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STATISTICAL PERSPECTIVES AND EXPERIMENTAL DESIGN WHEN COUNTING BIRDS ON LINE TRANSECTS[1]

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Abstract. We used data from 87 km of line transects in northern Michigan and northern Wisconsin in June 1985 to determine the optimum length of replicate transects required to assess bird populations. Data are from a study comparing bird populations in areas affected by electromagnetic fields (treatments) to those in areas unaffected (controls). Transects were subdivided into six different lengths varying from 100 m to 1,000 m. With equal effort, we were able to detect smaller differences in bird counts between control and treatment areas with short transects and large sample sizes than with long transects and small sample sizes. Transects shorter that 350 m required the smallest amount of effort to detect a 15% difference between means for number of individuals and species. The most efficient transect length for detecting a 25% difference between means was not consistent for individual species but was positively correlated with relative density. The shortest transect (100 m) was best for detecting differences for the Ovenbird (*Seiurus aurocapillus*), Red-eyed Vireo (*Vireo olivaceus*), and Nashville Warbler (*Vermivora ruficapilla*) the most abundant species; a 250-m transect was best for the Black-throated Green Warbler (*Dendroica virens*); and a 500-m transect for the least abundant species, the White-throated Sparrow (*Zonotrichia albicollis*).

Key words: Breeding birds; line transect; census; sample size; sample area; experimental design.

INTRODUCTION

Bird-counting techniques (Svensson 1977; Ralph and Scott 1981; Christman 1984; Verner and Ritter 1985, 1988; Verner 1985), population-estimation formulae (Emlen 1971, 1977; Järvinen and Väisänen 1975, 1983; Burnham et al. 1981; Otten and deVries 1984; Johnson and Routledge 1985; Pyke and Recher 1985), and statistical techniques (Connor and Dickson 1980, James and McCulloch 1985) used to analyze bird population data have been well evaluated. However, little attention has been directed toward the sample sizes and sample areas required to adequately assess differences in bird populations that occur naturally or as a consequence of environmental perturbations (but see Dawson 1981, Gates 1981, Verner 1984). As Morrison (1988) recently observed, few investigators have provided statistical or biological rationale for the number of samples or the sizes of the sample areas used in their investigations. Although basic guidelines on experimental design and sampling methodology exist (e.g., see Kish 1965, Green 1979), we are unaware of specific guidelines for determining the appropriate number of study sites or size of experimental units required for bird population studies using line-transect data.

An efficient and effective experiment gathers data that measure the variables of interest with an acceptable level of precision. Logistics of sampling, costs of obtaining samples, objectives of the study, and the size, shape, and behavior of the organism under investigation are factors that should be considered when selecting the size of the area and the number of study areas (Green 1979). Generally, the larger the sample size (number of replicates) the better the estimate of the true value of the parameter and, hence the smaller the difference that can be detected between means. However, small study areas and large sample sizes do not necessarily provide the best study design because depending on the parameter, the variance of data collected in small areas may be greater than the variance in large areas (Snedecor and Cochran 1967). In addition, as the size of the study area decreases, biological relevance as well as statistical characteristics of the data must be considered. Our objective was to determine the effects of the transect length and the number of replicates on the magnitude of differences that could be detected between breeding bird populations. We did this by examining

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differences in the numbers of species, individuals, and the numbers of individuals of five common species (Red-eyed Vireo *Vireo olivaceus,* Nashville Warbler *Vermivora ruficapilla,* Black-throated Green Warbler *Dendroica virens,* Ovenbird *Seiurus aurocapillus,* and White-throated Sparrow *Zonotrichia albicollis*) at six transect lengths.

STUDY AREAS

Bird counts used for the analyses were conducted in northern Michigan and northern Wisconsin as part of an investigation of the effects of electromagnetic fields produced by an extremely low frequency (ELF) antenna system on birds. Four broad study areas were selected: (1) control areas in Wisconsin (from 10 to 30 km from the antenna), (2) treatment areas in Wisconsin (adjacent to the antenna), (3) control areas in Michigan (from 15 to 40 km from the antenna), and (4) treatment areas in Michigan (adjacent to the antenna). The antenna in Wisconsin consists of two 22-km lines in an "X" configuration and has been operating since 1969. The antenna was installed in Michigan in 1985 and consists of three legs; one N–S leg 45 km in length, and 2 E–W legs each 22 km in length. The antenna in Michigan has been partly (e.g., not full power) operational since 1987.

