Boundary Plot Corrections for Variable Radius Plots—Simulation Results

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Abstract.—The boundary plot problem is encountered when a forest inventory plot includes two or more forest conditions. Depending on the correction method used, the resulting estimates can be biased. The various correction alternatives are reviewed. No correction, area correction, half sweep, and toss-back methods are evaluated using simulation on an actual data set. Based on the simulation results, no correction is recommended when the boundary between forest conditions is gradual. For abrupt boundaries, either the area correction or toss-back methods should be used.

THE PROBLEM

Forest inventory generally involves delineating relatively homogenous forest units (stands) or confirming existing stand boundaries, locating ground sampling plots and measuring some forest attributes on these plots. Alternately, ground plots can be located and measured first and the resulting data used alone to estimate forest attributes.

If the plots are randomly located within the stand, some will include the stand boundary and portions of the adjacent area. Analysis of the field data is complicated by these boundary plots that include one or more borders between stands and measurements corresponding to two or more stands. When plots are constrained to fall entirely within a single stand, the trees near the stand boundary have a lower probability of being sampled. If the stand characteristics near the boundary differ from the stand interior, the resulting stand estimates are biased. Various methods have been suggested to deal with this boundary plot problem (e.g., Forest Science Monograph 31, Iles (1993)), each with associated advantages and disadvantages. This report reviews the alternatives and, using simulation, quantifies the errors associated with some of these techniques for variable radius plots.

The seriousness of the boundary plot problem depends on the magnitude of the edge effect between forest conditions and the proportion of sample plots that include two or more forest conditions. The number of boundary plots depends on the size of the plot and the amount of stand edge relative to stand interior. In some landscapes, more than 30 percent of the sample plots may be boundary plots (Birdsey 1995), and biases of more than 6 percent may result from moving plots away from the boundary (Williams *et al.* 1996). Based on data from various sources, Hahn *et al.* (1995) reported that 2 percent of subplots within 1-acre cluster plots will straddle two or more forest conditions. In the two 8-ha (rectangular) forests studied by Ashley and Beers (1970), over 60 percent of the sample points required some correction for boundary overlap. Ignoring the boundary will introduce bias to the stand and strata estimates, but as population size increases, the bias should become negligible as the probability of locating plots along the population boundary decreases.

The boundary plot problem is confounded by the subjectivity involved in delineating stands (Fortin 1997) and the potential introduction of error when transferring hand-drawn boundaries from an aerial photograph to a digital database. The complications to the boundary plot problem arising from a vague or inaccurate stand boundary are not discussed here.

METHODS FOR DEALING WITH EDGE PLOTS

In practice, one of the main difficulties in dealing with edge plots in the field is identifying and locating the boundary. When the boundary is obvious in the field (e.g., forest - nonforest boundary), one or more of the following alternatives may be appropriate. However, even abrupt boundaries are generally not straight, sharp lines. For gradual transition zones or ecotones, the bias incurred by ignoring the border may be smaller than the uncertainty associated with locating the border in the field.

Each alternative may be most appropriate in some circumstances, with certain attributes. The challenge in inventory design is to select a method yielding generally robust results in most situations and consistent results in all situations. Alternatively, rules can be constructed to determine which option to use in specific circumstances. In evaluating the alternatives, some measurable edge effect is assumed. Otherwise, although some methods may yield biased stand estimates, given a statistically

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Table 1.—*The advantages and disadvantages of the various boundary corrections are given. Some degree of edge effect (ecotone) is assumed.*

Correction method	Advantages	Disadvantages
Ignoring the boundary	The chief advantage is simplicity. This alternative may be appropriate when the transition between stands is gradual (minimum bias) and the boundary is difficult to locate in the field. Unbiased at the population level.	Bias and imprecision at the stand and subpopulation levels. In general, stands appear more heterogeneous than they are.
Moving the plot (substitution)	Simple to implement. Unbiased at the population level.	The undersampling of conditions near the stand boundary leads to bias at all levels of inventory aggregation and incorrect estimates of the within and between stand variability.
Dropping the plot	Simple to implement. Unbiased at the population level.	The undersampling of conditions near the stand boundary leads to bias at all levels of inventory aggregation and incorrect estimates of the within and between stand variability.
Area correction (direct-weighting)	This alternative has relatively low bias and requires only the tree dbh and the distance from the tree to the boundary (or distance from the plot center to the tree and distance from the plot center to the boundary) to be measured.	This method is biased at all levels of inventory aggregation.
Area correction (tree centered)	This method provides unbiased estimates assuming the stand boundary is relatively straight within the tree circles.	This method is time-consuming in the field and requires precise locating of the stand boundary. In practice, estimates are likely to be imprecise.
Half plots	This method is relatively simple to implement.	Some bias remains and the resulting estimates have higher mean squared errors.
Grosenbaugh's method	This method provides unbiased estimates assuming the stand boundary is relatively straight within the tree circles.	This alternative requires the stand boundary and the boundary zone be delineated. The resulting estimates are somewhat imprecise.
Mirage method	This method provides unbiased estimates.	This method is somewhat cumbersome in the field and requires the stand boundary be located. Establishing two plots requires access to the adjacent stand.
Enlarged tree circle or Barett's method	This method provides unbiased estimates	In most cases, it is impractical to determine the tree areas near stand boundaries.
Fully mapped designs	This method provides unbiased estimates	Mapping the stand boundary may be difficult (impractical).
"Toss-back"	This method provides unbiased estimates and does not require measuring distances.	This method requires locating more plots and requires access to the area surrounding the stands. This method requires locating the boundary.

