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Differences in forest area classification based on tree tally from variable- and fixed-radius plots

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Abstract: In forest inventory, it is not enough to formulate a definition; it is also necessary to define the "measurement procedure." In the classification of forestland by dominant cover type, the measurement design (the plot) can affect the outcome of the classification. We present results of a simulation study comparing classification of the dominant cover type between fixed- and variable-radius plot designs. We also show the effect of species distribution and partially sampled plots on these classifications. Plot type, area sampled, and the way in which the species are distributed influence the outcome of the classification. Thus, estimated changes in forest area may be an artifact of plot design changes, rather than actual population change.

Résumé : En inventaire forestier, il ne suffit pas de formuler une définition; il faut également définir la procédure de mesure. Dans la classification des forêts par type de couvert dominant, le dispositif de mesure (la placette) peut influencer le résultat de la classification. Nous présentons les résultats d'une étude de simulation qui compare la classification du type de couvert dominant selon qu'on utilise des placettes à rayon fixe ou à rayon variable. Nous montrons aussi l'effet de la répartition des espèces et celui des placettes partiellement échantillonnées sur ces classifications. Le type de placette, la zone échantillonnée et la façon dont les espèces sont réparties influencent le résultat de la classification. Ainsi, les changements estimés dans la zone forestière peuvent être un artéfact causé par des changements dans le dispositif de placettes, plutôt qu'un changement réel de la population.

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Introduction

Estimation of forest attributes such as volume, number of trees, and area are mainstays of forest inventories. Classification of forest area into dominant species type (often referred to as forest type), age, stand size, and reporting of attributes such as timber volume, area, and number of trees by these classifications are also standard outputs (Smith 2004). Classification of forest area is typically based on trees observed or measured in a particular location. It is assessed either by the field crew or by a computer algorithm in the office. Because classification is usually based on the trees tallied on the plot, but the inclusion of a tree is determined by the plot design, one might expect the classification of a particular point to change if the plot design changes. This paper examines the differences in classification of dominant forest cover type that can occur when using a variable-radius (Grosenbaugh 1952) or a fixed-radius plot design. The differences found here also point to the complexities of combining different inventories and examining change using different plot designs.

The impetus for examining the differences from these sampling schemes stems from the change in the Forest Inventory and Analysis (FIA) program's sampling design as the national plot design adopted in 1995. The new design utilizes a fixed-radius plot, but most previous inventories were based on variable-radius plots. In Oregon, the previous design was a five-point variable-radius cluster, whereas the new national design is a four-point fixed-radius cluster installed over the old five-point location. We expect that there will be some changes in estimates of forest area that are strictly due to the change in plot design and not necessarily due to an actual change of forest attributes. Williams et al. (2001) examine the accuracy and efficiency of area classifications when using tree tally in determining the classification; they also discuss several types of errors that can

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occur. The objective of this study is to examine classification differences when using two different plot designs for data collection and the effect of species composition and plot size on area classification.

Much of the research on the comparison of the two plot designs focuses on the efficiency of one design over the other for volume estimation, including estimates of costs (Grosenbaugh and Stover 1957; Oderwald 1979; Scott and Alegria 1990). For commonly used sampling designs, estimators based on both fixed- and variable-radius plots are unbiased for population parameters such as total tree basal area, volume, or number of trees. Therefore, as the sample size increases, the ranking of species by basal area will become identical, regardless of plot design. However, this study is not concerned with estimation of basal area by species, but rather in the classification of the land based on attributes sampled on individual plots. The problem arises because determination of class membership occurs at the plot level, not at the population level, which in our case is the stand. Individual plots are assigned to a class based on the trees tallied in that particular plot. Therefore, the plot design, including plot type and size, may result in a different tree tally for the plot and, therefore, a different class allocation. There are a number of important consequences of this observation. First, classification changes may be reported as actual changes in land class, even though they are artifacts of the measurement process. Thus, the rates of change for some classes may be overestimated or underestimated. Second, estimates of land area by forest type are typically based on the proportion of plots that meet the classification criterion, not on the overall estimate of the basal area of a particular species in the population. Different plot designs may result in a different number of plots classified into a given forest type. Nevertheless, for large regions and common forest types with large sample sizes, we would expect that the number of plots classified into a forest type would be the same overall, even though the classification of individual plots may differ depending on the design. Thus, we would expect that the accumulated totals would tend to be similar between the two plot designs.

