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ROAD TRANSECT COUNTS FOR RAPTORS: HOW RELIABLE ARE THEY?

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ABSTRACT.—Biases in roadside counts of randomly placed three-dimensional models of perched Red-tailed Hawks (*Buteo jamaicensis*), Cooper's Hawks (*Accipiter cooperii*), and Sharp-shinned Hawks (*A. striatus*) were investigated. Counts were performed by seven, two-person survey teams in five vegetation types in September 1983 and March 1984 at Dulles International Airport in Fairfax and Loudoun counties, Virginia. Larger models were consistently seen more frequently than smaller models in grassland but not in forest or woodland. Models were more visible in grassland than in forested vegetation. Foliage structure variables accounted for 58% of variation in model detectability among vegetation types.

Overall, survey teams detected between 5.4% (deciduous forest in summer) and 48.4% (grassland in winter) of the models. Density indices calculated with line and strip transect methods were compared with known density. A modification of the mean visibility method produced the most accurate population estimates, whereas unadjusted counts had the highest precision.

Quantification of raptor populations is difficult and costly. Most raptors are widely distributed, occur in a variety of habitats and are secretive. Accordingly, survey techniques useful for other birds are often ineffective when used to survey raptors (Fuller and Mosher 1981).

A widely used raptor survey technique is the road transect, which yields sample sizes sufficient for quantitative analysis and is relatively inexpensive. In most cases researchers using road transects to survey raptors repeatedly drive a specified route at speeds of 15-40 km/hr on calm, clear days. One to two observers count all raptors sighted in a strip 0.4-0.8 km wide on either side of the road (Craighead and Craighead 1956; Johnson and Enderson 1972; Stahlecker and Belke 1974; Marion and Ryder 1975; Woffinden and Murphy 1977; Craig 1978; Wilkinson and Debban 1980; Peterson 1979; Diesel 1984). Road transects have been used to obtain indices to raptor density or relative abundance in order to assess or compare population structure, seasonal population changes, habitat use, distribution, yearly population trends and to determine activity (Craighead and Craighead 1956; Mathisen and Mathisen 1968; Johnson and Enderson 1972; Woffinden and Murphy 1977). Modifications of the technique also have been used to survey populations of rare or endangered species (Southern 1963; Sykes 1979).

Raptor road counts are affected by a number of inherent biases, principally intra- and interspecific variation in species detectability (Fuller and Mosher 1981). Many researchers have assumed that all raptors within a surveyed area were detected while others have acknowledged that not all are observed. Some researchers have developed correction factors to compensate for individuals not counted (Craighead and Craighead 1956; Millsap 1981); others have cautioned against literal interpretation of data collected from densely vegetated habitats or for less observable species (Mathisen and Mathisen 1968; Kiff and Axelson 1977; Craig 1978). Other sources of bias include variations in terrain and alterations in roadside vegetation that affect visibility; variation in raptor dispersion with changes in perch availability; variability in prey abundance; change in activity of raptors with weather, season and time of day; and differences in observer expertise (Cade 1969; Stahlecker and Belke 1974; Fuller and Mosher 1981).

Effect of biases on road transect data remain poorly understood since the technique has not been evaluated in an area where raptor populations are known. A number of techniques are available to adjust transect data for passerine birds (e.g., Emlen 1971; Burnham et al. 1980; Anderson and Ohmart 1981; Ramsey and Scott 1981; Tilghman and Rusch 1981). Compared to raptor road transects, however, passerine transects are shorter, sample sizes are often larger, habitat and terrain is generally more homogeneous and travel by foot through undisturbed vegetation is possible. Nevertheless, a modification of one or more techniques, when applied to raptor road counts, might improve reliability of population estimates (Andersen et al. 1985).

Objectives of this study were to 1) evaluate the accuracy and precision of population indices from unadjusted road transect data for three raptor species