We selected starting points for transects by numbering each possible starting location (by township section) and then randomly selecting numbers (five control and five treatment in each state). Direction of travel from starting points was randomly determined. Transect locations were not constrained to a particular habitat nor did we attempt to match control and treatment areas by habitat (see Niemi and Hanowski 1984). We assumed that habitats were sampled in proportion to their occurrence in the study regions (e.g., see Järvinen and Väisänen 1975). However, because the placement of treatment transects was constrained by the location of the ELF antenna, sampling of treatment areas was not strictly random. In both states, treatment transects had more coniferous habitat, particularly lowland conifer, whereas control transects had more deciduous habitat. These differences likely have influenced bird abundances in the control and treatment areas but not the results of this study.

Each transect, 4,350 m long (a total of 87 km) was measured with a 25-m rope. Treatment transects were placed 125 m away from and parallel to the antenna right-of-way (ROW) to avoid possible edge effects; the ROW was not studied. Control transects were located more than 10 km from the antenna where electromagnetic fields (72 or 76 Hz) associated with the antenna were less than one-tenth of those in treatment areas (Brosh et al. 1985).

METHODS

We counted birds in early to mid-June 1985 from 0.5 hr before to 4.5 hr after sunrise on days with little wind (<15 km/hr) and no precipitation. One control and one treatment area (one 4,350-m transect) were counted simultaneously by each of two observers daily to control for possible temporal variation in bird activity. Both observers were experienced in the identification of birds by sight and sound and simultaneous counts by the observers were conducted prior to the study to standardize methods. Each observer walked the designated transect at a rate of 1 km/hr and recorded the following information for each bird observed up to 100 m from the transect center line: (1) species; (2) estimated perpendicular distance from the transect in meters; and (3) distance along the transect in meters from the start. Birds flying above the canopy were not included in the analyses.

We used the number of individuals observed along the transect in all data analyses instead of calculating a density value. Density could be calculated with a variety of formulae (Emlen 1971, 1977; Järvinen and Väisänen 1975; Burnham et al. 1981; Buckland 1985), but there are several assumptions that must be met before these methods can be used. A critical assumption of these methods is that distances are measured accurately—a difficult achievement with singing birds. Without accurate distance estimates these methods do not provide valid density estimates. Instead, they provide a density index which may be no better than the original counts (Wilson and Bart 1985). In addition, density calculations are not needed in most investigations, especially when comparisons of "relative density" are less costly and allow the investigator to meet the objectives of the experiment (see Verner 1985). Here, we only assume that the number of birds observed is related to the bird density in an area (see Raphael 1987).

To examine effects of the transect length and the number of replicates on interpretations of the data, we divided each 4,350-m transect into six

TABLE 1. Mean ($\bar{x}$), variance (v^2), and result of ANOVA (P) or Kruskal-Wallis (NP) tests for differences between control and treatment groups in Michigan and Wisconsin for six different transect lengths and corresponding sample sizes for each group (control or treatment) and state.

			Transect length					
			100 m $n = 145$			250 m $n = 70$		
Parameter	State	Group	$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test
Number of individuals	MI	Control	6.4	6.3	NP***	16.1	16.8	P***
		Treatment	7.7	9.0		19.5	31.4	
	WI	Control	6.4	7.3	NP***	15.8	25.0	P***
		Treatment	7.5	6.8		19.2	23.0	
Number of species	MI	Control	4.6	2.6	NP***	8.9	6.3	NP
		Treatment	5.3	3.2		9.1	4.8	
	WI	Control	4.7	3.9	NP**	8.4	9.0	NP**
		Treatment	5.3	3.2		9.7	7.8	
Red-eyed Vireo	MI	Control	0.7	1.0	NP	1.8	4.8	NP
		Treatment	0.9	1.0		2.1	4.8	
	WI	Control	0.8	1.0	NP	2.1	3.6	NP
		Treatment	0.9	1.0		2.2	3.6	
Nashville Warbler	MI	Control	0.4	0.5	NP***	1.1	2.0	NP***
		Treatment	1.0	1.7		2.7	7.8	
	WI	Control	0.6	0.8	NP*	1.5	4.4	NP*
		Treatment	0.9	0.7		2.3	5.8	
Black-throated Green Warbler	MI	Control	0.5	0.6	NP	1.2	2.0	NP
		Treatment	0.3	0.4		0.8	1.4	
	WI	Control	0.6	0.6	NP	1.4	1.9	NP
		Treatment	0.5	0.6		1.2	2.6	
Ovenbird	MI	Control	1.1	1.4	NP	2.6	3.9	NP
		Treatment	1.1	1.4		2.1	3.2	
	WI	Control	1.1	1.2	NP	2.7	4.8	NP
		Treatment	1.3	1.7		3.4	6.3	
White-throated Sparrow	MI	Control	0.2	0.2	NP**	0.4	0.8	NP***
		Treatment	0.4	0.4		1.0	1.6	
	WI	Control	0.1	0.2	NP	0.4	0.8	NP*
		Treatment	0.2	0.3		0.6	0.9	