In many cases, a partial plot, referred to a condition class by FIA (Bechtold and Patterson 2005), must be classified with less than a full plot's area. This occurs when a plot straddles two or more distinct land types such as a forest and a pasture. Within FIA, condition class divisions are made by field crews and mapped in the field. Forest attributes are assigned to each condition class separately. Postclassification routines can only use the information garnered on the plot or portion of plot. We looked at classification differences based on full plots and plot fractions represented by one, two, or three subplots to investigate the effect of the amount of area sampled in the classification algorithm. In some cases, this can be evidence of the effect that the size of the plot would have on classification.

Methods

We used 13 mapped stands (Acker et al. 1998) at least 1 ha in size as our populations. A toroidal edge correction procedure was used to join the edges of each stand and ensure equal selection probability for all trees and eliminate boundary plots (Griffith 1983; Boots and Getis 1988). Five-hundred randomly selected points within each stand were used to center variable-radius and fixed-radius plot designs. The fixed-radius plot design has the same area as the current FIA design, and the variable-radius plot design follows previous Pacific Northwest FIA inventories: a basal area factor of 7 $m^2 \cdot ha^{-1}$ with a limiting distance of 17 m. FIA uses a four-subplot cluster sample as its national standard plot design (Bechtold and Patterson 2005). At each subplot, trees and snags between 12.7 and 76.2 cm and ≥ 76.2 cm are tallied in a set of concentric plots of 7.32 and 17.95 m radi, respectively (Bechtold and Patterson 2005).

It is common for a plot to straddle more than one stand condition, as evidenced by differing owners, stand ages, or species composition among other attributes. To simulate a partial plot with less than a full plot in the same condition, we changed the area used in the classification. We selected either one, two, or three subplots per point and classified the stand based on that area.

The stands were relatively homogenous with regard to tree size and species composition, being dominated by a few species, the most common being Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), Noble fir (*Abies procera* Rehd.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western red-cedar (*Thuja plicata* Donn ex D. Don). To enable comparisons of plot designs across populations with different patterns of species distribution, a random species label was assigned to each tree in each stand according to four scenarios, the last three having a dominant species:

1. six species with even distribution of trees (same number of trees assigned at random to each species, no dominant species);
2. three species, with 50%, 30%, and 20% of trees assigned to each species (dominance by numbers of trees);
3. three species, with 80% of trees assigned to one species if the tree diameter is over the stand median, even distribution to the rest (dominance by size);
4. six species, with 50% of the trees assigned to one species if the tree diameter is over the stand median, even distribution for the rest (dominance by size).

These examples represent varying levels of species dominance.

Dominant cover type (forest type) was assigned to the species that had the most accumulated basal area per hectare within the sampled plot. This rule was chosen for its simplicity and because it can be related to crown cover and relative stocking (Bechtold 2004), two other common metrics used for classification. Comparisons are made between individual plots, assessing the effects of full plots and partial plots, and between the accumulated total of plots by dominant species for either variable- or fixed-radius design. The latter comparison mirrors what is done in standard inventory reporting, i.e., the estimation of area occupied the "forest-type" attribute. Both of these comparisons are important, in the general inventory sense, because areas that have various attributes are reported and usually compared with other inventories. In studies of change, a different classification result in an individual plot may be recorded as actual change and used to estimate the population change in area and volume.

Table 1. Percentage agreement from variable-radius and fixed-radius plots for dominant species classification scenarios, by number of subplots sampled.

	No. of subplots sampled			
Scenario	1	2	3	4
Actual species	79	83	85	85
Three species, 50%–30%–20%	69	76	82	86
Six species, equal weight	44	43	42	42
Three species, weight proportion to size	86	95	98	99
Six species, weight proportion to size	66	80	88	93

Table 2. Percentage of samples assigned to the dominant species when one was defined

	No. of subplots sampled			
	1	2	3	4
Three species, weight proportion to size				
Variable radius	97	95	99	99
Fixed radius	86	95	98	99
Three species, random with 50%–30%–20%				
Variable radius	71	81	87	91
Fixed radius	65	76	83	87
Six species, weight proportion to size				
Variable radius	84	94	97	99
Fixed radius	64	80	88	94

Table 3. Agreement matrix (number of plots) for dominant species classification based on six species evenly distributed using one subplot (the worst case).

