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Evaluation of sampling methods to quantify abundance of hardwoods and snags within conifer-dominated riparian zones

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Abstract

- ***Aims*** Six sampling alternatives were examined for their ability to quantify selected attributes of snags and hardwoods in conifer-dominated riparian areas of managed headwater forests in western Oregon.
- ***Methods*** Each alternative was simulated 500 times at eight headwater forest locations based on a 0.52-ha square stem map. The alternatives were evaluated based on how well they estimated the number of hardwoods and snags per hectare and their basal area per hectare using root mean square error and percent bias.
- ***Results*** In general, 3.6-m wide systematic strips oriented perpendicular to the stream outperformed the other alternatives. However, the variance of all six sampling alternatives was quite high and further research is needed to determine an optimal sampling method for quantifying hardwood and snag attributes in forests dominated by live conifers.
- ***Conclusion*** When sampling snag and hardwood as a minor component of the overall forest composition within a riparian area, we suggest using 3.6-m strips perpendicular to the stream.

Keywords Pacific Northwest · Monitoring · Stand structure · Strip sampling

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Contribution of co-authors Theresa Marquardt collected data and wrote most part of the manuscript.
Dr. Hailemariam Temesgen wrote part of the manuscript, contributed to the design and analysis of the simulations, and handled reviews.
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1 Introduction

Forest landscape planning has evolved from a simple harvest scheduling concept to a more detailed analysis involving commodity production as well as habitat preservation/creation and provision of ecosystem services (Adams 2007; Temesgen 2003; Temesgen et al. 2007). The US national listing of salmonids resulted in increased consideration for habitat features that may be limiting species abundance on private and public lands in the Pacific Northwest. This change requires resource management plans to increasingly consider stand, landscape, and forest level attributes. This has led to the need to link and integrate riparian and upland forests.

Prior to the mid-1990s, forest management practices oriented toward timber production lead to the development of relatively homogeneous forests on much of the landscape in the Douglas-fir region of the Pacific Northwest. The presence of small intermittent or first-order headwater streams were often unmapped and frequently ignored or given little protection in the application of harvest and reforestation practices (Richardson and Danehy 2007). Snags were often felled as a safety measure in harvest operations. Past thinning practices removed overtopped and diseased trees (Parish et al. 2010). Hardwoods, with the exception of red alder, were often seen as weeds in plantation forestry and removed. As a result, unlogged areas have higher densities of large snags than managed forests (Ganey and Vojta 2010), and snags and hardwood trees occur with lower frequency within the 30- to 80-year-old managed forests on private and public lands than unmanaged forests in western Oregon and Washington (Ohmann et al. 1994).

Snags and hardwoods are important components of forest diversity and habitat (Eskelson et al. 2009; Holden et al. 2006; Hagar 2007; Temesgen et al. 2008). Snags serve as homes for primary cavity nesting birds and a large number of bird species which continue to use the cavities over the life of the snag. When a snag falls it may provide cover for small mammals (Holden et al. 2006), or supply downed wood for streams (Harmon et al. 1986). Hardwoods are important to a variety of songbird species, bats, and small mammals (Hagar 2007). Hardwood vegetation provides key sources of food and cover for bird habitat (Ellis and Betts 2011). The proportion of hardwoods within conifer forests influences the abundance and diversity of birds (Ellis and Betts 2011) and insectivorous avian species (Hagar 2007). For example, in intensively managed coastal forests of Oregon, “the relative bird abundance doubled with an increase of hardwood composition from 1 to ~6 %” (Ellis and Betts 2011). In riparian areas, hardwood leaf litter is important to macro invertebrates and as a source of allochthonous inputs to streams (Richardson and Danehy 2007).

With recognition of their importance to ecosystem functioning, there is increasing necessity to quantify snags and hardwoods. In general, the size and density of snags and hardwoods indicates the suitability of a forest stand for wildlife habitat (Eskelson et al. 2009; Ohmann et al. 1994; Ganey 1999). Forest certification efforts often use wildlife tree retention as a local criterion and indicator to evaluate a management plan of a given area (Rametsteiner and Simula 2003). Snag and hardwood abundance are important inputs to habitat suitability models applicable to forest stands and landscapes. Size and density of snag and hardwood trees vary with crown closure, understory vegetation, and stand structure. Snags and hardwoods add variability to vertical and horizontal structure within a stand. To account for these variations, many types of sampling designs are used to quantify the frequency of snags and hardwoods in forested stands. Managers and planners seek defensible sampling methods to assess wildlife habitat for their forests.