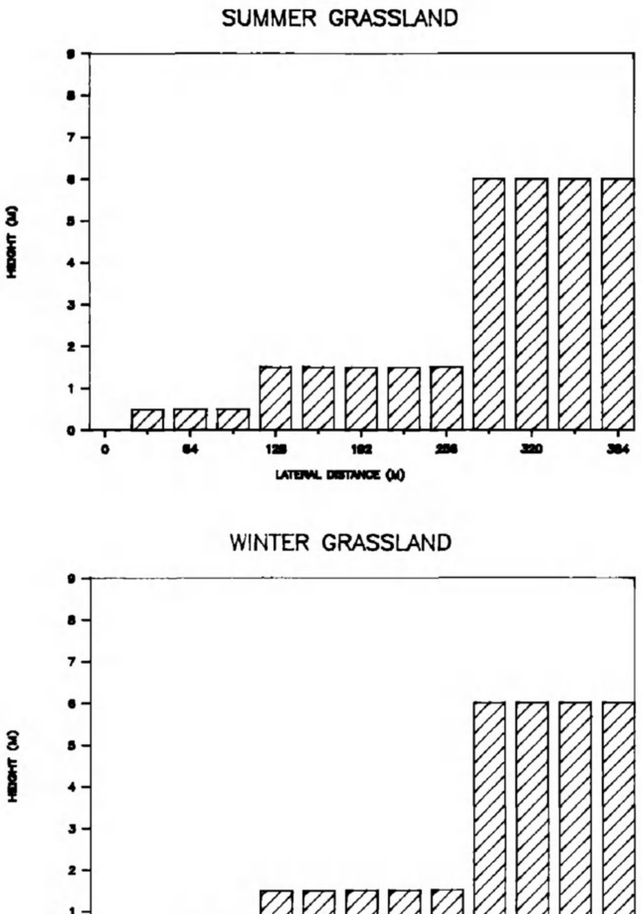

Figure 1. Vegetation profile of grassland vegetation type, Dulles Airport, Virginia. Lateral distance refers to the mean distance perpendicular to the roadway at which ≥½ density board was obstructed by vegetation. Shaded region represents the portion of the sample strip not visible to observers.

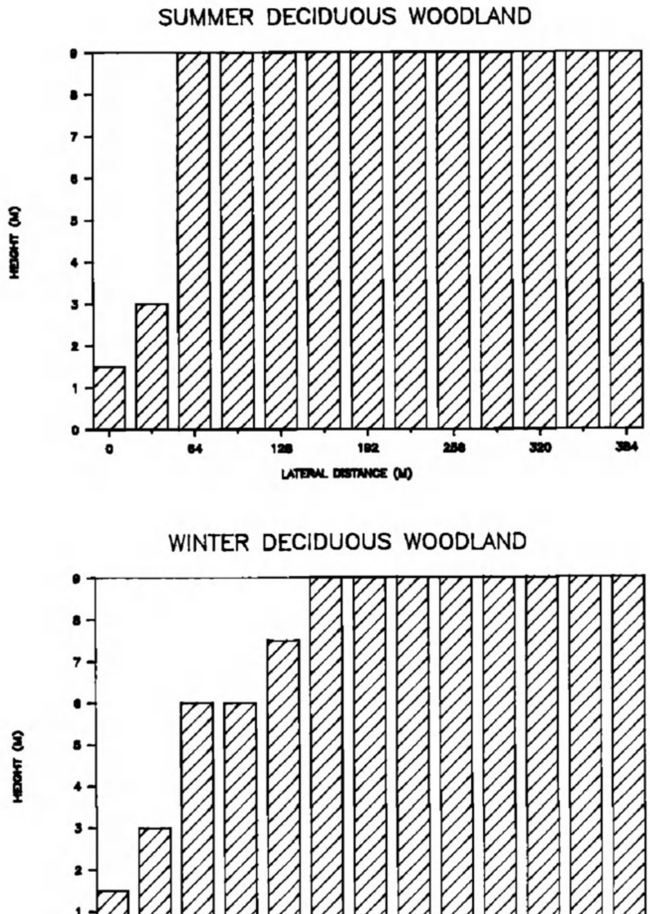

Figure 2. Vegetation profile of deciduous woodland vegetation type, Dulles Airport, Virginia. Lateral distance refers to the mean distance perpendicular to the roadway at which ≥½ density board was obstructed by vegetation. Shaded region represents the portion of the sample strip not visible to observers.

of known density in five vegetation types, and 2) determine if line and strip transect analysis techniques improve accuracy and precision of road count density estimates.

Study Area and Methods

The study was conducted on the 59 km^2 Dulles International Airport complex, located in Fairfax and Loudoun counties, Virginia. Oak (*Quercus* spp.)-pine (*Pinus* spp.) forest is the climax plant community although seral stages ranging from open grassland, eastern red-cedar (*Juniperus virginiana*) woodland and oak forest are represented. Airport property is closed to public access, and unimproved roads are present through all vegetation types.

Data Collection. Data were collected from May 1983–March 1984. A 29.5 km transect was established along existing roadways that passed through five different vegetation types: grassland, deciduous woodland (second growth deciduous forest ≤12 m in height), deciduous forest (mature deciduous forest), coniferous woodland (red-cedar stands ≤10 m in height), and coniferous forest (planted loblolly pine [*P. taeda*]). Homogeneous vegetation plots were identified along the transect route in each vegetation type. Size and number of plots in each type were in proportion to each type's abundance along the transect. Plots started at the edge of the road and were 402 m wide. Plot length varied with the extent of homogeneous vegetation (range = 390–1520 m). A total of 13 plots was selected in summer and 14 in winter (four [summer] or five [winter]

