRS), systematic random sampling (SYRS), stratified random sampling (STRS), two-stage sampling, horizontal line sampling (HLS) and sector sampling for quantifying trees per hectare, basal area per hectare, and height to diameter ratio. The sampling alternatives consisting of different sizes and arrangements of circular plots and rectangular strips were chosen to address the following hypotheses regarding sources of variation within riparian areas:

1. Variation is greater moving from the stream to upslope than moving parallel along the stream.
2. Structural attributes may differ on opposite sides of the stream such that sampling only one side of the stream will produce inadequate stand-level estimates.
3. Variation along the length of the streams will be better sampled with alternating, or staggering strips from one streamside to the other than a continuous strips that span both sides of the stream.

A variety of methods have been used to compare the quality of estimates derived from different sampling designs. Common criteria are standard error of the mean (Dahl et al., 2008; Ducey et al., 2002; Lindsey et al., 1958; Paulo et al., 2005; Schreuder et al., 1987), and bias (Kenning et al., 2005; Nelson et al., 1998; Schreuder et al., 1992; Temesgen, 2003; Tokola and Shrestha, 1999). This study compared the precision and accuracy of stand attributes derived from each sampling method to the known values determined from complete census of a stem mapped plot at each of eight headwater stream locations.

2. Methods

This study was conducted on United States Bureau of Land Management (BLM) Density Management Study (DMS) sites. A primary goal of the DMS is to evaluate various thinning treatments in young, relatively uniform stands as means to enhancing structural complexity and the development of older forest characteristics. The DMS sites are located in the Coast Range and the western foothills of the Cascade Range in Oregon (Fig. 1). At the time of treatment between 1997 and 2000 stand ages ranged among sites from 40 to 70 years. Riparian areas associated with headwater streams (generally first- or second-order streams) within experimental density management treatment units were the focus of this study.

The riparian areas sampled in this study were chosen using a stratified random sampling scheme. A list of all possible headwater reaches within the DMS was generated from maps and stream attribute data provided by the US Forest Service. Stream reaches were stratified to sample two overstory density treatments, three

Table 1
Description of stream reaches sampled from the DMS site locations.

Location	Reach number	BLM district	Density	Buffer	% Slope	Slope class	Aspect
Bottom Line	13	Eugene	Moderate	Two tree height	51	S	NE/SW
Keel Mountain	17	Salem	Control	Control	18	M	N/S
Keel Mountain	18	Salem	Moderate	Two tree height	21.2	M	NW/SE
Keel Mountain	19	Salem	Moderate	Two tree height	14	M	NW/SE
Keel Mountain	21	Salem	Moderate	Variable width	38	S	N/S
O.M. Hubbard	36	Roseburg	Moderate	Variable width	31	S	NW/SE
Ten High	46	Eugene	Control	Control	19	M	N/S
Ten High	75	Eugene	Moderate	Variable width	33	S	N/S

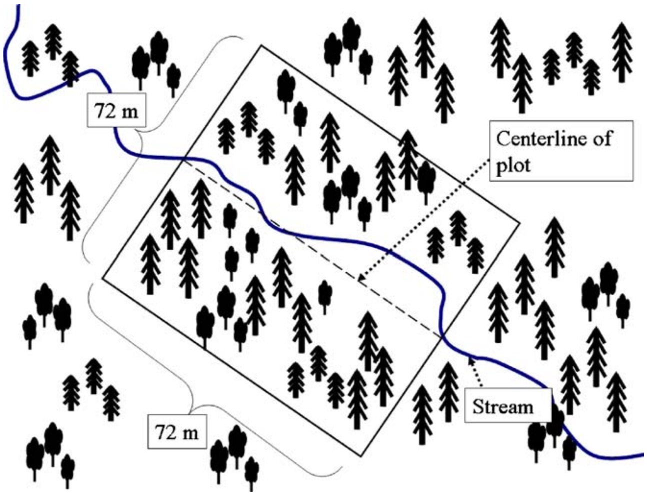

Fig. 2. Illustration of plot layout on the sampled stream reach. The centerline of the 72 m square block was oriented in the general direction of the stream. Sampling of trees took place 36 m from the centerline to upslope.

Table 2
List of tree parameters measured on each stem mapped tree and the recording protocol for each measurement.