Riparian areas are diverse ecosystems in vertical and horizontal structure, species diversity, and habitat types (Richardson and Danehy 2007). Riparian hardwood and conifer components vary in density, diameter, and total tree height. Snags and hardwoods add to the vertical structure within riparian areas and their density may vary based on disease pockets or changes in tree density. In a conifer-dominated forest, snags, and hardwoods may be present in very low numbers and could be characterized as rare. As a result, quantifying stand structure within riparian areas can be extremely difficult and a sampling alternative that performs well for conifers may not perform as well in sampling hardwoods and snags.

Despite the importance of snags and hardwoods in creating suitable wildlife habitat, comparison of sampling methods that quantify abundance of hardwoods and snags within conifer-dominated riparian zones is lacking. This study evaluated the variation and accuracy of six sampling alternatives in estimating snag and hardwood stem density and basal area per hectare for eight headwater stream sites in western Oregon. Headwater streams are distinct from larger streams (Richardson and Danehy 2007) and serve as important habitat for amphibians and other non-fish vertebrates (Olson and Weaver 2007). These streams make up a high percentage of total stream length (Richardson and Danehy 2007) and typically drain much of the overall watershed area (Anderson et al. 2007). An accurate sampling alternative is important to describe wildlife habitat and species diversity within headwater stream systems. The primary objective of this study was to determine whether sampling alternatives that performed well in quantifying conifers within riparian areas would also perform well when quantifying snags and hardwoods in riparian areas.

2 Methods

Data were collected at four Density Management Study (DMS) sites (Cissel et al. 2006; Olson and Weaver 2007). The sites are distributed among the Salem, Roseburg, Eugene, and Coos Bay Bureau of Land Management (BLM) districts; three sites are within the Oregon Coast Range and one site is in the west-side Cascades (Table 1). Sites are dominated by even-aged conifer stands predominantly Douglas-fir (*Pseudotsuga menziesii*), and to a lesser extent western hemlock (*Tsuga heterophylla*), ranging in ages from 40 to 80 years. For each study site, detailed topographic, elevation, and climatic data had been previously recorded (Cissel et al. 2006). Streams classified as headwater streams (generally first- or second-order streams) were the focus of the DMS.

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 uncut buffer treatments, and two channel side slope classes. Of 12 reaches originally selected for sampling time constraints limited sampling to eight reaches (Table 1). The eight randomly selected sample stream reaches were distributed across four DMS sites

Table 1 Description of tree density, buffer width, slope, and aspect for the eight stream reaches sampled from the DMS site locations

Site	Reach	BLM district	Latitude (N)	Longitude (W)	Density	Buffer	% Slope	Slope class	Aspect
Bottom Line	13	Eugene	43°46′20.0″	123°14′11.0″	Moderate	Two Tree Height	51	S	NE/SW
Keel Mountain	17	Salem	44°31′41.0″	122°37′55.0″	Control	Control	18	M	N/S
Keel Mountain	18	Salem	44°31′41.0″	122°37′55.0″	Moderate	Two Tree Height	21	M	NW/SE
Keel Mountain	19	Salem	44°31′41.0″	122°37′55.0″	Moderate	Two Tree Height	14	M	NW/SE
Keel Mountain	21	Salem	44°31′41.0″	122°37′55.0″	Moderate	Variable Width	38	S	N/S
O.M. Hubbard	36	Roseburg	43°17′30.0″	123°35′00.0″	Moderate	Variable Width	31	S	NW/SE
Ten High	46	Eugene	44°16′50.0″	123°31′06.0″	Control	Control	19	M	N/S
Ten High	75	Eugene	44°16′50.0″	123°31′06.0″	Moderate	Variable Widths	33	S	N/S

Slopes greater than 30 % were classified as an "S" for steep, slopes less than 30 % were classified as "M" for moderate

including Bottomline, Keel Mountain, O.M. Hubbard, and Ten High. Attributes of the sampled reaches are summarized in Table 1 and in Marquardt et al. (2010). The two density management treatments were an unthinned control, 200–350 trees per acre (TPA) (494–864 trees per hectare) and a moderate density retention where 60–65 % of the stand had been thinned to 80 TPA (197 trees per hectare). The two slope classes were moderate, less than 30 %, or steep, greater than 30 % in slope.