valid design and a large population (low probability of locating plots along the population boundary), none of the methods will add appreciable bias to the population estimates. In this discussion, the population is assumed to be large (>1,000 km^2) with strata (subpopulations) defined prior to sampling.

The advantages and disadvantages of each method are summarized in table 1.

Ignoring the Border

If trees are tallied regardless of whether they fall within the stand or not, the stand boundary is ignored (referred to as fuzzing by Hahn *et al.* (1995)). This results in bias and increased variance in stand and subpopulation estimates but no bias at the population level (ibid.), assuming all the points fall within the population of interest and all strata are sampled. All trees have the same probability of being sampled so the population estimates are unbiased, but some trees are attributed to the wrong stand and possibly stratum leading to biased stand and subpopulation estimates. This method leads to unbiased population estimates assuming all strata are sampled using a statistically valid design.

Moving the Plot (Substitution)

If a sample plot falls within a stand boundary zone, it can be moved away from the edge so that it falls entirely within the stand. Areas near the stand edge have a lower probability of being sampled and areas slightly farther from the edge have a higher probability of being sampled than the rest of the stand. The larger the amount of edge in a stand relative to area, the greater the resulting error (Shiver and Borders 1996).

The undersampling of conditions near the stand boundary leads to bias at all levels of inventory aggregation and incorrect estimates of the within- and between-stand variability.

Dropping the Plot

If part of the plot falls outside the stand, it can be dropped and the stand attributes estimated from a reduced number of plots. Ashley and Beers (1970) do not recommend restricting plots to the interior of the stand since the bias is more difficult to quantify and correct than the bias due to boundary plots.

Area Correction—Plot Centered (Direct-weighting)

If part of the sample plot falls outside of the stand, the portion within the stand can be sampled. The treatment of this partial plot depends on the type of plot. For fixed-area plots, the resulting data can be weighted by the partial plot area (called direct-weighting by Gregoire and Scott (1990)) although determining the plot area can be time-consuming. Variable radius plots are trickier. Beers (1966) (cited in Ashley and Beers (1970)) described direct-weighting where the distance from the point to the boundary is measured. The hypothetical circular plot area associated with each tree is calculated and centered at the sample point. The proportion of the hypothetical circular plot falling within the stand boundary is used as the inverse weight for the tree (see the area correction formula given in the next section). Either a lookup table or computer program is required to make this approach practical. In general, a more practical approach is to use the half-plot method discussed later.

Area Correction—Tree Centered

The area correction method (Iles' (1993) second approach, called FOLD by Hahn *et al.* (1995) and tree-concentric by Gregoire and Scott (1990)) compensates for the decreased selection probability of boundary trees by increasing their weight. For each tree, generate the tree circle with radius equal to the limiting distance of the tree, *r*, or the plot radius for fixed area plots and measure the shortest distance, *d*, from the tree to the stand boundary. The tree is weighted by the inverse of the proportion of the tree circle falling within the stand

$$weight = \frac{\pi r^2}{\pi r^2 - r^2(\theta - \frac{1}{2}\sin(\theta))} \quad \text{where} \quad \theta = 2\cdot\cos^{-1}(\frac{d}{r})$$

This method requires that the distance from trees to the stand boundary be measured for trees close to the boundary. Alternatively, for stand boundaries that are relatively straight within the tree circle, the perpendicular distance and azimuth from the plot center to the boundary and the distance and azimuth from the plot center to the subject tree can be measured. The distance from the subject tree to the boundary can then be computed. The subsequent calculation of weights is best undertaken by a computer program.

This method assumes the stand boundary is relatively straight within the tree circles.

Half Plots

Rather than determine which portion of the plot falls within the stand and which falls outside, a half plot can be located. The original plot is bisected roughly parallel to the stand edge and the interior half is sampled. The plot results are then doubled to represent a whole plot. This procedure has some of the disadvantages of the relocating the plot method, namely that the edge trees have a slightly altered probability of being selected. However, these probabilities are not as distorted as in the relocating plot method.