Tree attribute	Recording protocol
Diameter at breast height	Nearest 1/10th centimeter
Species	4 Letter code, appendix
Canopy classification	Visually determined, 1 letter code, Dominant (D), Codominant (C), Intermediate (I), Suppressed (S)
Condition	Visually determined, Dead (D), Live (L)
	2 Letter code, visually determined
	F1-Live, full crown
	F2-Partially dead crown
	F3-Dead crown
	S1-Two or more crowns
Crown class	S2-One crown broken off
	B1 to B5—snags with different size classes
Decay class	2 Letter code, visually determined

uncut buffer treatments, and two channel sideslope classes. Of twelve reaches originally selected for sampling time constraints limited sampling to eight reaches (Table 1). The two density management treatments were an unthinned control with 200–350 trees per acres (TPA) (494–865 trees per hectare) and moderate density retention where 60–65% of the stand had been thinned to 80 TPA (198 trees per hectare). Buffer treatments consisted of a two site potential tree height buffer (2SPTH), a variable width buffer and an unthinned control. The 2SPTH buffer is measured in slope distance from the stream center and is based on the 50 year site index height of trees for each site, on average 146 ft (44.5 m). The variable width buffer had a minimum width of 15.2 m each side of the stream, but varied based on channel topographic features or the inclusion of sensitive areas, such as those prone to landslide or where plant species of concern were present. Reaches were stratified between those having sideslopes less than 30% or greater than 30%.

One 0.518 ha (72 m × 72 m) square sample plot was randomly located along each of the headwater streams. The plot ran 72 m parallel to the stream and 36 m upslope, on each side of a centerline anchored in the stream channel at the upper and lower ends of the stem mapped sample plot (Fig. 2). Randomization of sample plot locations was accomplished by measuring the available length of stream reach from GIS stream layers and generating a random number to determine to the nearest location of the downstream end of the block. On site, a laser rangefinder was used to locate the predetermined plot location for each stream.

On each 0.518 ha plot the positions of all woody stems greater than 6.9 m tall or 7.6 cm breast height diameter (dbh) were mapped using Total Station Survey Equipment. A survey-grade GPS was used to determine the coordinates for mapping control points (station locations). A reflector was held against the outside of the tree or within 0.3 m of the center of the tree. The distance to each tree (estimate of precision for distance) was calculated by internal software based on the bearing from the station to the tree, and the latitude and longitude of the station. The size of the plot and the density of stems required mapping from multiple control locations per plot.

Tree observations including breast height diameter (DBH), species, condition, canopy classification, crown class, and decay class were made and recorded during stem mapping (Table 2).

Diameter was measured with a diameter tape to the nearest 0.1 cm at a stem height of 1.37 m on the uphill side of the tree. Multiple-stemmed trees forking below 1.37 m were counted as multiple trees. Diameter was measured above any stem abnormalities such as bulging. Pistol butt or leaning trees were measured at 1.37 m along the stem. The condition of the tree was visually assessed. A tree without any green foliage was considered dead; a tree having any green foliage was considered live.

Table 3
Description of the sampling alternatives examined in this study including the number of plots simulated at the 10% and 20% sampling intensity. Under "Shape", R = rectangular, C = circular, and T = transect, and Ra = radial plot.

Sampling alternative	Description	Size	Shape	Plots (10%)	Plots (20%)
FAP5R	Random fixed area plots	5.64 m radius	C	5	10
FAP9R	Random fixed area plots	9 m radius	C	2	4
FAP5S	Systematic fixed area plots	5.64 m radius	C	5	10
FAP9S	Systematic fixed area plots	9 m radius	C	2	4
ASTP3	Alternate perpendicular strips	3.6 m × 36 m	R	4	8
ASTP7	Alternate perpendicular strips	7.2 m × 36 m	R	2	4
PEST3	Perpendicular strips	3.6 m × 72 m	R	2	4
PEST7	Perpendicular strips	7.2 m × 72 m	R	1	2
OSSP3	Perpendicular, one side only	3.6 m × 36 m	R	4	8
OSSP7	Perpendicular, one side only	7.2 m × 36 m	R	2	4
PAST3	STRS parallel strip sampling	3.6 m × 36 m	R	4	8
PAST9	STRS parallel strip sampling	9 m × 28.8 m	R	2	4
HLS08	Horizontal line sampling	BAF 8	22 m T	2	4
HLS10	Horizontal line sampling	BAF 10	27 m T	2	4
SEC11	Sector sampling	11.46°	36 m Ra	4	8
SEC22	Sector sampling	22.92°	36 m Ra	2	4