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

transect segment lengths: 100 m, 250 m, 350 m, 500 m, 750 m, and 1,000 m. Sample sizes associated with each length, for controls and treatments separately, were 145, 70, 55, 40, 25, and 20, respectively (for each treatment), in each state. To contrast the effects of transect length and sample size, we randomly selected 20 segments from each group of lengths and analyzed those data separately. For comparisons of different transect lengths based on effort, we calculated the number of transects of each length that could be counted in 1 day. These numbers were: 29, 14, 11, 8, 5, and 4, respectively, for transects 100 m to 1,000 m in length. For these calculations we assumed that transects were aligned in a linear fashion and were separated by 50 m.

To ensure that segments were independent, adjacent segments were separated by a 50-m buffer. We tested whether adjacent segments were spatially autocorrelated with Moran's I statistic (Sokal and Oden 1978). This statistic tests whether values of variables at one locality are independent of values at adjacent localities. Results of Moran's I statistic indicated that a 50-m buffer eliminated autocorrelation between 99% (831 of 840 tests) of adjacent segments.

STATISTICAL ANALYSES

We used seven variables (number of species observed, number of individuals observed, and numbers of individuals observed of the five most abundant species) to determine effects of the

TABLE 1. Extended.

Transect length											
350 m $n = 55$			500 m $n = 40$			750 m $n = 25$			1,000 m $n = 20$		
$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test
22.3	25.0	P***	33.3	54.8	P***	48.4	100.1	NP**	64.2	127.7	NP*
27.3	57.8		40.9	102.1		57.8	161.3		77.4	349.7	
22.3	32.5	NP***	33.9	67.2	P**	48.0	110.3	NP**	63.5	225.0	P**
26.6	39.7		38.9	64.0		56.8	118.4		76.6	190.4	
10.8	8.4	NP	13.9	9.6	NP	16.8	14.4	NP	20.2	19.0	NP
11.2	8.4		14.3	9.6		17.0	7.3		20.0	7.3	
9.9	10.9	NP**	13.1	14.4	NP**	15.6	21.2	P**	18.9	24.0	P*
11.9	10.9		15.0	12.3		18.4	15.2		21.9	18.5	
2.5	7.6	NP	3.6	11.6	NP	5.4	32.5	NP	8.9	33.6	P
3.1	9.0		4.7	16.8		6.4	36.0		8.6	60.8	
2.9	6.3	NP	4.5	9.6	NP	6.4	23.0	P	8.2	24.0	P
3.2	7.3		4.7	10.9		7.0	22.1		9.1	35.5	
1.7	4.0	NP***	2.4	6.3	NP***	3.5	11.6	NP**	4.5	12.3	P**
3.7	12.9		5.7	23.0		8.3	46.2		11.3	79.2	
2.0	6.8	NP	3.2	10.2	NP	4.2	20.3	NP	6.0	28.1	NP
2.9	10.9		4.3	17.6		6.7	37.7		8.7	62.4	
1.7	3.2	NP	2.6	4.8	NP	3.6	6.8	NP	4.9	11.6	NP
1.1	1.9		1.8	2.9		2.2	4.8		3.5	12.3	
2.0	3.6	NP	3.1	4.8	NP	4.4	7.8	NP	5.6	10.9	NP
1.7	3.6		2.5	5.3		3.5	10.2		4.6	13.7	
4.1	8.4	NP	6.1	15.2	P	9.2	28.1	P	12.1	28.1	P
4.4	10.9		6.5	18.5		9.2	44.9		11.9	60.8	
3.9	9.0	NP	6.0	13.7	NP	8.9	23.0	P	11.1	35.9	P
4.9	12.3		6.9	21.2		9.8	33.6		13.0	47.6	
0.5	0.9	NP***	0.9	2.3	NP***	1.2	3.9	NP**	1.6	4.4	NP**
1.3	1.7		1.9	2.6		2.8	4.4		3.7	5.3	
0.6	1.4	NP*	0.9	2.3	NP	1.4	4.4	NP	1.8	5.3	NP
1.0	1.7		1.3	2.3		2.0	5.7		2.6	6.3	