	Variable radius – predicted class						
Fixed radius – predicted class	1	2	3	4	5	6	Total
1	493	149	112	124	126	140	1144
2	123	524	118	125	118	133	1141
3	93	135	479	105	116	111	1039
4	120	125	106	467	121	132	1071
5	128	112	118	117	459	116	1050
6	113	113	114	98	119	491	1048
Total	1070	1158	1047	1036	1059	1123	6493

Note: Several subplots had no dominant species.

Results and discussion

When four subplots were sampled, the agreement on forest-type classification between the two plot designs ranged from 42% to 99%, depending on the tree distribution scenario (Table 1). In general, agreement rates decreased as the number of subplots sampled decreased. The main implication of these results is that the difference in classification would have been recorded as changes in the forestland area occupied by a given forest type. For example, for the stands with the actual species, a change in plot design would have resulted in an estimated 15% area change, even though no change had occurred.

The difference between the two plot designs lies in the number of trees selected by species and their relative size. When four subplots were tallied, the fixed-radius plot design selected, on average, roughly four more trees per plot than the variable-radius plot design, but the difference depended on the tree size distribution. A maximum difference of 29 trees occurred when sampling from the stand that had the smallest quadratic mean diameter. However, the probability of selecting a tree with variable-radius plots increased with basal area. Because forest type was defined based on the relative majority of basal area in the plot, the rate of correct classification was greater for variable-radius plots than for fixed-radius plots, regardless of the number of subplots (Table 2). As expected, the rate of correct classification increased with the number of plots sampled and the difference between plot designs decreased (Table 2).

Both the rate of agreement between plot designs and the rate of correct classification depended on the underlying distribution of trees by species and size within the stand. The greater the dominance, in terms of size and numbers, of a species, the greater is the agreement between plot designs. The greatest agreement stemmed from a stand composed of 80% of the larger trees allocated to one of three species

(99%), whereas the worst case occurred when trees were assigned with equal proportions to six species (42%) (Table 1).

Although the percentage agreement for the design comparison of the trial of six species evenly distributed is only 44% for one sampled subplot, the maximum difference in the marginal totals was 6.9% of the expected marginal totals (one-sixth of the sample) (Table 3). There is better plot-to-plot agreement for the trial of six species proportionally allocated, a one-subplot sample having 66% agreement; however, the marginal totals for the nondominant species are nearly double for the fixed-radius design over the variable-radius design.

Classification of forested systems is well documented throughout the literature of the last 60 years (Daubenmire 1952; Dyrness et al. 1974; Pfister and Arno 1980). Classification is commonplace in forest inventory, with various rules to determine whether the land is forested or not and its climax vegetation class, site class, forest type, stand age, stand size class, and a host of habitat-type classifications. The need to categorize systems allows researchers to develop a discrete number of workable management options. As Kleinn (2001) pointed out, the definition of forestland must be complimented by a definition of sampling unit; this study shows that when using the trees from a ground-sampled unit to classify a piece of forest, it is important to understand the differences that one might expect based on how and (or) how much land is being sampled. This simulation study shows that there can be very real differences based on the type of plot used to sample, and the difference may also depend on unknown characteristics of the population. The size of the plot, related to the number of subplots sampled, affects the classification of the area.

This study shows that it is important to know the sampling and measurement design used for collecting the data used for classification, and that combining inventories that use distinct plot designs can be problematic. In this study, we investigate a simple classification of dominant cover type. Although in aggregate, the difference in the area assigned to each forest type may be similar between designs, comparisons at the plot level can produce differences between fixed- and variable-radius designs in the same area. The differences that can be seen are an indication that when the design changes, the plots have to be viewed as semipermanent in nature, even though they occupy the same piece of ground. In conjunction with changes in tree selection are the changes in subplot locations between the previous FIA plot footprint and the present, where only one subplot has the same center, which further supports the semipermanent nature of plots between inventories. To alleviate this problem, it would be necessary to remeasure the previous plot at the time of the installation of the new one. Estimates of change in area by forest type will contain some amount of uncertainty due to the design shift alone, and without a remeasure, that uncertainty cannot be estimated. The greatest effect may be seen in stands with the greatest species diversity and in areas with the greatest rates of fragmentation.

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