The sixteen sampling design alternatives (Table 3) were evaluated by simulation using SAS (v. 9.1, SAS Institute, 1990). All hardwoods and dead conifers were removed from the dataset and the sampling designs were evaluated for live conifer trees only. Because the relative abundance of hardwoods and dead trees was generally small, it was assumed that different sampling designs better suited to rare or highly variable phenomenon would be needed to sample these features. Sampling of the hardwood and snag component is being addressed in a separate study (Marquart et al., in preparation). To address edge effects associated with the stem mapped area, the plot data was wrapped edge to end. Each design was simulated for both a 10% ($0.1^*72^2 = 518.4\,\text{m}^2$) and a 20% ($0.2^*72^2 = 1036.8\,\text{m}^2$) sampling intensity.

Each of the sixteen sampling alternatives was implemented in simulation 500 times with a different random starting point for each simulation. The plot center coordinates were randomly selected and the number of sample plots per design varied with plot size and sampling intensity (Table 3).

Simple random sampling (SRS) used circular, fixed area plots with radii of 5.64 m or 9 m. Systematic random sampling (SYRS) used circular plots as well as several strip sampling alternatives. The alternating strip designs (ASTP3 and ASTP7, Table 3) were distinct. These designs were simulated by breaking the 72 m grid into either 3.6 m or 7.2 m wide strips which were 36 m in length. The strips were oriented perpendicular to the centerline of the plot (Fig. 2), approximately perpendicular to the stream. Each strip consisted of a rectangular plot on one side of the stream and the rectangular strip diagonal to it on the opposite side of the stream. For example, one could think of this as running a transect perpendicular to the stream and sampling a 3.6 m strip to the left of the transect line on one side of the stream, and all trees within 3.6 m to the right of the transect line on the opposite side of the stream. Stratified random sampling (STRS) was used to sample strips running parallel to the stream, but also with at least one strip close to the stream, and another upslope. For the 9 m option, the 72 m grid was first split into 9 m strips running parallel to the stream; the two outermost strips on either side of the stream comprised one stratum and the four innermost strips comprised a second stratum.

Two-stage sampling was simulated as sampling only one side of the stream using the strip sampling approach. The stream side to be sampled was selected in the first stage. In the second stage, the selected sample area was broken into strips that were systematically sampled. This approach was simulated using strips 3.6 m and 7.2 m width, The 500 simulations were evenly distributed between the two stream sides for each reach.

The horizontal line sampling (HLS) alternative provided designs using variable radius plots to the comparison. Each transect for the HLS design began at the centerline of the plot and were placed perpendicular to the stream. Lynch's (2006) equations were used to expand the data from each transect(s) to a per hectare basis. Two BAF were chosen based on the approximate amount of area that was sampled. Unlike the other alternatives that ran 36 m perpendicular to the stream, this alternative sampled at 22 m and 27 m upslope from the stream for the 8 BAF and 10 BAF alternatives respectively.

The sector sampling design was adapted from Iles and Smith (2006). For this study, the sector was essentially a fixed area plot to simplify area calculations. First, a 36 m radius fixed area circular plot was selected randomly within the 72 m grid. Next, two to four sectors of either 11.46° or 22.92° were sampled depending on the alternative. Sectors were sampled based on a bearing that was randomly generated as a starting point for the first plot. Remaining plots were systematically sampled. In the 20% intensity design for the 11.46° sized sector, two 36 m fixed area plots were placed within the 72 m grid and four sectors were sampled from each of the circular plots.

Three methods were used to evaluate each of the sampling designs compared to the actual stem map. The designs were evaluated based on how well they predicted trees per hectare (TPH), basal area per hectare (BAPH) and height to diameter ratio (H/D) using root mean square error (RMSE), absolute percent bias (APB), and mean absolute deviation (MAD). Individual tree heights were estimated using a height-diameter equation based on the Chapman–Richards function (Richards, 1959) as applied by Garman et al. (1995) for western Oregon species. Height to diameter ratio was calculated based on estimated height and measured diameter.

The RMSE was computed as:

$$\text{RMSE} = \sqrt{\frac{\sum_{k=1}^{500} (\hat{Y}_k - Y)^2}{500}} \tag{1}$$

where $\hat{Y}_k$ is the estimated attribute (TPA, H/D, or BAPH) for the kth replication and Y is the known attribute value.