Following reach selection, a sampling 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 the plot centerline (Fig. 1). The 72-m square block was oriented with its centerline running along the general azimuth of the stream.

To quantify overstory composition and structure (basal area and density by conifer and hardwood species), a complete census of trees on each sample plot was conducted by stem mapping using total station survey equipment (LS250 Pulse Laser Total Station, Laser Technology, Inc).

Tree species was recorded and trees were classified as small or large trees and their status (dead/alive). Small trees had a diameter at breast height (DBH) between 2.0 and 7.5 cm, and large trees were greater than 7.5 cm DBH. Individual tree data were compiled to obtain the number of hardwoods and snags per hectare (TPH) and their basal area per hectare (BAPH; Table 2). These values, based on a complete census, defined assessment standards for alternative sampling strategies via simulation.

Six sampling alternatives comprising two design classes: systematic sampling with random start (SYRS) and stratified random sampling (STRS) were evaluated in this study. Within these classes, alternatives consisted of strip plot configurations differing in strip width and orientation with respect to the stream. All six of these alternatives were previously assessed for their performance in sampling conifers using the same study plots (Marquardt et al. 2010).

SYRS was used for four strip sampling alternatives. The perpendicular to stream alternatives, PEST3 and PEST7, were 3.6- and 7.2-m wide strips which were oriented perpendicular to the centerline of the plot with a strip length of 72 m (e.g., Fig. 1, center). The alternating strip option, ASTP3 and ASTP7, was simulated by breaking the 72-m grid into either 3.6- or 7.2-m strips which were 36 m in

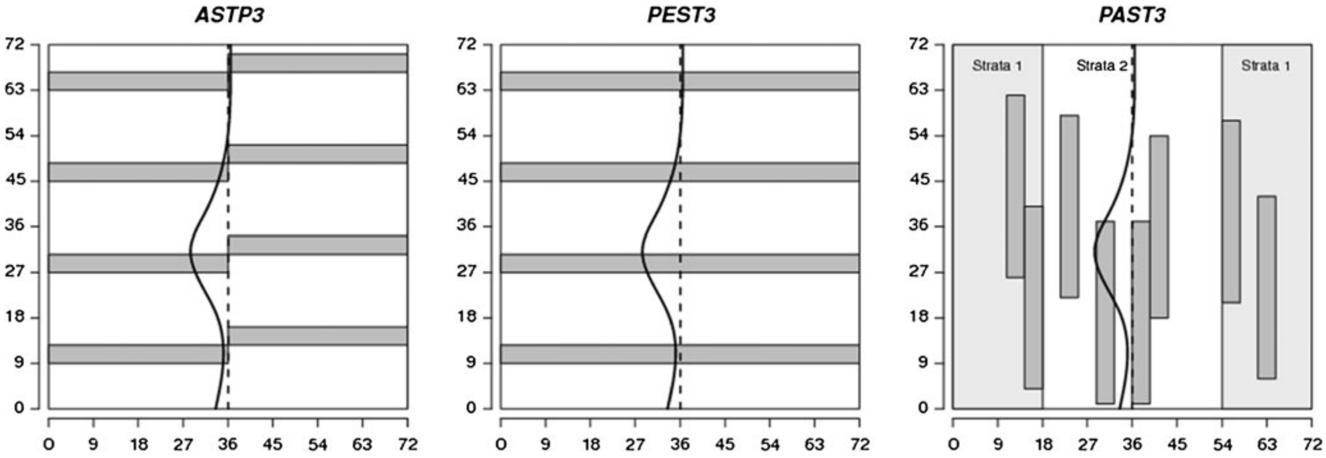

Fig. 1 Illustration of the 20 % intensity ASTP3 (*left*), PEST3 (*center*), and PAST3 (*right*) plot layout on the sampled stream reaches. The centerline (*dashed*) of the 72-m square block was oriented in the general direction of the stream (*solid line*)

Table 2 Description of stream and tree characteristics of sampled reaches from the DMS site locations

Site	Reach	Average stream flow width (m)	Dominant conifer species	Total stems per hectare	No. of trees measured	% dead trees[a]	% Hardwoods
Bottom Line	13	0.2	PSME	405	210	20	7
Keel Mountain	17	1.1	TSHE	461	239	7	8
Keel Mountain	18	2.2	TSHE	740	384	13	5
Keel Mountain	19	0.8	PSME	658	341	17	2
Keel Mountain	21	3	TSHE	434	225	13	10
O.M. Hubbard	36	0.5	PSME	467	242	13	8
Ten High	46	0	PSME	461	239	10	0
Ten High	75	4.3	PSME	716	371	8	26

PSME Pseudotsuga menziesii (Mirb.), *TSHE Tsuga heterophylla* (Raf.)