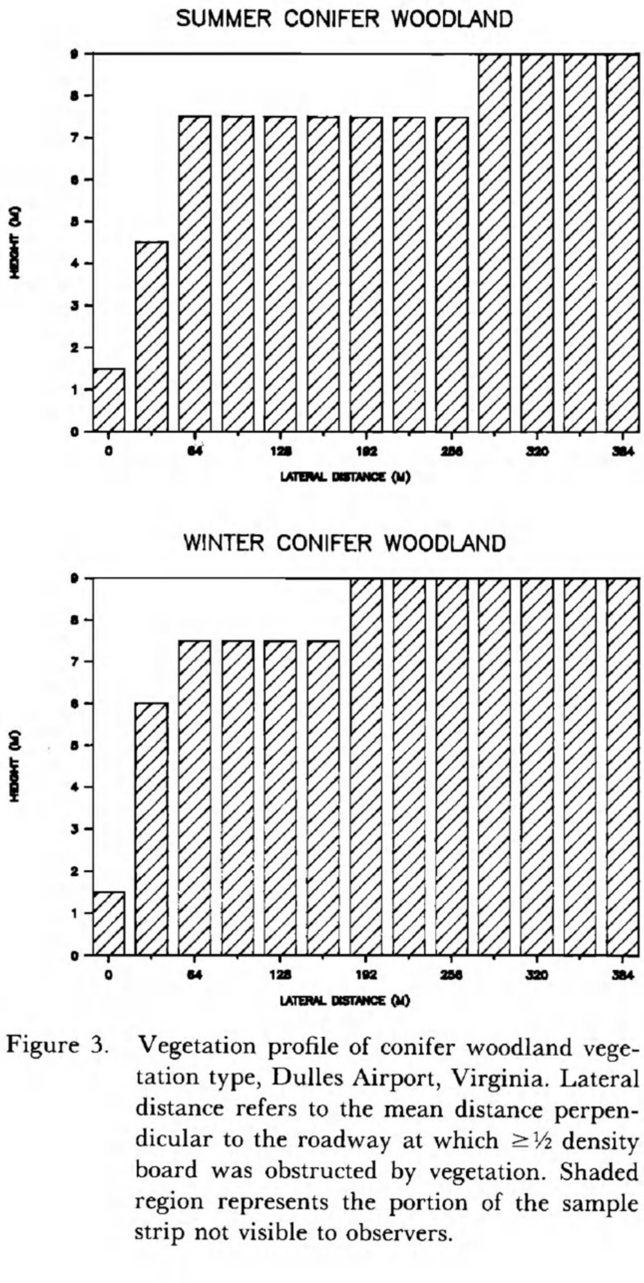

Figure 3. Vegetation profile of conifer woodland vegetation type, Dulles Airport, Virginia. Lateral distance refers to the mean distance perpendicular to the roadway at which ≥½ density board was obstructed by vegetation. Shaded region represents the portion of the sample strip not visible to observers.