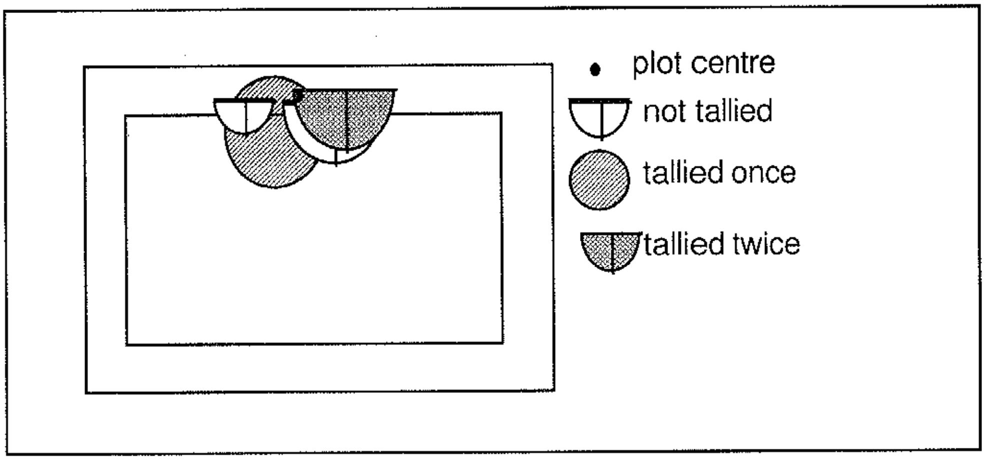

Figure 1.—*In Grosenbaugh's method, the tree circles for trees near the boundary zone are folded inward, parallel to the stand boundary. Trees are tallied the number of times the tree circle overlaps the plot center.*

This method requires that some sort of boundary zone be established. Within the boundary zone, half plots are used.

Grosenbaugh's Method (Grosenbaugh 1958)

The area within a fixed distance of the stand boundary is designated the boundary zone. The boundary zone should be a little wider than the radius of the maximum tree circle expected (Grosenbaugh 1958). Within the boundary zone, the tree circles are folded inward, parallel to the stand boundary. Trees within the boundary zone are tallied twice if their folded tree circles overlap the plot center. Trees in the stand's interior are tallied once. Trees within the fixed distance of two stand boundaries are folded twice, away from the boundary. These trees are tallied four times if the quarter circle includes the plot center (fig. 1).

For non-rectangular plots, this technique can be extended using fractional tree circles and sweeps. In practice, the angles should be limited to fractions with associated integer weights, i.e., sweeps of 180°, 120°, 90°, 72°, 60°, etc. leading to tree weights of 2, 3, 4, 5, and 6.

Both Ashley and Beers (1970) and Gregoire and Scott (1990) found that Grosenbaugh's method produced large variances due to the large weights associated with some boundary trees.

Mirage Method

Conceptually, the mirage method folds the plot along the stand boundary back into the stand. Trees within the folded area are tallied twice (fig. 2). In practice, the mirage method is implemented by establishing two plot centers, one inside the stand and the other the same distance from the stand boundary (measured perpendicular to the stand boundary) but outside the stand. For both plots, only the trees within the stand of interest are tallied and create one full plot (Shiver and Borders 1996).

This method assumes a relatively straight boundary. This method can be extended to plots near stand corners by adding a second mirage plot along the second side of the corner and a third mirage plot by rotating the original point 180° along one of the sides (Gregoire 1982). Beers (1977) recommends the mirage method because it is unbiased and simple.

Enlarged Tree Circle or Barett's Method

In Barett's method, the tree circle associated with a tree is enlarged until the area of the tree circle within the stand of interest is equal to the original tree circle. Those trees whose enlarged tree circle includes the sample point are tallied (Barett 1964). For all suspected boundary trees, this method requires measurement of the tree diameter, shortest distance from tree to boundary, and distance from the plot center to the tree.

Fully Mapped Design

In fully mapped designs, the entire plot is mapped including stand boundaries. Trees are then assigned to a stand. This method is best suited when the plots are located randomly from the entire population rather than within specific stands. This procedure is recommended for the USDA Forest Service Forest Inventory and

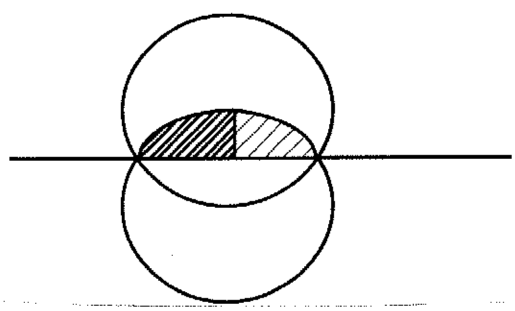

Figure 2.—*In the mirage method, tree circles are folded in along the stand boundary. Trees are tallied the number of times the tree circle overlaps the plot center.*

Analysis (FIA) program (Hahn *et al.* 1995) and the Forest Health Monitoring (FHM) program (Scott and Bechtold 1995).