[a] % Dead trees and % hardwoods are based on stem per hectare values

length oriented perpendicular to the centerline of the plot, approximately perpendicular to the stream (e.g., Fig. 1, left). Each plot 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.

STRS was used to sample strips running parallel to the plot centerline, approximately parallel to the stream, with at least one strip close to the stream, and another upslope. The strips parallel to the stream, PAST3 and PAST9, were either 3.6 or 9 m wide, respectively (e.g., Fig. 1, right). There were two strata; one stratum was close to the stream and the other upslope. For PAST9, the 72-m grid was first split into 9-m strips running parallel to the stream, strata 1 was the two outermost strips on either side of the stream and strata 2 was the four most inner strips. For each sampling, the dimensions and sample sizes of the strip plots alternative are described in detail in Table 3.

The six alternative sampling approaches were simulated using SAS (v. 9.1, SAS Institute 1990). Only snags and hardwoods were included in the simulations; the live conifers were removed from the dataset. To avoid incomplete plots landing along edges of the stem map, plot data was wrapped around the edge. Simulations for each of the eight locations were conducted independently. Each design was simulated at a 10 % ($0.1\times72^2=518.4\ \text{m}^2$) and 20 % ($0.2\times72^2=1036.8\ \text{m}^2$) intensity of the area (Table 3). Every alternative was simulated 500 times with a different random starting point for each replication.

The designs were evaluated based on how well they predicted TPH and BAPH compared to the actual stem map using root mean square error (RMSE), and percent bias (PB):

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

$$\text{PB} = \frac{\sum_{k=1}^{500}\frac{\widehat{Y}_k - Y}{Y}}{500} \tag{2}$$

where $\widehat{Y}_k$ is the estimated attribute (TPH or BAPH) for the kth replication and Y is the known attribute value.

3 Results

The statistical efficiency of all sampling methods improved as sample size increased. The RMSEs for TPH and BAPH

Table 3 Description of the sampling alternatives examined in this study including the number of plots simulated at the 10 and 20 % sampling intensity

Sampling alternative	Description	Size	Plots (10 %)	Plots (20 %)
ASTP3	Alternate perpendicular strips	3.6×36 m	4	8
ASTP7	Alternate perpendicular strips	7.2×36 m	2	4
PEST3	Perpendicular strips	3.6×72 m	2	4
PEST7	Perpendicular strips	7.2×72 m	1	2
PAST3	STRS parallel strip sampling	3.6×36 m	4	8
PAST9	STRS parallel strip sampling	9×28.8 m	2	4

decreased substantially when sampling intensity was increased from 10 to 20 % (Table 4). The RMSE values for TPH ranged from approximately 44 to 55 for the 10 % intensity and approximately 29 to 39 for the 20 % sampling intensity (Table 4). For the 10 % sampling intensity, the RMSE values for BAPH ranged from 4.3 to 4.7 and from 3.0 to 3.5 for the 20 % sampling intensity. PEST3 performed well for both sampling intensities. The “Congruity” columns indicate the number of sites for which the sampling alternative had one of the two smallest RMSE values. In this case, the PEST3 alternative was among the two smallest RMSE values at five of the eight sites when predicting TPH at the 20 % sampling intensity.

On average, for TPH the PEST alternatives (PEST3 and PEST7) are 1.2 and 1.1 times more efficient (lower RMSE) than the PAST (PAST3 and PAST9) and the ASTP (ASTP3 and ASTP7) alternatives (Table 4). The higher statistical efficiency of the PEST alternatives over the PAST and ASTP alternatives is a reflection of the differences in strip plot configurations and orientation with respect to the stream.