All the selected sampling alternatives are known to be unbiased, so the traditional measure of bias was not computed. Instead, an absolute value of the cumulative bias was used. It is the average of the absolute value of the percent bias for each replication. The absolute value does not allow one to know if the alternative is over or underestimating the mean, but only by how much. The equation used to estimate absolute percent bias is as follows:

$$\text{APB} = \frac{\sum_{k=1}^{500} \left| \frac{\hat{Y}_k - Y}{Y} \right|}{500} \tag{2}$$

where $\hat{Y}_k$ is the estimated attribute (TPA, H/D, or BAPH) for the kth replication and Y is the known attribute value.

MAD was used as a measure of variation from the mean of the 72 m square subpopulations. The equation used to estimate MAD is as follows:

$$\text{MAD} = \frac{\sum_{k=1}^{500} \left| \hat{Y}_k - Y \right|}{500} \tag{3}$$

where $\hat{Y}_k$ is the estimated attribute (TPA, H/D, or BAPH) for the k$^{\text{th}}$ replication and Y is the known attribute value.

3. Results

Estimates of TPH had RMSE values that ranged from 64.3 to 261.8 for 10% sampling intensity and from 40.4 to 261.6 for 20% sampling intensity (Table 4). ASTP3 and PEST3 had the smallest values. The RMSE values for BAPH (m^2) ranged from 8.5 to 28.3 for the 10% sampling intensity and 5.6 to 28.4 for the 20% sampling intensity. ASTP3 and ASTP7 had the smallest values. The RMSE values for the height to diameter ratio ranged from 1.3 to 2.4 for the 10% sampling intensity and from 0.8 to 1.9 for the 20% intensity. ASTP3 and PEST3 estimated height to diameter ratio most accurately. Standard deviations suggested that the variation among estimates was quite large for HLS08, HLS10, and OSSP3 (Table 4).

Absolute percent biases when estimating TPH, BAPH and H/D ratio were least using ASTP3, ASTP7, PAST3, and PEST3 designs (Table 5). The standard deviation about the mean was relatively large for FAP5S and FAP9S. Standard deviations ranged from 15.8% to 61.4% and 9.7% to 61.3% when estimating TPH at the 10% and 20% intensity respectively. When estimating BAPH, absolute percent bias values ranged from 16.8% to 56.0% for the 10% intensity and 11.0% to 56.1% for the 20% intensity. The alternatives that performed well when estimating the height to diameter ratio were the ASTP3, ASTP7, PAST3, PEST3, SEC11, FAP5S and PEST7 alternatives. Values ranged from 1.7% to 3.0% for the 10% sampling intensity and from 1.0% to 3.0% for the 20% intensity (Table 5).

Sampling alternatives that performed well when evaluated using MAD were ASTP3, ASTP7, PAST3, PEST3, PEST7, and SEC11

Table 4
Summary of sampling alternatives evaluated using RMSE. Values under trees per hectare (TPH), basal area per hectare (BAPH, m^2) and height to diameter ratio (H/D) are the mean RMSE values from the eight locations. Shaded values are the five smallest. "SD" is the standard deviation of the mean RMSE.