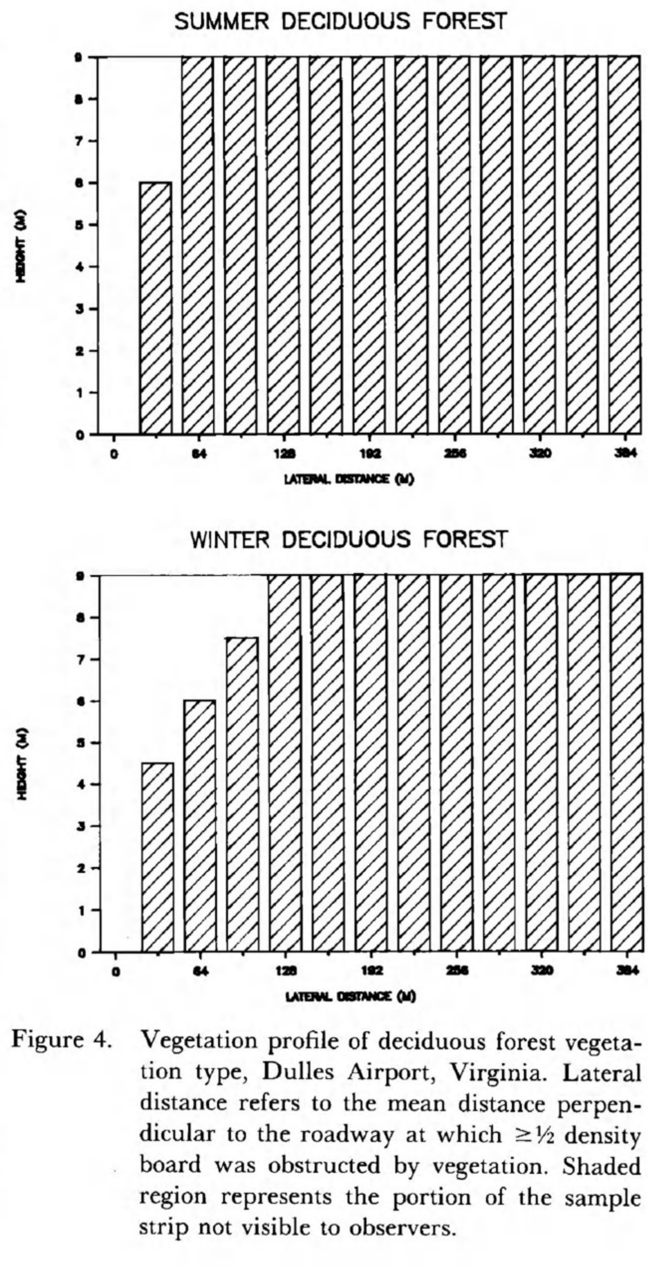

Figure 4. Vegetation profile of deciduous forest vegetation type, Dulles Airport, Virginia. Lateral distance refers to the mean distance perpendicular to the roadway at which ≥½ density board was obstructed by vegetation. Shaded region represents the portion of the sample strip not visible to observers.

in grassland, two in deciduous woodland, two in coniferous woodland, two in deciduous forest, and three in coniferous forest).

Horizontal foliar density was measured using a density board along 107 randomly selected transects stratified among plots (MacArthur and MacArthur 1961; Hays et al. 1981). Transects were oriented perpendicular to the road and covered the full width of the plot (402 m). Horizontal foliar density was measured at standardized height intervals (1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 m) and set lateral distances (25 points from 0–402 m at 16 m intervals) along each transect. Distance from the road at which ≥½ of the density board was obscured by vegetation was determined at each point for each height interval. Measurements taken in winter (January) and summer (July) were used to calculate relative degree of vegetative screening and amount of habitat visible to observers in each vegetation type during each season (Figs. 1–5).

We constructed three-dimensional styrofoam models that resembled perched Sharp-shinned Hawks (*Accipiter striatus*) (summer: N = 35; winter: N = 32), Cooper's Hawks (*A. cooperii*) (summer: N = 46; winter: N = 45), and Red-tailed Hawks (*Buteo jamaicensis*) (summer: N = 24; winter: N = 24). The number of models of each type was determined by logistic constraints and availability of material. Models were randomly placed along the transect in vegetation plots. To facilitate random placement, plots were gridded into 16 m^2 cells. Each model was randomly allocated to a cell, height class (0%–10%, 10%–20%, . . . , 80%–100% of the maximum vegetation height in the cell),