PB values ranged from 1.26 to 5.33 % and from −0.93 to 0.78 % for the 10 and 20 % sampling intensities, respectively, when evaluated for their ability to estimate TPH (Table 5). The PB was slightly larger for BAPH, values ranged from 0.74 to 6.49 % and from −0.73 to 0.78 % for the 10 and 20 % sampling intensities, respectively. Not only were PB values greater for the 10 % sampling intensity, there was a consistent tendency for overestimation by the sampling alternatives applied at 10 % that was not evident for the range of alternatives applied at 20 % intensity. This might be ascribed to the small sample size. Despite that anomaly, the PEST3 alternative performed was among the two most accurate alternatives for at least four of the eight sites.

The standard deviation calculated for the mean PB and RMSE values and the performance of the alternatives varied across the eight sites (columns 8 and 9 in Tables 4 and 5). The standard deviation was quite large for all sampling alternatives, however, the PEST3 alternative had among the smallest standard deviation at both intensities when evaluated using PB and RMSE. The ASTP3, PAST3, and PEST7 alternatives also performed well. When estimating TPH at the 10 % sampling intensity: (1) there was less variation in the smaller strip widths (Table 4); and (2) the ASTP3, PAST3, and PEST3 alternatives outperformed the ASTP7, PAST9, and PEST7 alternatives (Table 5). There were no apparent trends for the ASTP3 and ASTP7 alternatives when estimating BAPH at either intensity. However, for BAPH at both intensities, PAST3 and PEST3 performed better than PAST9 and PEST7. This trend was similar when estimating TPH at the 20 % sampling intensity.

The ASTP3 and ASTP7 alternative typically performed better than the PAST9 alternative, but not as well as the

Table 4 Summary of performance of sampling alternatives evaluated using RMSE and summary of the standard deviation for sampling alternatives evaluated using RMSE

Sampling methods	TPH	BAPH	Rank TPH	Rank BAPH	Congruity TPH	Congruity BAPH	SD TPH	SD BAPH	Rank TPH	Rank BAPH
10 % intensity										
ASTP3	45.6	4.47	3	5	5	3	31.56	4.39	1	6
ASTP7	46.8	4.34	4	2	3	3	34.97	3.92	4	3
PAST3	43.9	4.38	2	3	1	3	36.86	3.75	5	1
PAST9	55.2	4.69	6	6	1	0	42.35	4.29	6	5
PEST3	43.3	4.29	1	1	3	3	31.59	3.83	2	2
PEST7	51.3	4.41	5	4	3	4	33.43	4.09	3	4
20 % intensity										
ASTP3	32.2	3.30	3	5	2	3	23.20	2.30	4	5
ASTP7	32.6	3.24	5	4	2	2	23.17	2.23	3	3
PAST3	32.3	3.06	4	1	2	5	23.44	2.16	5	1
PAST9	38.7	3.54	6	6	1	2	24.91	2.27	6	4
PEST3	29.9	3.19	2	2	5	2	18.81	2.22	1	2
PEST7	29.0	3.20	1	3	4	2	20.09	2.38	2	6

Values for trees per hectare (TPH) and basal area per hectare (BAPH, square meters per hectare) are the average RMSE values from the eight locations. Shaded values have the two smallest RMSE values. The values under the “Congruity” columns are the number of times the alternative was among the two most accurate alternatives for each location. Alternatives were shaded if they performed well at four or more of the eight locations. Values under SD trees per hectare (TPH) and SD basal area per hectare (BAPH, square meters per hectare) are the average standard deviation for the mean RMSE values from the eight locations. Shaded values under the SD columns have the two smallest standard deviation values

Table 5 Summary of performance of sampling alternatives evaluated using percent bias (PB) and summary of the standard deviation (SD) for sampling alternatives evaluated using PB