Sampling alternative	Intensity	TPH	BAPH (m^2)	H/D Ratio	SDTPH	SD BAPH (m^2)	SDH/D ratio
ASTP3	10%	64.3	8.5	1.3	11.5	1.9	0.5
ASTP7	10%	71.0	8.5	1.7	17.0	2.1	0.8
FAP5R	10%	83.2	10.5	1.7	15.5	1.6	0.5
FAP5S	10%	105.1	12.6	1.7	29.1	3.5	0.5
FAP9R	10%	94.3	11.3	1.9	16.6	2.1	0.8
FAP9S	10%	115.2	13.7	2.3	21.7	2.9	1.1
HLS08	10%	261.8	28.3	2.4	80.8	6.5	0.8
HLS10	10%	260.0	27.9	2.2	82.7	6.0	0.9
OSSP3	10%	211.2	25.4	2.3	53.9	5.3	0.8
OSSP7	10%	91.0	12.0	1.9	45.1	8.5	0.8
PAST3	10%	66.6	9.0	1.5	20.6	1.1	0.6
PAST9	10%	94.0	11.6	2.0	27.0	2.5	0.8
PEST3	10%	64.5	9.1	1.4	11.3	2.3	0.5
PEST7	10%	70.3	9.4	1.7	16.5	1.9	0.8
SEC 11	10%	90.4	11.1	1.7	17.3	1.6	0.8
SEC22	10%	90.1	10.5	1.8	12.7	1.9	0.7
ASTP3	20%	40.4	5.6	0.8	14.2	1.8	0.3
ASTP7	20%	41.5	5.6	1.0	7.6	1.5	0.5
FAP5R	20%	60.2	7.5	1.2	11.1	1.2	0.4
FAP5S	20%	51.1	6.2	0.9	23.5	1.3	0.2
FAP9R	20%	87.3	9.4	2.3	22.5	1.9	1.1
FAP9S	20%	101.9	10.5	2.2	31.3	3.1	1.1
HLS08	20%	261.6	28.4	1.9	81.1	6.6	0.9
HLS1O	20%	260.5	28.0	1.8	82.5	6.0	0.9
OSSP3	20%	214.0	25.6	1.8	53.9	5.4	0.8
OSSP7	20%	55.0	6.7	1.5	21.8	2.5	0.9
PAST3	20%	45.9	6.1	1.1	14.9	0.9	0.5
PAST9	20%	49.7	6.7	1.2	15.7	1.2	0.6
PEST3	20%	42.3	6.2	0.9	18.7	2.5	0.4
PEST7	20%	46.1	6.0	1.0	9.1	1.5	0.4
SEC 11	20%	53.2	7.0	1.2	12.9	1.3	0.9
SEC22	20%	71.2	8.0	1.3	14.2	1.7	0.8

Table 5
Summary of performance of sampling alternatives evaluated using APB. Values under trees per hectare (TPH, %), basal area per hectare (BAPH, %) and height to diameter ratio (H/D, %) are the mean APB values from the eight locations. Shaded values are the five smallest percentages. "SD" is the standard deviation of the mean APB for TPH, BAPH, and H/D.

Sampling alternative	Intensity	TPH	BAPH (m^2)	H/D ratio	SDTPH	SD BAPH (m^2)	SDH/D ratio
ASTP3	10%	15.9%	16.8%	1.7%	4.6%	2.5%	0.6%
ASTP7	10%	17.2%	17.1%	2.2%	4.8%	4.5%	1.1%
FAP5R	10%	20.1%	21.0%	2.2%	3.1%	2.7%	0.7%
FAP5S	10%	25.6%	25.7%	2.2%	8.2%	8.9%	0.7%
FAP9R	10%	22.8%	22.7%	2.5%	3.6%	3.4%	1.1%
FAP9S	10%	28.2%	27.6%	3.0%	6.2%	5.2%	1.5%
HLS08	10%	61.4%	56.0%	3.1%	5.8%	6.2%	1.1%
HLS10	10%	60.7%	55.2%	2.9%	5.4%	4.7%	1.1%
OSSP3	10%	49.7%	50.1%	3.0%	0.4%	0.5%	1.1%
OSSP7	10%	22.1%	22.4%	2.5%	11.6%	11.1%	1.1%
PAST3	10%	16.0%	18.4%	1.9%	4.2%	4.2%	0.7%
PAST9	10%	22.5%	23.3%	2.5%	5.4%	5.8%	1.1%
PEST3	10%	15.8%	17.8%	1.8%	3.8%	3.2%	0.7%
PEST7	10%	17.0%	18.9%	2.2%	4.5%	3.7%	1.1%
SEC 11	10%	22.3%	22.7%	2.2%	6.6%	5.6%	1.0%
SEC22	10%	22.2%	21.3%	2.3%	5.8%	4.4%	0.9%
ASTP3	20%	9.7%	11.0%	1.0%	2.6%	2.8%	0.4%
ASTP7	20%	10.1%	11.0%	1.2%	2.4%	2.4%	0.6%
FAP5R	20%	14.5%	15.0%	1.6%	1.9%	2.0%	0.5%
FAP5S	20%	11.8%	12.5%	1.2%	3.4%	2.4%	0.3%
FAP9R	20%	21.2%	18.6%	3.0%	5.7%	1.6%	1.4%
FAP9S	20%	25.0%	21.4%	2.9%	8.3%	7.4%	1.4%
HLS08	20%	61.3%	56.1%	2.4%	5.7%	6.0%	1.1%
HLS1O	20%	60.8%	55.3%	2.3%	5.3%	4.6%	1.1%
OSSP3	20%	50.4%	50.5%	2.3%	0.3%	0.3%	1.1%
OSSP7	20%	13.0%	13.3%	2.0%	3.8%	3.6%	1.2%
PAST3	20%	11.0%	12.5%	1.4%	3.0%	3.1%	0.6%
PAST9	20%	11.9%	13.8%	1.5%	3.7%	3.7%	0.8%
PEST3	20%	9.9%	12.1%	1.2%	3.0%	4.5%	0.6%
PEST7	20%	11.4%	11.7%	1.3%	3.6%	1.3%	0.5%
SEC 11	20%	13.3%	14.1%	1.5%	5.3%	3.0%	1.1%
SEC22	20%	17.7%	16.3%	1.7%	5.8%	4.6%	1.0%