transect length and the number of replicates on comparisons between control and treatment areas. We first examined for: (1) normality of distribution with the Wilk-Shapiro test (Shapiro and Wilk 1965); and (2) homogeneity of variances with Bartlett's test. Power transformations (Box-Cox) were calculated for all variables that did not meet assumptions of parametric statistical tests. We used a one-way ANOVA or a Kruskal-Wallis test to test for differences between control and treatment means for the seven variables. Kruskal-Wallis tests were used for data that did not meet assumptions of parametric tests even after appropriate transformations but that met assumptions of nonparametric tests (e.g., independence [Hollander and Wolfe 1973]).

The major criterion used to determine the transect length and the number of replicate transects was a measure of precision: the ability to detect differences between two means and the power associated with each test. Although the magnitude of the effect that any investigator wants to detect is not standard (Toft and Shea 1983), for this investigation we set desired detection levels a priori at a 15% difference for number of species and individuals and a 25% difference for an individual species. These values were chosen for our study because we anticipated that any effects of electromagnetic fields on bird population would be small. We used the equation:

$$\% \text{ difference} = [(v^2 \times 15.8/n)/m]^{0.5} \times 100$$

where v^2 = sample variance, n = sample size, and m = sample mean for a power of 0.80 (Type

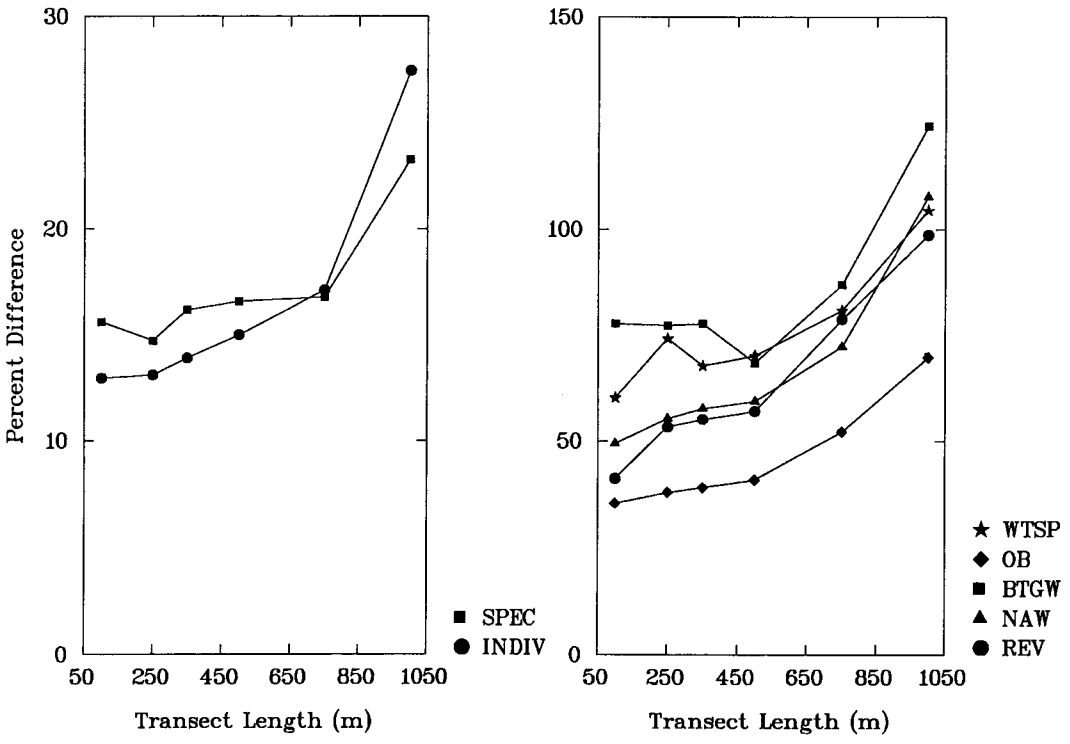

FIGURE 1. Average percentage difference detectable between control and treatment means for number of individuals, number of species, and numbers of five species for six transect lengths. Means were calculated from Michigan and Wisconsin data combined. All comparisons were based on equal effort.

II error) and alpha level of 0.05 (Type I error) for parametric tests (Snedecor and Cochran 1967, p. 113, table 4.13.1). Sample mean and variance used in the equation were mean values for control and treatment in each state.

RESULTS

In general, the calculated percentage difference detectable between control and treatment means tended to decrease (i.e, precision increased) as transect length decreased for all variables when calculations were based on equal effort (Table 1, Fig. 1). This decrease was primarily due to the larger sample sizes associated with shorter transects. Much smaller (at least a factor of three) differences could be detected for community parameters than for individual species (Fig. 1). Percentage differences detectable varied among individual species, but was generally positively correlated with density of the species in the study areas (Table 1, Fig. 1). For example, a 35% difference could be detected with 100-m transects for the most common species (Ovenbird) and a 60% difference (with 350-m transects) was the lowest percentage detectable for the least common (White-throated Sparrow) of the five species.

Based on calculated differences detectable, we expected more significant differences at shorter transect lengths and this was observed (Table 1). For example, differences were detected between numbers of Nashville Warblers observed in Wisconsin for transects of 100 m and 250 m, but not for longer transects. This sample size effect (vs. sample area) was confirmed when we analyzed data with equal sample sizes ($n = 20$) (Table 2). Percentage difference detectable between control and treatment means decreased substantially from 100 m to 500 m transect lengths, but did not decrease much for transects >500 m (Fig. 2). Slightly more tests were significant at the longer (≥ 500 m) transects (15 tests) than the shorter transects (11 tests) (Table 2).

Another factor that was considered in the analysis of transect length and sample size was the