Sampling methods	TPH	BAPH	Rank TPH	Rank BAPH	Congruity TPH	Congruity BAPH	SD TPH	SD BAPH	Rank TPH	Rank BAPH
10 % intensity										
ASTP3	2.95 %	3.48 %	3	3	3	1	48.05 %	89.53 %	2	5
ASTP7	4.00 %	3.74 %	4	4	3	4	51.13 %	85.30 %	3	3
PAST3	2.71 %	1.77 %	2	2	4	2	54.85 %	81.93 %	5	1
PAST9	4.55 %	4.18 %	5	5	1	3	63.38 %	93.86 %	6	6
PEST3	1.26 %	0.74 %	1	1	4	5	47.58 %	83.86 %	1	2
PEST7	5.33 %	6.49 %	6	6	1	1	53.31 %	88.92 %	4	4
20 % intensity										
ASTP3	−0.40 %	0.25 %	4	4	5	4	34.87 %	57.44 %	3	4
ASTP7	0.24 %	0.78 %	2	2	2	3	35.78 %	57.02 %	4	3
PAST3	0.78 %	−0.34 %	5	5	1	2	36.01 %	53.24 %	5	1
PAST9	−0.27 %	−0.73 %	3	3	2	3	42.08 %	62.22 %	6	6
PEST3	−0.93 %	−0.54 %	6	6	3	3	31.63 %	55.74 %	2	2
PEST7	0.21 %	−0.33 %	1	1	3	1	31.31 %	58.30 %	1	5

Values for trees per hectare (TPH) and basal area per hectare (BAPH, square meters per hectare) are the average PB values from the eight locations. Shaded values have the two smallest PB values. The values under the "Congruity" columns are the number of times the alternative was among the two most accurate alternatives for each location. Alternatives were shaded if they performed well at four or more of the eight locations. Values under SD trees per hectare (TPH) and SD basal area per hectare (BAPH, square meters per hectare) are the standard deviation for the mean PB values from the eight locations. Shaded values under the SD columns have the two smallest standard deviation values

PEST3 and PEST7 alternatives. However, there was little difference in the performance of the ASTP3 and ASTP7 alternatives. In addition, there did not seem to be a trend for either alternative to be better at estimating TPH compared to BAPH. Although the ASTP3 and ASTP7 alternatives were very similar to the PEST3 and PEST7 alternatives, they performed slightly better than the PEST7 alternative and slightly worse than the PEST3 and PAST3 alternatives.

The PAST3 alternative outperformed the PAST9 alternative and was second to the performance of the PEST3 alternative. When evaluated using RMSE, the PAST3 alternative outperformed the PAST9 alternative when estimating TPH and BAPH at both intensities. However, when evaluated using PB, the PAST9 alternative performed better at the 20 % intensity when estimating TPH. The standard deviation for the mean RMSE and PB was smaller for the PAST3 alternative than the PAST9 alternative at both intensities. The PAST9 alternative was almost always ranked at the bottom of the six alternatives in terms of variation.

The PEST3 alternative overall performed the best in estimating TPH and BAPH of snags and hardwoods in the stem mapped stands. In general the sampling alternative ranked either first or second in estimating TPH and BAPH at the two intensities; its weakest performance was at the 20 % sampling intensity when evaluated using PB. The PEST7 alternative performed best at the 20 % sampling intensity.

4 Discussion

The variation for the six sampling alternatives simulated within this study was quite large. Reasons for the high variation may be attributed to: (1) the small number of snags and hardwood trees within the stem mapped plots; and (2) the clumped or patchy distribution of snags and hardwoods within riparian areas. There were more snags and hardwoods closer to the stream than further from the stream. The results of this study suggest that hardwood and snag attributes were better captured by sampling alternatives that had more narrower strips than those that had fewer wider strips. This may be explained by the fact that more narrower strips provide better coverage of the area than fewer wider strips and thus better allow capturing the variability of snags and hardwoods in riparian areas. Although our results indicate that more narrower strips may be statistically more efficient than fewer wider strips, field measurement costs for more narrower strips are likely to be higher than for fewer wider strips at the same sampling intensity. Field measurement costs were not considered in this study, but trade-offs between plot size and field measurement costs are to be expected and an optimal strip width for a given sampling intensity and sampling budget remains to be determined. Whether sampled at 10 or 20 % intensity, variation of TPH estimates was less for strips 3.6 m wide than for strips 7.2 or 9 m wide for the PEST and PAST designs. The tendencies for strip width effects were less clear when bias estimates were compared. This suggests that the alternatives simulated in this study may not be optimal for sampling trees that make up a small fraction of the population.

Our results further suggest that strip plots perpendicular to the stream (PEST and ASTP alternatives) provide better estimates of hardwood and snag attributes than strip plots parallel to the stream (PAST3 and PAST9), which indicates that strips parallel to the stream do not capture the inherent variability of the riparian areas as well as the perpendicular strips. Strips perpendicular to the stream capture the upslope gradient in stand structure, which is characterized by higher abundance of snags and hardwoods close to the stream than in the upland forests. It can be expected that strips perpendicular to the stream have higher within strip variability but less among strip variability, whereas strips parallel to the stream have little within strip variability but large among strip variability. A possible reason for the high variability of the PAST alternatives could be the greater frequency of hardwood and snags close to the stream compared to upslope.