Table 6
Summary of performance of sampling alternatives evaluated using MAD. Values under trees per hectare (TPH), basal area per hectare (BAPH m^2) and height to diameter ratio (H/D) are the MAD values from the eight locations. Shaded values have the smallest MAD. "SD" is the standard deviation of the mean APB for TPH, BAPH, and H/D.

Sampling alternative	Intensity	TPH	BAPH (m^2)	H/D ratio	SDTPH	SD BAPH (m^2)	SDH/D ratio
ASTP3	10%	64.3	8.5	1.3	11.5	1.9	0.5
ASTP7	10%	71.0	8.5	1.7	17.0	2.1	0.8
FAP5R	10%	83.2	10.5	1.7	15.5	1.6	0.5
FAP5S	10%	105.1	12.6	1.7	29.1	3.5	0.5
FAP9R	10%	94.3	11.3	1.9	16.6	2.1	0.8
FAP9S	10%	115.2	13.7	2.3	21.7	2.9	1.1
HLS08	10%	261.8	28.3	2.4	80.8	6.5	0.8
HLS10	10%	260.0	27.9	2.2	82.7	6.0	0.9
OSSP3	10%	211.2	25.4	2.3	53.9	5.3	0.8
OSSP7	10%	91.0	12.0	1.9	45.1	8.5	0.8
PAST3	10%	66.6	9.0	1.5	20.6	1.1	0.6
PAST9	10%	94.0	11.6	2.0	27.0	2.5	0.8
PEST3	10%	64.5	9.1	1.4	11.3	2.3	0.5
PEST7	10%	70.3	9.4	1.7	16.5	1.9	0.8
SEC 11	10%	90.4	11.1	1.7	17.3	1.6	0.8
SEC22	10%	90.1	10.5	1.8	12.7	1.9	0.7
ASTP3	20%	40.4	5.6	0.8	14.2	1.8	0.3
ASTP7	20%	41.5	5.6	1.0	7.6	1.5	0.5
FAP5R	20%	60.2	7.5	1.2	11.1	1.2	0.4
FAP5S	20%	51.1	6.2	0.9	23.5	1.3	0.2
FAP9R	20%	87.3	9.4	2.3	22.5	1.9	1.1
FAP9S	20%	101.9	10.5	2.2	31.3	3.1	1.1
HLS08	20%	261.6	28.4	1.9	81.1	6.6	0.9
HLS10	20%	260.5	28.0	1.8	82.5	6.0	0.9
OSSP3	20%	214.0	25.6	1.8	53.9	5.4	0.8
OSSP7	20%	55.0	6.7	1.5	21.8	2.5	0.9
PAST3	20%	45.9	6.1	1.1	14.9	0.9	0.5
PAST9	20%	49.7	6.7	1.2	15.7	1.2	0.6
PEST3	20%	42.3	6.2	0.9	18.7	2.5	0.4
PEST7	20%	46.1	6.0	1.0	9.1	1.5	0.4
SEC 11	20%	53.2	7.0	1.2	12.9	1.3	0.9
SEC22	20%	71.2	8.0	1.3	14.2	1.7	0.8

(Table 6). The values ranged from 64.3 to 261.8 when estimating TPH at the 10% intensity and from 40.4 to 261.6 for the 20% intensity. Sampling alternatives that did not perform well included HLS08, HLS10, and FAP9S. When evaluated for their ability to estimate BAPH, values ranged from 8.5 to 28.3 at the 10% intensity and 5.6 to 28.4 at the 20% intensity. When estimating the height to diameter ratio, values ranged from 1.3 to 2.3 and from 0.8 to 2.3 at the 20% intensity. The alternative that performed best overall was ASTP3.