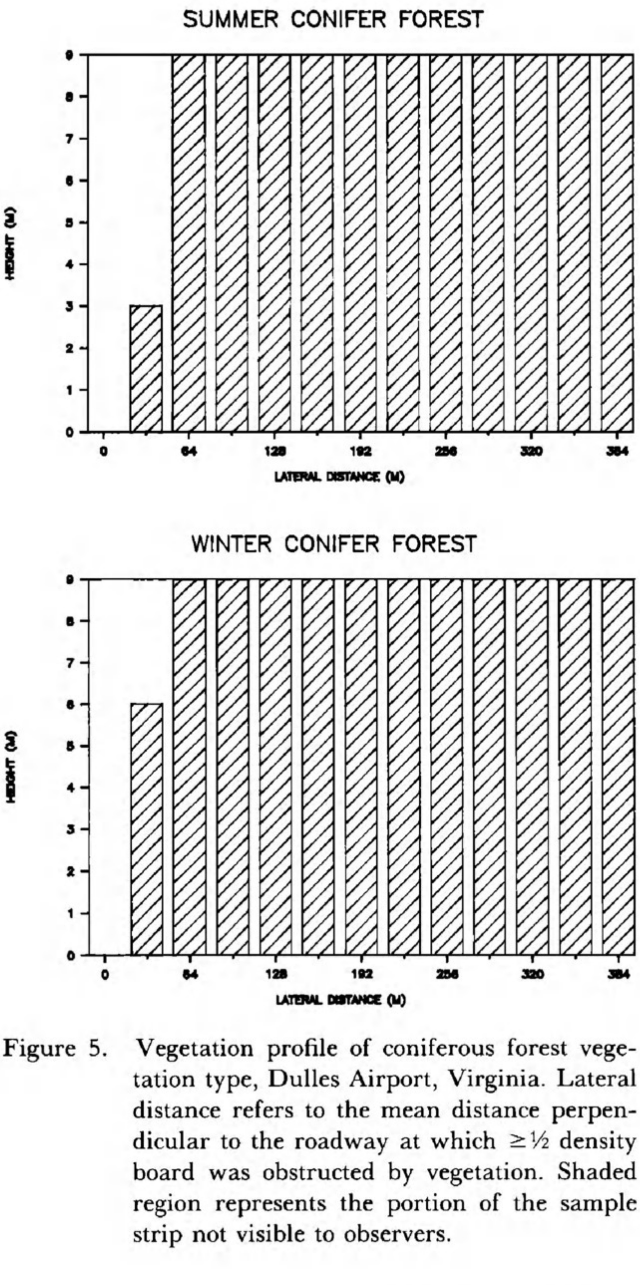

Figure 5. Vegetation profile of coniferous forest vegetation type, Dulles Airport, Virginia. Lateral distance refers to the mean distance perpendicular to the roadway at which ≥½ density board was obstructed by vegetation. Shaded region represents the portion of the sample strip not visible to observers.

side of the perch substrate and facing direction (north, south, east or west). Models were placed on the outside of the tree or shrub (meeting height requirements) that was closest to the center of the cell. No models were placed higher than 10.5 m for logistical reasons, even though tallest vegetation exceeded this height in deciduous and coniferous forest. Models randomly allocated to locations impossible to observe from the transect were relocated randomly until a potentially detectable site was selected. All locations used were considered in analyses, so that our total model population size was 598 in summer (141 Red-tailed Hawk, 265 Cooper's Hawk, and 192 Sharp-shinned Hawk models) and 339 in winter (80 Red-tailed Hawk, 129 Cooper's Hawk, and 130 Sharp-shinned Hawk models).

Seven teams of two observers each drove the transect at speeds from 25–42 km/hr and counted models under similar weather and lighting conditions once in each season.

Data Analysis. Differences in model detectability among model types and vegetation types were evaluated using one- and two-way ANOVAs, followed by T-method unplanned comparisons of groups (Sokal and Rohlf 1981). Analyses were based on the arcsine transformation of the proportion of models detected (Sokal and Rohlf 1981).

Multiple regression analysis on model counts in each of the 27 study plots (13 in summer; 14 in winter) was used to assess effects of vegetative structure on detectability. Vegetation variables used were: 1) foliage height diversity (Hays et al. 1981); 2) foliage volume index, calculated as the mean lateral distance at which ≥½ of the density board was obscured by vegetation over all height increments; 3) visible plot area, calculated as the maximum lateral distance at which ≥½ the density board was obscured by vegetation at any height interval × length of the plot, and divided by the total plot area (assuming a 402 m lateral width); 4) visible plot volume, calculated as the visible volume in each height interval (plot length × lateral distance at which ≥½ density board was obscured by vegetation × 1.5 m) summed over all height intervals and divided by total volume (plot length × 402 m × 9 m); and 5) maximum overstory vegetation height in the plot. Regression was performed using Statistical Package for the Social Sciences (Nie et al. 1975).

Accuracy of model density indices and relative abundance estimates calculated using the following line and strip transect methods were evaluated: 1) unadjusted counts (i.e., raw counts); 2) Emlen's estimator based on perpendicular distances (Emlen 1971); 3) the bounded count method (Robson and Whitlock 1964; Overton 1971); 4) the Fourier series estimator (Burnham et al. 1980, as used by Andersen et al. 1985); and 5) a modified version of the mean visibility method (Hirst 1969) using the bounded count approach. Fourier series estimator performs best with sample sizes ≥40 and for monotonic decreasing detection curves with a well defined shoulder near the center line (Burnham et al. 1980). We did not calculate density indices using the Fourier series estimator in cases where these conditions were not met. Modified mean visibility method involves the same procedures as bounded count (i.e., [two × the largest number of individuals detected on one of a series of counts in sample strip] − the second highest count is taken as the best estimate of population size for the strip), except that density indices were based on volume of roadside habitat actually visible to observers

Throughout, accuracy is defined as the closeness of the estimate to the true or known value, expressed as a percent of the true value. Accuracy bias is defined as the absolute value of (accuracy minus 100%). Precision is defined as the closeness of repeated measurements, and is expressed as the coefficient of variation (CV).

RESULTS

We were unable to adequately test for differences in detectability among teams of observers. Pooled summer and winter counts showed no significant interteam differences (one-way ANOVA; 0.25 >

Table 1. Mean % of hawk models detected by model type and by vegetation type in summer (N = 7) and winter (N = 7) on road transect counts at Dulles Airport, Virginia, 1983–1984.