It was anticipated that the difference in performance between the PEST and ASTP alternatives would be small. However, the results were quite different, although the ASTP alternatives still tended to outperform the PAST alternatives. The difference in performance of the PEST and ASTP alternatives may be explained by the alternate strips were analyzed as separate plots resulting in twice the number of plots than in the comparable PEST design (see Table 3). It is possible that if adjacent alternate strips were considered as one strip, the results would be comparable to those of the PEST alternatives. Some inconsistency in the performance of the sampling alternatives could be attributed to the high variation reflected in Tables 4 and 5. The PEST3 alternative was most consistent when evaluated using PB at the 10 % intensity. The performance of the smaller strip widths may be attributed to their higher chance to capture the clustering distribution of hardwood trees and snags than small number of wide strip plots.

Rectangular strip plots have been used in the past to sample snags for the purpose of estimating snag density (Holden et al. 2006; Bate et al. 1999). Kenning et al. (2005) compared *n*-tree sampling to fixed area and modified horizontal line sampling. Fixed area sampling with small plots was recommended for cases where sample size could be fairly large, when only one crew member was available and basal area per hectare was of primary importance. Ducey et al. (2002) compared horizontal point sampling and modified horizontal line sampling (MHLS) for snag inventory in the northeast United States and found relatively small standard error when using MHLS to estimate snags and basal area per hectare. However, Ducey et al.'s study was implemented on stands where snags were known to be somewhat common. Although the use of transects for strip sampling is quite prevalent, based on this simulation, in conifer-dominated stands, one can expect high variation with this sampling method and other sampling methods be considered.

There may also be benefits to simulating additional approaches including variable radius plots and modified horizontal line sampling. Live conifers made up 66 to 90 % of the stems within the study site (Table 2), making the number of hardwoods and snags within each stem mapped plot quite small. Other sampling methods such as distance sampling which specialize in sampling of rare objects should also be considered. Although the PEST3 alternative performed best among the six simulated alternatives, the high variation indicates that it might be not an optimal design when sampling snags and hardwoods in riparian areas.

From this analysis, one can see that there is a high amount of variation in the TPH and BAPH of hardwoods and snags within riparian areas. Among 16 sampling alternatives examined using the same stem mapped data collected from eight headwater streams in western Oregon, Marquardt et al. (2010) identified ASTP3 sampling method as the most accurate method for quantifying the number of conifer trees per hectare and their basal area per hectare. In this study, PEST3 was identified as the best alternative for quantifying the number of hardwoods and snags. Hence, the selection of sampling method depends on the objective of the survey.

5 Conclusion

Strip plots perpendicular to the stream outperformed strip plots parallel to the stream in capturing attributes of clumped snag and hardwood populations in riparian areas. The use of more narrower strips resulted in higher accuracy than the use of fewer wider strips. Of the investigated sampling methods, we recommend 3.6-m strips perpendicular to the stream (PEST3 alternative) for quantifying hardwood and snag abundance. If a greater sampling intensity is not desired, one could consider another design which specializes in capturing a small component of the overall forest composition. When sampling a minor component of the overall forest composition within a stand, sampling using 3.6 m strips perpendicular to the stream is suggested.

Forest attributes in riparian areas vary not only with species composition, but also with the longitudinal and vertical variations within and among riparian zones. There were several reasons for the high variation that occurred within this study. First, there were eight sites on which these alternatives were simulated. It is possible that with the high variation within riparian areas, a higher sampling intensity is needed for sampling snags and hardwoods.

The scope of inference for this study falls within headwater streams with 40–60-year-old Douglas-fir forests of western Oregon with a buffer of approximately 220 ft. The results and inference of our study can be applied to forests with similar species composition and stand density. The history of the study sites includes no management prior to 1994 when thinning treatments began. While this study may not be representative of areas with narrower streamside buffers, it affirmed the high variation within riparian areas and the need for higher sampling intensity to quantify snags and hardwoods within conifer-dominated riparian zones. Further research is needed to find an optimal design for stands with the attributes not included in this study if snags and hardwoods are the primary objective.

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