"Toss-Back" Method

A variation on the fully mapped designs is the toss-back method (Haga and Maezawa 1959). In effect, plots are randomly located within the entire inventory area and only trees within the stands of interest are tallied. The stand of interest is embedded in a larger, superstand that contains all the tree circles in the stand of interest. Plots are randomly located within the superstand until the stand of interest contains the desired number of sample plots. All the plots in the superstand are sampled, but only trees falling within the stand of interest are tallied. The effective sample size is the number of plots whose centers fall within the stand of interest. The tallied trees from exterior plots (those plots whose center is outside the stand of interest) can be assigned to any of the interior plots. Iles (1993) recommends this system on theoretical grounds, and Stage (1993) prefers it over the fold methods. The possibility exists of trees being tallied but no plot centers falling within the stand of interest. This leads to the awkward case of a plot sample size of zero.

EXTERNAL PLOTS

When the sample unit consists of a cluster of points, a cluster with a center near the edge of the stand may include some points that fall outside the stand. These are referred to here as external plots. Some of the techniques used for boundary plots may be used, but substitution is the most common technique. If the only way of determining if a plot straddles two stands is by looking at the resulting data, Moisen *et al.* (1995) do not feel the plots need any special treatment.

No Substitution

Sampling plots with no substitution is equivalent to ignoring the border.

Dropping External Plots

The plot centers that fall outside the stand of interest can be dropped and the remaining points checked for boundary conditions. This results in biased estimates since, on average, fewer points are located near the boundaries.

Substitution

The current U.S. FIA substitution rule tends to move plots too far towards the interior of the stand so that the edge is underrepresented and the area slightly interior to the edge is overrepresented by sample points. In a simulation study using the U.S. FIA substitution rule, Moisen *et al.* (1995) found that if the tree variable of interest decreases by 100 percent from stand interior to edge and if 25 percent of the sample plots fall outside the boundary and have to be moved, the percent bias caused by not sampling all areas with equal probability would be approximately 3 percent. They recommend a new substitution rule that tends to substitute external plots with internal plots that are approximately the same distance from the boundary and are close to the cluster center. They also found little effect of a 10-percent uncertainty in boundary location relative to the boundary transition zone.

In a simulation study, Williams *et al.* (1996) compared substitution and no substitution using the USDA Forest Service Intermountain Forest Inventory and Analysis unit's five-point cluster design and substitution rules. The artificial populations were constructed to simulate various levels of edge effect between forest conditions. They found that using the no substitution alternative resulted in lower bias than using the substitution rules.

SIMULATION STUDY

A simulation study was undertaken to quantify the errors associated with the various alternatives presented earlier. Gregoire and Scott (1990) evaluated most of the alternatives using fixed-area plots. Therefore, this study concentrates on the two methods they didn't deal with—the half sweep and the toss-back methods—as well as ignoring the border and the tree-centered area correction.

Methods

The data set of Gregoire and Scott (1990) was used and consists of a rectangular forest area composed of a rectangular sapling stand and an adjacent rectangular sawlog stand. The 213- x 229-m area was stem mapped, and the data include dbh, height, and volume. A single variable-radius plot was randomly located within the forest stand. For this study, the plot cluster center x-coordinate was generated to lie between 50 and 163 m, while the y-coordinate was constrained to lie between -122 and 107 m. This ensured that a maximum of two forest conditions were encountered by any plot cluster, the sapling:sawlog boundary and the forest:non-forest boundaries that are parallel to the sapling:sawlog boundary. The Microsoft C++ random number generator was used to locate the cluster center. Only trees larger than 2 cm were tallied.

No correction, the tree centered area correction, half sweep, and toss-back methods were compared. Except for the toss-back method, only points whose center fell within the stand of interest were sampled. All plots were checked for boundary conditions and the relevant correction method applied where appropriate. An edge effect was noticeable within 15 to 30 m of the stand boundary

(Gregoire and Scott 1990), so a default boundary distance of 50 m was used. The half-sweep boundary distance was varied in a separate simulation. A range of BAF's from 1 to 10 m^2/ha was used.

Results

The results are given in table 2 and in figures 3 and 4. The stand values differ slightly from Gregoire and Scott (1990) because plot centers were not located within 50 m of the side boundaries. This results in a lower probability of encountering boundary plots. Not sampling the side boundaries yields slightly lower estimates because they contain more and larger trees.