			Deciduous		Coniferous		Veg. Types
Model Type		Grassland	Woodl.	Forest	Woodl.	Forest	Combined
		($\bar{x}$GR)	($\bar{x}$DW)	($\bar{x}$DF)	($\bar{x}$CW)	($\bar{x}$CF)	($\bar{x}$VEG)
			Summer[a]				
Red-tailed Hawk	($\bar{x}$RT)	44.1	14.3	6.8	32.4	8.0	11.3
	95% CL	41.7–46.5	13.2–15.4	5.9–7.7	11.9–25.9	6.6–9.3	10.3–12.2
	CV	3.8	14.7	24.1	40.0	18.5	10.8
Cooper's Hawk	($\bar{x}$CH)	39.1	7.4	5.6	6.9	6.4	9.4
	95% CL	34.8–39.1	6.2–7.9	2.0–9.1	5.6–8.3	3.4–9.4	8.5–10.4
	CV	12.5	17.7	68.4	20.9	50.3	10.9
Sharp-shinned Hawk	($\bar{x}$SS)	21.0	4.8	7.1	16.5	6.8	7.1
	95% CL	16.5–26.3	2.3–7.2	5.2–9.1	10.1–22.9	4.2–9.3	5.1–9.1
	CV	27.7	55.3	29.0	42.2	40.9	30.6
Model types combined	($\bar{x}$MOD)	33.9	7.0	5.7	11.8	7.7	9.2
	95% CL	29.0–37.7	6.0–8.1	4.6–6.8	10.0–13.6	6.3–9.2	8.0–10.4
	CV	12.9	16.6	20.8	16.7	20.5	14.0
			Winter[b]				
Red-tailed Hawk	($\bar{x}$RT)	71.9	10.5	19.4	4.9	3.4	10.3
	95% CL	63.5–79.4	0.2–20.6	12.5–26.1	3.1–2.0	1.1–2.5	8.4–12.3
	CV	15.5	106.5	22.2	38.4	68.6	20.7
Cooper's Hawk	($\bar{x}$CH)	70.0	22.2	13.1	5.1	6.2	13.8
	95% CL	63.6–75.9	14.4–30.0	8.4–17.8	4.1–6.1	2.8–7.5	11.1–16.5
	CV	12.0	38.6	38.9	20.3	41.8	21.1
Sharp-shinned Hawk	($\bar{x}$SS)	30.9	7.8	3.6	6.6	9.7	8.7
	95% CL	16.6–44.4	5.7–9.8	1.5–5.7	3.5–9.6	7.6–11.7	7.1–10.3
	CV	50.4	28.4	62.2	50.0	23.1	20.3
Model types combined	($\bar{x}$MOD)	48.4	13.7	9.4	5.8	6.8	11.3
	95% CL	29.5–65.2	9.2–17.8	6.5–12.2	4.5–7.3	5.0–8.6	9.5–13.2
	CV	44.0	32.0	33.3	25.7	28.6	18.0

[a] Mean accuracy was significantly different among vegetation types and model types (2-way ANOVA; $P < 0.05$). T-method unplanned comparisons (experimentwise $\alpha \leq 0.05$) (Sokal and Rohlf 1981) indicated that, among model types, $\bar{x}$RT > $\bar{x}$CH in deciduous and coniferous woodland; $\bar{x}$RT > $\bar{x}$SS in grassland, and in deciduous and coniferous woodland; and $\bar{x}$CH > $\bar{x}$SS in grassland and deciduous woodland. Among vegetation types, $\bar{x}$GR > $\bar{x}$DW, $\bar{x}$DF, $\bar{x}$CF for all model types; $\bar{x}$GR > $\bar{x}$CW for Red-tailed and Cooper's Hawk models; $\bar{x}$CW > $\bar{x}$DF, $\bar{x}$CF for Red-tailed and Sharp-shinned Hawk models.

[b] Mean accuracy was significantly different among vegetation types and model types (2-way ANOVA; $P < 0.05$). T-method unplanned comparisons (experimentwise $\alpha \leq 0.05$) (Sokal and Rohlf 1981) indicated that, among model types, $\bar{x}$RT > $\bar{x}$CH in deciduous forest, $\bar{x}$CH > $\bar{x}$RT in deciduous woodland and conifer forest; $\bar{x}$RT > $\bar{x}$SS in grassland, deciduous forest; $\bar{x}$SS > $\bar{x}$CH in conifer forest; $\bar{x}$CH > $\bar{x}$SS in grassland, deciduous woodland, and deciduous forest; $\bar{x}$SS > $\bar{x}$CH in conifer forest. Among vegetation types, $\bar{x}$GR > $\bar{x}$DW, $\bar{x}$DF, $\bar{x}$CW, $\bar{x}$CF for all model types; $\bar{x}$DW > $\bar{x}$CF for Cooper's Hawk models.

$P > 0.10$), but the large within-group variance (due to seasonal disparities in detectability) potentially masked between-group effects. Data from all survey teams were pooled in subsequent analyses.