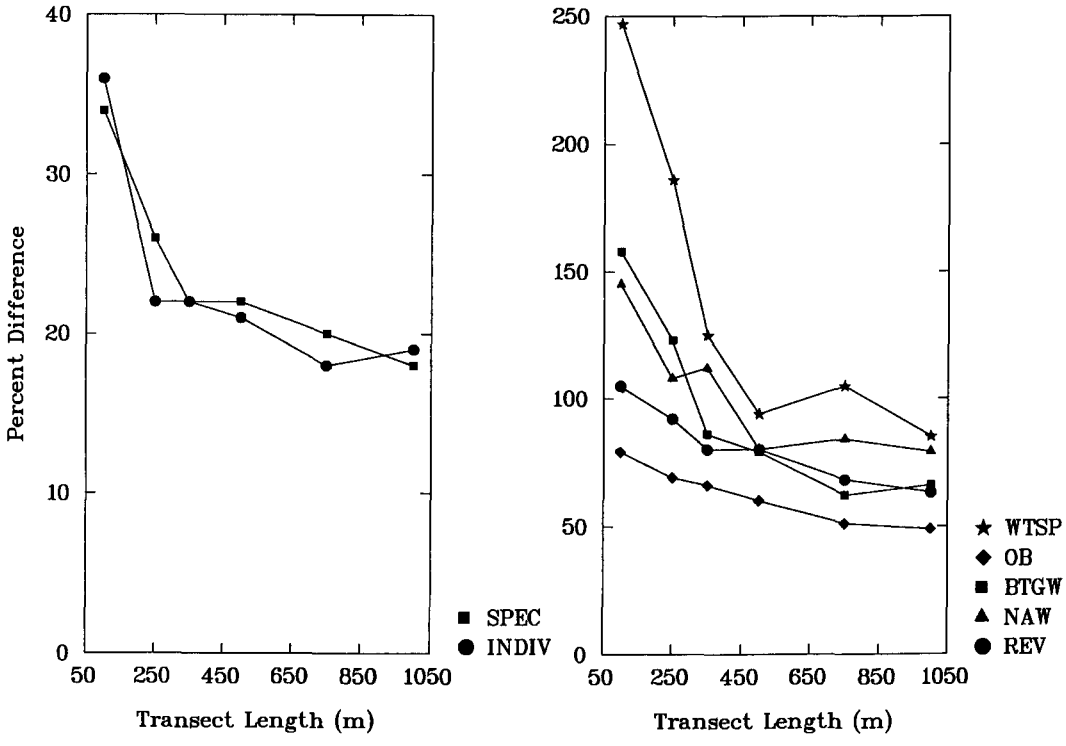

FIGURE 2. Average percentage difference detectable between control and treatment means, number of individuals, number of species, and numbers of five species for six transect lengths. Means were calculated from Michigan and Wisconsin data combined. All comparisons were based on equal sample size (n = 20).

relative cost to collect samples to detect the specified difference between means. We calculated the number of samples required to detect a 15% difference in number of individuals or species or a 25% difference in numbers of individuals for a common bird species and the effort required (count days/treatment group). For these calculations, we assumed that the segments were arrayed in a single line (as in this study) and not randomly distributed. Although fewer samples were needed to detect the specified difference for longer transects, less effort was needed to achieve the same results for shorter transects (Fig. 3). For example, approximately 4 days of censusing would be required to detect a 15% difference between means for number of individuals and species if 100-m segments were used. In contrast, more than 8 days would be needed to detect the same difference if 1,000-m transects were used (Fig. 3). The transect length that required the smallest amount of effort to detect a 25% difference for individual species was not consistent for every species (Fig. 3). The Ovenbird, Nashville Warbler, and Red-eyed Vireo illustrated the expected trend: a general linear relationship between transect length and effort (Fig. 3). However, a 350-m transect required the least amount of effort to detect a 25% difference in the Black-throated Green Warbler and 500-m transects were best for the White-throated Sparrow (Fig. 3).

DISCUSSION