The differences between the alternatives and any bias decrease with increasing BAF. This is due to the tree circles shrinking with increasing BAF and therefore a decreasing likelihood of encountering the boundary. This decrease in bias is accompanied by an increase in variance.

Using no correction resulted in an underestimate of the population attributes since some of the plots included the non-forested outer boundary. The sawlog basal area and volume were underestimated, and the sapling basal area and volume were overestimated. The variances of the population estimates were lower, in general, than the other techniques, but the stand estimate variances were higher.

The half sweep, in general, had lower bias than no correction at the stand level. In addition, the ranges and variances of the estimates were higher due to the reduced number of trees sampled and the increased weights. Except for the half sweep, the variances are very close.

DISCUSSION

Each technique for dealing with boundary plots has its strengths and weaknesses. Again, the magnitude of the boundary plot effect depends on the size and shape of the stands as well as the magnitude of the edge effect and the differences between the stands. In general, the unbiased techniques are more complex and time-consuming. Of the biased techniques, some are biased only at the stand and subpopulation level and unbiased at the population level (e.g., ignoring the border) assuming a statistically valid sampling design.

Since the differences between the techniques decrease with increasing BAF, another alternative is to increase the BAF near stand boundaries and minimize the need for any correction. Leaving such an important decision to the field crews may not be desirable.

Simplicity is extremely desirable so ignoring the border is a strong contender on that basis alone. Ignoring the border is biased at the stand level because some of the neighboring stand areas are included in the sample. This increases the estimate of the within-stand heterogeneity and decreases the estimate of the between-stand heterogeneity; some of the differences between stands are smoothed out. The seriousness of this smoothing depends on a number of factors including the magnitude of the edge effect and the percentage of plots that straddle two or more forest conditions.

All the other techniques require locating the stand boundary in the field. Although this may be difficult when the transition between stands is gradual, the importance of correcting boundary plots decreases for gradual boundaries. Thus, the bias caused by incorrectly locating the boundary in these conditions is minimal. Of greater concern may be the time field crews spend trying to locate a fuzzy boundary.

The half sweep is biased at all levels of inventory aggregation due to undersampling of the trees closest to the edge and oversampling of the trees a bit further from the edge. A lower BAF could be used for half sweeps to compensate for the increased variability, but the bias increases with lower BAF's. In the simulations undertaken here, the average bias for the basal area estimate was up to 2 percent at the stand level and 1.5 percent at the population level. However, the bias associated with a single sample point in the sapling stand ranged from 0 to 138 percent. For well-defined boundaries, both the area correction and toss-back methods provide good estimates. The area correction is a bit more time-consuming in the field, while the toss-back method requires locating more plots in the field.

RECOMMENDATIONS

A good compromise between practicality and accuracy appears to be the use of the area correction or toss-back methods when the boundary is distinct. For gradual boundaries or boundaries between similar types, the boundary should be ignored. In practice, the points should be located on photos and the type of correction for boundary plots selected, based on the photos. Rules for classifying a boundary as gradual or abrupt need to be established.

This combination of no correction and area correction and/or toss-back methods will lead to unbiased population estimates. Using no correction for gradual boundaries will lead to some minor bias at the stand and subpopulation levels.

The half sweep is not recommended except where there is no edge effect (e.g., edges due to recent disturbances) where it is unbiased. Otherwise an unknown amount of bias is present at all levels of compilation. Since unbiased

Table 2.—*The results of the 10,000 simulations are summarized by basal area factor. Ignoring the boundary (uncorrected - UC) is centered area correction (AC), half sweep (HS), and toss-back (TB) methods. The standard error (s.e.) is calculated as the square root of the s.e. of the simulations divided by the number of simulations.*