The sector sampling alternative using 11.46 degree sector (SEC11) did not appear to perform well overall, but performed well several times at the different locations. The alternative that most frequently performed well at the eight locations was ASTP3 alternative. Other alternatives that performed well were SEC11 and ASTP7. Sampling alternatives that performed well at multiple sites when estimating BAPH were PEST3 and ASTP3. Several alternatives performed well when estimating TPH. PAST3, ASTP3, ASTP7, and PEST3 all performed well in estimating BAPH, TPH, and H/D ratio at multiple sites. The majority of the sampling alternatives that performed well at more than one location also performed well when evaluated using RMSE, APB and MAD. These included ASTP3, ASTP7, PAST3, PEST3, and PEST7.

4. Discussion

The designs that performed best were generally those that sampled perpendicular to the stream. The best performing designs were the SYRS designs that used rectangular shaped plots. However, the STRS designs (PAST3, PAST9) also performed well. The alternatives that performed poorly in this simulation were OSSP3, FAP9R, FAP9S, HLS10, and HLS08 alternatives. Overall, ASTP3 performed the best among the alternatives. However, PEST3, ASTP7, and PAST3 alternatives also performed well.

In this comparison of alternatives, the circular fixed area plots did not perform as well as the rectangular plots. The smaller 5.64 m radius plots performed better than the 9 m radius plots. The FAP5S performed best among the circular fixed area plots at the 20% intensity, but the FAP5R alternative outperformed the other circular fixed area plots at the 10% intensity. These designs performed similarly whether evaluated using MAD, APB, or RMSE. The poor performance of the other designs could be attributed to plots falling entirely within gaps in the canopy or under-representing conifers upslope from the stream.

STRS design performed better than all other designs except for the rectangular SYRS designs. PAST3 performed better than PAST9 overall. The alternative performed similarly in estimating TPH, BAPH or H/D. Because the rectangular strips of PAST3 and PAST9 were oriented parallel to the stream, one would have expected the alternatives to perform poorly if there was one prominent gradient within riparian areas that existed from the stream to upslope. Even though strips were placed using stratified sampling, the performance of these design indicates that in addition to the strong lateral gradients extending upslope from the stream there are other sources of longitudinal variation in these riparian areas.

Although ASTP3 performed the best at the most locations and had the lowest amount of error, PEST3, PEST7 and ASTP7 also performed very well with respect to RMSE, APB, and MAD.

These two-stage designs performed inconsistently throughout this analysis. The OSSP7 alternative (7.2 m wide strips) performed well at several locations, but OSSP3 alternative (3.6 m wide strips) did not perform well at any of the locations. One would expect that stand attributes would differ markedly for opposing north and south facing slopes bounding a steeply incised stream. About half of the locations sampled appeared in the field to have fairly symmetrical selected stand attributes each side of the stream. The poor performance of OSSP3 shows that when a source of variation within a riparian area is ignored, sampling designs perform poorly. Overall, this design is not recommended for use in sampling selected stand attributes.

Even though the HLS alternatives performed well when estimating height to diameter ratio, the rectangular strip designs were more consistent. Unlike other alternatives, the HLS alternatives did not sample the full 36 m on either side of the stream. Schreuder et al. (1987) suggested that using longer lines with a larger angle gauge will lead to more accurate samples. If one was going to evaluate this design again, increasing the transect length to 36 m would be recommended. Even though HLS10 had the smallest error at the 20% intensity, it was not among the best overall performing designs. Kenning et al. (2005) found that a modified horizontal sampling design was more efficient in sampling basal area compared to fixed area sampling. Several research studies have found this design to be time-efficient and perform well (Kenning et al., 2005; Schreuder et al., 1987, 1992), especially in forests with larger diameter trees. Had a longer transect line been used in this study, one would suspect it would have been able to perform among the top designs.

The modified sector sampling design was suggested for use when sampling small clusters of objects by Iles and Smith (2006). In sector sampling an 11.46 wide angle performed better than a 22.92 wide angle. Use of a random azimuth in sector sampling created the potential for only the trees closest to the stream to be sampled rather than sampling from the stream to upslope. It may have been better to orient the sectors opposite each other with the center point in the stream. This alternative did perform well at several of the locations when evaluated using RMSE, APB, and MAD. Although sector sampling was not among the worst alternatives, it was generally outperformed by ASTP3, ASTP7, PEST3 and PEST 7.