Relatively little effort is required to detect a 15% difference in community parameters for any transect length in comparison to the effort required to detect a 25% difference for individual species. We anticipated that one transect length would appear to be most efficient for detecting differences for all parameters and expected a general linear relationship between precision, effort, and transect length. However, this was found only for the Ovenbird, Red-eyed Vireo, and Nashville Warbler; the other two species had distributions (e.g., less uniform) throughout the study areas that dictated the best transect length for those species. The percentage difference detect-

TABLE 2. Mean ($\bar{x}$), variance (v^2), and result of ANOVA (P) or Kruskal-Wallis (NP) tests for differences between control and treatment transects in Michigan and Wisconsin for six transect lengths and a sample size of 20 in each group.

Parameter	State	Group	Transect length: 100 m $\bar{x}$	100 m v^2	100 m Test	250 m $\bar{x}$	250 m v^2	250 m Test
Number of individuals	MI	Control	6.0	4.4	P	14.8	8.4	P***
		Treatment	7.5	8.4		19.0	17.6	
	WI	Control	5.3	4.8	P*	15.5	21.2	P*
		Treatment	7.2	10.2		19.4	26.0	
Number of species	MI	Control	4.7	2.3	P	7.8	4.0	P
		Treatment	5.4	4.0		8.4	3.6	
	WI	Control	4.2	2.9	P	7.8	7.3	P*
		Treatment	5.2	4.8		10.1	10.2	
Red-eyed Vireo	MI	Control	0.5	0.6	NP	2.5	7.8	NP
		Treatment	1.1	1.7		1.7	4.0	
	WI	Control	0.7	0.8	NP	2.4	4.4	NP
		Treatment	0.7	0.8		2.0	4.4	
Nashville Warbler	MI	Control	0.7	0.8	NP	0.9	1.2	NP*
		Treatment	0.8	2.3		2.8	8.4	
	WI	Control	0.5	0.5	NP	1.4	5.3	NP*
		Treatment	0.8	1.4		2.8	6.3	
Black-throated Green Warbler	MI	Control	0.1	0.2	NP	1.1	2.3	NP
		Treatment	0.2	0.2		0.6	0.8	
	WI	Control	0.8	0.8	NP*	1.7	2.9	NP
		Treatment	0.3	0.4		0.8	3.2	
Ovenbird	MI	Control	0.7	0.6	NP	3.1	2.9	NP
		Treatment	1.1	1.2		3.2	8.4	
	WI	Control	1.1	1.0	NP	2.5	4.8	P
		Treatment	1.1	1.4		2.7	4.8	
White-throated Sparrow	MI	Control	0.2	0.2	NP	0.2	0.5	NP**
		Treatment	0.6	0.6		0.8	1.7	
	WI	Control	0.1	0.9	NP	0.5	1.2	NP
		Treatment	0.3	0.5		0.6	1.0	