baf	Stand		Basal area (m²/ha)				Density (stems/ha)				Volume (m³/ha)				N
			UC	AC	HS	TB	UC	AC	HS	TB	UC	AC	HS	TB	
1	sapling	average	13.62	12.43	12.45	12.25	1,431	1,442	1,442	1,424	25.2	13.7	13.6	13.56	4,561
		s.e.	0.07	0.06	0.07		7.36	7.59	7.59		0.47	0.13	0.16		4,561
	sawlog	average	27.65	29.87	29.26	28.80	463	477	477	469	226.1	245.3	241	235.9	5,439
		s.e.	0.07	0.07	0.08		2.22	2.35	2.35		0.60	0.53	0.62		5,439
	total	average	21.25	21.91	21.59	21.25	904	917	917	905	134.4	139.7	137.3	134.5	10,000
		s.e.	0.09	0.10	0.10		10.85	11.00	11.00		1.08	1.19	1.18		10,000
2	sapling	average	13.31	12.43	12.50	12.31	1,434	1,441	1,441	1,428	22.2	13.8	13.8	13.64	4,561
		s.e.	0.08	0.07	0.10		9.70	9.90	9.90		0.43	0.17	0.22		4,561
	sawlog	average	28.33	29.94	29.43	29.17	469	480	480	474	231.5	245.6	241.7	238.7	5,439
		s.e.	0.08	0.08	0.10		2.95	3.06	3.06		0.68	0.65	0.84		5,439
	total	average	21.48	21.96	21.71	21.48	909	919	919	909	136	139.9	137.8	136	10,000
		s.e.	0.09	0.10	0.11		11.31	11.42	11.42		1.12	1.21	1.23		10,000
3	sapling	average	13.17	12.46	12.49	12.35	1,436	1,442	1,442	1,431	20.8	14	14	13.84	4,561
		s.e.	0.09	0.09	0.12		11.44	11.59	11.59		0.42	0.20	0.27		4,561
	sawlog	average	28.51	29.84	29.41	29.20	469	478	478	473	233.1	244.7	241.3	238.9	5,439
		s.e.	0.10	0.10	0.13		3.57	3.66	3.66		0.79	0.79	1.07		5,439
	total	average	21.51	21.91	21.69	21.51	910	918	918	910	136.3	139.5	137.6	136.3	10,000
		s.e.	0.10	0.11	0.12		11.71	11.80	11.80		1.16	1.23	1.28		10,000
4	sapling	average	12.98	12.43	12.50	12.33	1,433	1,439	1,439	1,428	19.4	13.9	14	13.84	4,561
		s.e.	0.10	0.10	0.14		12.94	13.09	13.09		0.40	0.23	0.32		4,561
	sawlog	average	28.62	29.76	29.44	29.17	468	476	476	472	234.1	244.1	241.6	238.8	5,439
		s.e.	0.11	0.11	0.16		4.13	4.23	4.23		0.88	0.90	1.26		5,439
	total	average	21.49	21.85	21.71	21.49	908	915	915	908	136.1	139.1	137.8	136.2	10,000
		s.e.	0.11	0.12	0.14		12.06	12.15	12.15		1.19	1.25	1.33		10,000
5	sapling	average	12.95	12.5	12.52	12.40	1,440	1,447	1,447	1,438	18.7	14	14.3	13.94	4,561
		s.e.	0.11	0.11	0.16		14.34	14.49	14.49		0.40	0.26	0.36		4,561
	sawlog	average	28.75	29.75	29.49	29.21	470	476	476	471	235.2	243.9	241.8	239.2	5,439
		s.e.	0.12	0.13	0.18		4.60	4.67	4.67		0.98	1.00	1.43		5,439
	total	average	21.55	21.88	21.75	21.54	913	919	919	912	136.4	139.1	138	136.5	10,000
		s.e.	0.11	0.12	0.15		12.48	12.57	12.57		1.22	1.27	1.38		10,000
7	sapling	average	12.97	12.63	12.70	12.54	1,453	1,459	1,464	1,451	17.9	14.4	14.8	14.34	4,561
		s.e.	0.13	0.13	0.19		17.06	17.19	24.68		0.40	0.30	0.44		4,561
	sawlog	average	28.85	29.64	29.45	29.21	471	476	482	473	236	242.9	241.3	239	5,439
		s.e.	0.14	0.15	0.21		5.43	5.51	7.79		1.17	1.20	1.73		5,439
	total	average	21.61	21.88	21.81	21.61	919	924	930	919	136.5	138.7	138.0	136.5	10,000
		s.e.	0.13	0.13	0.17		13.33	13.41	15.97		1.27	1.32	1.48		10,000
10	sapling	average	12.87	12.67	12.77	12.60	1,462	1,467	1,467	1,460	16.9	14.6	15.1	14.52	4,561
		s.e.	0.16	0.16	0.23		20.69	20.80	20.80		0.43	0.37	0.54		4,561
	sawlog	average	29.12	29.73	29.74	29.34	472	475	475	474	238.2	243.5	243.6	240.2	5,439
		s.e.	0.17	0.18	0.27		6.53	6.56	6.56		1.42	1.45	2.19		5,439
	total	average	21.71	21.95	22.00	21.71	923	928	928	924	137.3	139.1	139.4	137.3	10,000
		s.e.	0.14	0.15	0.20		14.5	14.6	14.6		1.36	1.40	1.66		10,000