There was a significant difference in detection rates among model types (Table 1), but small sample sizes and a randomized method of model placement potentially introduced bias. Differences varied seasonally and among vegetation types. In grassland in both summer and winter Red-tailed Hawk and Cooper's Hawk models were detected more frequently than Sharp-shinned Hawk models. In other vegetation types there were no consistent differences in accuracy with model type. Counts of Red-tailed

Table 2. Accuracy bias and precision of density indices by vegetation type for hawk models based on road transect counts at Dulles Airport, Virginia, 1983–1984.

	Accuracy Bias[a]			
Technique	Red-tailed Hawk	Cooper's Hawk	Sharp-shinned Hawk	Models Pooled
Summer grassland				
Unadjusted count	55.9	60.9	79.0	66.7
Emlen's	94.1	85.4	43.7	38.7
Bounded count	49.9	40.0	58.8	49.9
Mean visibility	0	0	33.4	10.0
Fourier series	ND[b]	59.6	65.1	62.4
Winter grassland				
Unadjusted count	28.1	30.0	69.1	51.6
Emlen's	124.8	8.5	19.7	27.4
Bounded count	30.3	10.8	58.0	30.6
Mean visibility	0	16.7	0	10.0
Fourier series	ND	ND	41.2	41.2
Summer woodland				
Unadjusted count	77.6	92.8	89.7	86.9
Emlen's	33.1	64.5	58.8	60.6
Bounded count	76.2	91.8	89.1	89.3
Mean visibility	0	10.0	10.0	6.7
Fourier series	42.5	ND	36.5	37.1
Winter woodland				
Unadjusted count	92.3	87.7	92.8	90.0
Emlen's	70.0	35.4	65.2	54.4
Bounded count	90.2	83.8	89.4	86.6
Mean visibility	0	33.9	14.4	24.3
Fourier series	11.0	24.2	9.6	3.6
Summer forest				
Unadjusted count	92.2	94.0	93.1	93.0
Emlen's	58.6	73.6	72.5	54.5
Bounded count	89.7	90.1	89.7	87.9
Mean visibility	8.5	17.7	13.6	14.2
Fourier series	60.5	71.6	36.0	55.9
Winter forest				
Unadjusted count	89.2	91.1	93.3	92.4
Emlen's	63.5	58.3	73.4	66.1
Bounded count	70.0	81.8	92.3	86.7
Mean visibility	22.4	26.8	29.3	24.5
Fourier series	63.4	112.7	10.6	47.9
Vegetation types pooled[c]				
Unadjusted count ($\bar{x}$)	72.6A	76.1A	86.2A	80.3A
CV	35.6	33.0	11.5	21.4
Emlen's ($\bar{x}$)	74.0A	54.3A	55.6B	50.3B
CV	42.8	51.5	37.2	28.8
Bounded count ($\bar{x}$)	67.7A	66.4A	79.6A	71.8A,B
CV	34.8	50.1	20.6	35.0

Table 2. Continued.

	ACCURACY BIAS[a]			
TECHNIQUE	RED-TAILED HAWK	COOPER'S HAWK	SHARP-SHINNED HAWK	MODELS POOLED
Mean visibility ($\bar{x}$)	5.2B	17.5B	16.8C	15.0C
CV	175.0	68.5	74.8	51.3
Fourier series ($\bar{x}$)	44.4A	67.0A	33.2C	41.4B
CV	27.0	27.1	62.6	50.0

[a] Accuracy bias was calculated as the absolute value of the percent of models present that were detected or accounted for minus 100%.

[b] No Fourier series density estimate was calculated because fewer than 40 models of this type were detected (with data pooled over survey teams) or detection functions did not appear monotonic decreasing.

[c] Mean accuracy was significantly different among methods for all model types (1-way ANOVA; $P < 0.05$). Means in columns that do not share a letter (A, B, C) differ significantly (T-method for unplanned comparisons [Sokal and Rohlf 1981]; experimentwise $\alpha = 0.05$)

Hawk models were generally most precise, but CVs of Red-tailed Hawk model counts were not smaller than those for other model types more often than could be expected by chance (binomial probability = 0.136).

Accuracy was significantly higher in grassland than in other vegetation types. In general detectability was greater in conifer woodland and winter deciduous woodland than in forests. Count precision was also greatest in grassland; CVs were smallest in grassland more often than expected by chance (binomial probability = 0.016).

Foliage volume index, visible plot volume and foliage height diversity contributed significantly to variation in model detectability among sample plots ($R^2 = 0.58$, $F = 10.65$, $P < 0.001$, df = 3,23). Partial regression coefficients were biased due to multicolinearity, but foliage volume index appeared to be the most important single variable (contribution to $R^2 = 0.39$).

In grassland, models of all three types were detected with about equal frequency to lateral distances of 100 m. Detectability of Sharp-shinned Hawk models dropped sharply beyond this distance, whereas detectability of Red-tailed Hawk and Cooper's Hawk models began dropping sharply at about 300 m. Detectability of all models dropped simultaneously at lateral distances 32–48 m in woodland and forest.