Although this study did not specifically focus on plot size, there were some trends that emerged. The fixed area circular shaped plots performing the best were 5.6 m radius in size. The larger 9 m plot size may not have been as efficient in capturing the variation occurring parallel to the stream. In stratified designs, there were more 3 m wide strips to choose from and strips landing on or in the stream may have been sampled less frequently. In general, PEST3 and ASTP3 performed better than ASTP7 and PEST7 alternative. One would expect the larger strip width to perform better. In a prior study, Lynch (2003) found that as plot size increased from 0.01 to 0.05 ha, precision increased, but did not increase enough to justify the larger plot size which was consistent with the findings of Maclean and Ostaff (1983). The OSSP7 alternative performed much better than OSSP3. Doubling the strip width allows one to capture more variability at a local (i.e., plot) level, but there are half as many strips throughout the area if the sampling intensity is maintained at the same level. Nelson et al. (1998) found that widths of rectangular plots best for measuring forest canopy height were at least 6–8 m in width. It should be noted that there were a limited number of plot sizes evaluated for each of the sampling alternatives and that the stream size and location likely played a role in the results of each alternative.

Throughout this study, rectangular plots performed better than other shapes. When comparing circular fixed area plots to rectangular plots, Johnson and Hixon (1952) found that rectangular plots outperformed circular plots. ASTP3, ASTP7, PEST3, and PEST7 generally had the smallest difference from the actual mean at each site. The only exception was the performance of HLS for estimating height to diameter ratio. Husch et al. (2003, p. 329) note that "it is desirable to orient strips at right angles to the drainage pattern in order to increase the likelihood of having the strip intersect all stand conditions." The alternatives using circular fixed area plots may not have done a good job of intersecting the different stand conditions when moving from stream to upslope. Despite the circular fixed area alternatives performing well in some cases, these alternatives were much less consistent than the rectangular alternatives in accurately estimating TPH, BAPH, and H/D.

The source of spatial variation most pivotal to determining the effectiveness of a sampling design occurred along slopes running upslope from the stream. It is difficult for a sampling design to provide reliable estimates of TPH, BAPH, or H/D without capturing the gradients present within riparian areas. In comparing PEST3, PEST7, PAST3 and PAST9, one can see that PEST3 and PEST7 did better at estimating TPH, BAPH and H/D. PAST3 alternative did perform well when estimating TPH, but was inconsistent in estimating BAPH and H/D at the individual locations. In addition, alternatives that did not sample both sides of the stream were outperformed by those that sampled from both sides of the stream. This can be seen in the performance of OSSP3 and OSSP7 compared to PEST3 and PEST7. ASTP3 and ASTP7 performed similarly to PEST3 and PEST7. However, PEST3 and ASTP3 performed well at a variety of locations. Variation running parallel to the stream impacted the performance of the sampling alternatives and alternating the strips across the stream led to more accurate estimates. In addition, the smaller strip widths may have captured the patchiness of the trees within this location. Overall, ASTP3 alternative performed better than the other alternatives examined.

Because of the lack of data relating to sampling or measurement costs, none of the sampling alternatives were examined for cost of plot layout and measurement or sampling time required to execute them. Further research is warranted to identify the most cost-efficient design, which will depend on the underlying pattern of variability and on the issues affecting the time to obtain the measurements (e.g., difficulty of crossing the stream to work on both sides).

5. Conclusion

From this analysis, one can see that there is a high amount of variation within riparian areas, even those located relatively close to each other. Although some alternatives performed quite a lot better than others, the standard deviation around the mean was quite large for some of the alternatives. Overall, rectangular strip plots outperformed all other plot shapes. Plot sizes varied from 3.6 m in width to 9 m in width. In general the narrower strip widths performed better than the wider strip widths. Although the wedge shaped sector sampling alternative did perform well at some of the locations, it did not perform among the most accurate alternatives overall. The circular shaped plots performed better than the alternatives that used horizontal line sampling. In addition, one would have expected a greater decrease in error as one moved from the 10% to 20% sampling intensity.

This analysis was conducted using small scale stem maps from eight headwater streams in western Oregon. Under these conditions, ASTP3 alternative was found to be the most accurate and was able to perform well at the eight locations. This alternative consisted of rectangular plots systematically sampled. The rectangular plots were offset 3.6 m wide strips each side of the stream. The other alternatives that performed well were ASTP7, PEST3, PEST7, and PAST3. The alternatives that did not perform well included the circular fixed area plots that were 9 m in radius. In general, strips oriented perpendicular to the stream outperformed those oriented parallel to the stream.

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