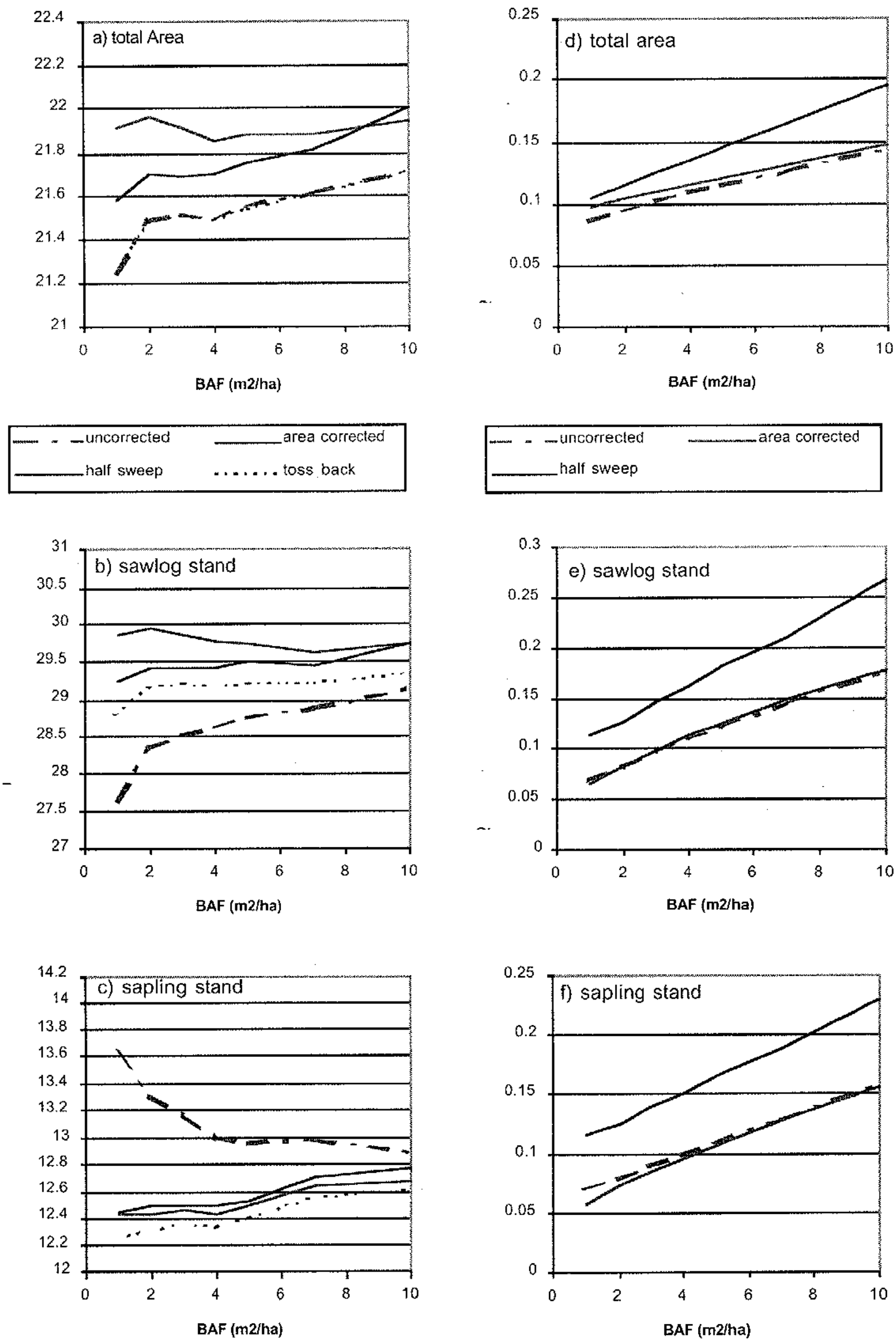

Figure 3.—*The relationship between the basal area estimates and the various correction methods is shown for various basal area factors (BAF) based on 10,000 simulations (data are from table 2).*