Accuracy bias of various density indices differed significantly (Table 2). In general, mean visibility, Fourier series and Emlen's method yielded the most accurate results; mean visibility was by far the most accurate. Unadjusted counts yielded estimates that averaged only 20% of actual values. Even in grassland, accuracy of unadjusted counts averaged only 33% (summer) to 48% (winter) over all plots. However, unadjusted counts were more precise than adjusted counts. CVs for density indices tested ranged from 21%–175%; range for unadjusted counts was from 12%–36%.

DISCUSSION

Two important differences exist between our experiment and actual raptor counts. First, hawks do not randomly select perches (Marion and Ryder 1975). Experienced observers develop a search image, based in part on perch-site characteristics, for particular species or groups of species (e.g., buteos) (Craighead and Craighead 1956; Cade 1969; Fuller and Mosher 1981). Thus, a difference in detectability on actual raptor counts is likely between experienced and inexperienced observers. Second, movement by live birds would increase detectability and boost accuracy. Despite these differences, we believe many of our findings have application to counts of raptors.

Many researchers have concluded that small raptors are detected less frequently than large raptors on road transect counts (Craighead and Craighead 1956; Mathisen and Mathisen 1968; Fitch et al. 1973). Despite potential bias, our results suggest the size of models consistently affected detectability only in open vegetation, where observers regularly sighted models >100 m away from the vehicle. In closed vegetation, such as woodland and forest, observers seldom detected models >48 m away due to the screening effects of vegetation. At <48 m variation in model detectability did not appear to be related to model size.

Variation in accuracy of counts among vegetation types has been suspected as a major bias in road transect counts (Hiatt 1944; Cade 1969; Millsap 1981). Our results support the intuitive hypothesis that volume and distribution of foliage are primary factors affecting detectability. For stationary models differences in average detectability between grassland and forest were as high as 46%. Even in grassland, accuracy ranged from 40% (summer) to 85% (winter) among plots. As noted above, however, under actual conditions bias would probably not be as severe.

Our results suggest that adjustment of counts to account for detectability differences will usually improve accuracy but may lower precision. Line or strip transect estimators should be considered in studies comparing abundances of different species or of a single species in different vegetation types. Unadjusted counts might be superior, however, in monitoring studies where trends in raptor numbers over time along the same transect route is the object of interest.

Both line and strip transect methods are based on assumptions that are difficult to meet using roads as transects. Line transect estimators have the following assumptions and requirements (Burnham et al. 1980):

Assumption 1) All raptors on the transect line are detected.

Assumption 2) Raptors do not flush away from the transect line before being observed.

Assumption 3) No raptors are counted twice.

Assumption 4) Perpendicular distance measures are accurate.

Assumption 5) Sightings are independent.

Assumption 6) If the transect line is not randomly placed, that raptors are distributed randomly with respect to the transect.

Andersen et al. (1985) and Smith and Nydegger (1985) justified using line transect estimators on road transect data from southeastern Colorado and southwestern Idaho, respectively. Nevertheless, we believe that Assumption 6 above is violated in many raptor road transect studies because transect routes are not randomly selected and some raptor species probably avoid and others might be attracted to roadside areas to differing degrees in different habitats. Under these conditions inferences to nonroadside target populations might not be appropriate. Strip transect methods assume that all objects within the strip are observed or accounted for (Eberhardt 1978), an assumption that was not met in our study with models. Detection rates decreased sharply for all models beyond 32 m in forest and, for Sharp-shinned Hawk models, beyond 100 m in grassland. Detection rates would likely be greater for hawks, but it is unlikely that all individuals would be detected in all habitats.

Although our results show that accuracy and precision can be greater with a strip transect technique (mean visibility method using bounded counts), Burnham et al. (1985) determined that line transect methods are generally more efficient. Regardless which approach is taken, presenting results based on volume of habitat searched allows more direct comparison of results between studies than do other measures of search effort. Raptors per km^2, per km driven, or per hour do not take into account effects on sample area size of screening vegetation and topography. A disadvantage is the additional time required to measure vegetation variables necessary to calculate volume estimates. A range finder used to measure distances to screening vegetation might expedite such measurements.

Road transect counts are most appropriate for sampling raptor populations in open vegetation. The chief difficulty in woodland and forest vegetation is obtaining suitable sample sizes. We were unable to perform Fourier series analyses in four of 18 comparisons due to inadequate sample sizes (i.e., $N \leq 40$). An alternative to road transect counts is available for sampling breeding woodland raptors; playback recordings of calls have been used with good success to estimate the proportion of area occupied by a species during the breeding season (Geissler and Fuller 1986; Fuller and Mosher 1987). When feasible this method appears superior to road transect counts in woodland and forest.

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