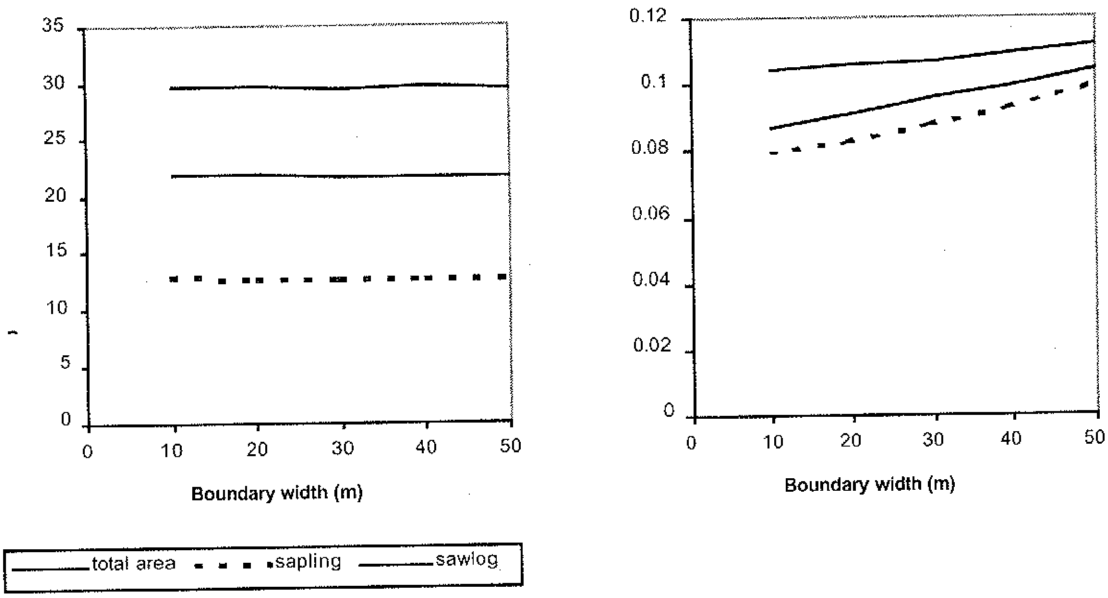

Figure 4.—*The relationship between the basal area estimates and boundary width for the half-sweep correction method is shown for a basal area factor of 2 m²/ha based on 10,000 simulations.*

methods are available and practical, this unquantified bias is unacceptable.

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LITERATURE CITED

Ashley, M.D.; Beers, T.W. 1970. Boundary-line overlap in horizontal point-sampling. Res. Bull. 865. West Lafayette, IN: Purdue University, Agricultural Experiment Station. 15 p.

Barett, J.P. 1964. Correction for edge effect bias in point sampling. Forest Science. 10: 52-55.

Beers, T.W. 1966. The direct correction for boundary-line slopover in horizontal point sampling. Res. Prog. Rep. 224. West Lafayette, IN: Purdue University, Agricultural Experiment Station.

Beers, T.W. 1977. Practical correction of boundary overlap. Southern Journal of Applied Forestry. 1: 16-18.

Birdsey, R.Q. 1995. A brief history of the "straddler plot" debates". Forest Science Monograph. 31: 7-11.

Fortin, M.-J. 1977. Effects of data types on vegetation boundary delineation. Canadian Journal of Forest Research. 27: 1851-1858.

Gregoire, T.G. 1982. The unbiasedness of the mirage correction procedure for boundary overlap. Forest Science Monograph. 31: 504-508.

Gregoire, T.G.; Scott, C.T. 1990. Sampling at the stand boundary: a comparison of the statistical performance among eight methods. In: Research in forest inventory, monitoring, and growth and yield: IUFRO World Congress; 1990 August 5-11; Montreal, Canada. Publ. FWS-3-90. Blacksburg, VA: Virginia Polytechnic Institute and State University: 78-85.

Grosenbaugh, L.R. 1958. Point-sampling and line-sampling: probability theory, geometric implications, synthesis. Occas. Pap. 160. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 33 p.

Haga, T.; Maezawa, K. 1959. Bias due to the edge effect in using the Bitterlich method. Forest Science. 5: 370-376.

Hahn, J.T.; MacLean, C.D.; Arner, S.L.; Bechtold, W.A. 1995. Procedures to handle inventory cluster plots that straddle two or more conditions. Forest Science Monograph. 31: 12-25.

Iles, K. 1993. Edge effect in forest sampling: the "lower back pain" of field work: a background paper for the sampling sub-committee of the BC Inventory Design. Nanaimo, BC: Kim Iles & Associates Ltd. 17 p.

Moisen, G.G.; Stage, A.R.; Born, J.D. 1995. Point sampling with disjunct support near population boundaries. Forest Science Monograph. 31: 62-82.

Scott, C.T.; Bechtold, W.A. 1995. Techniques and computations for mapping plot clusters that straddle stand boundaries. Forest Science Monograph. 31: 46-61.

Shiver, B.D.; Borders, B.E. 1996. Sampling techniques for forest resource inventory. New York, NY: John Wiley and Sons, Inc. 356 p.

Stage, A.R. 1993. How to sample within stands. In: Lund, H.G.; Landis, E.; Atterbury, R., eds. Stand inventory technologies 92: proceedings of the stand inventory technologies: an international multiple resource conference. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 85-91.

Williams, M.S.; Schreuder, H.T.; Reich, R.M. 1996. The extent of bias caused by substituting points in forest survey: a simulation study. Res. Pap. RM-327. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 7 p.