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

able for individual species was also positively related to the frequency of occurrence in the study areas. For example, the Ovenbird was the most common species and the least amount of effort was required to detect differences between means for this species. In contrast, the White-throated Sparrow was least abundant of the five species tested and required the most effort to detect the specified difference. Although less common species (e.g., the majority of the species in the study areas) were not tested, we would expect that substantially more effort would be required to detect the specified difference between means. For example, Verner (1989) estimated that 15,000 count days would be required to detect a 10% change in Pileated Woodpecker (*Dryocopus pileatus*) populations (an uncommon species in most areas).

It is evident that much effort is required to detect a 25% difference between means for the most abundant species and more effort is required for less common species. The consequence, however, of collecting large sample sizes is that more bias (and more variance) is contributed to the parameter of interest. Many factors contribute to variation in bird counts including observer differences (Svensson 1977, Kavanagh and Recher 1983), weather (Robbins 1981), time of day (Verner and Ritter 1986), habitat (Verner 1985), and phenology of breeding season (Wilson and Bart 1985). Although a large sample size will improve the precision of the count, taking large

TABLE 2. Extended.

Transect length											
350 m			500 m			750 m			1,000 m		
$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test	$\bar{x}$	v^2	Test
20.8	20.3	NP**	32.2	43.6	P**	47.4	98.7	NP**	64.2	127.7	NP*
26.5	57.8		39.8	104.0		59.0	150.1		77.4	349.7	
22.4	36.0	P**	34.0	68.9	P*	49.3	100.2	P*	63.5	225.0	P**
24.2	24.0		39.1	72.3		58.1	112.3		76.6	190.4	
10.0	5.8	NP	13.7	10.9	NP	16.1	15.2	P	20.2	19.0	NP
10.7	7.8		14.6	7.8		17.0	7.3		20.0	7.3	
9.7	8.4	P	12.8	15.2	P	16.1	20.2	P	18.9	24.0	P*
11.9	4.8		14.9	13.7		18.3	14.2		21.9	18.5	
2.4	6.8	NP	3.9	10.9	NP	6.3	31.5	P	8.9	33.6	P
3.2	8.4		5.2	21.2		6.5	35.0		8.6	60.8	
3.0	5.8	P	3.9	11.6	P	7.0	22.0	P	8.2	24.0	P
2.5	4.4		4.7	19.9		7.2	21.1		9.1	35.5	
1.4	3.6	NP*	2.0	5.3	NP*	3.2	10.6	P**	4.5	12.3	P**
3.5	10.9		5.4	21.2		8.7	45.2		11.3	79.2	
1.6	7.8	NP	3.8	12.3	NP	4.0	19.3	P	6.0	28.1	NP
2.4	8.4		4.8	13.7		6.3	36.7		8.7	62.4	
1.4	1.9	NP	2.5	4.8	NP	3.8	5.8	NP*	4.9	11.6	NP
1.1	1.9		1.6	2.6		2.0	3.8		3.5	12.3	
1.9	1.9	NP	2.8	4.8	NP	5.0	6.8	P	5.6	10.9	NP
2.0	4.0		2.5	6.3		3.4	9.2		4.6	13.7	
4.2	11.6	P	4.7	9.6	P	10.1	27.1	P	12.1	28.1	P
4.7	16.0		6.3	12.3		9.4	43.9		11.9	60.8	
4.8	8.4	NP	5.5	15.2	P	8.9	22.0	P	11.1	35.9	P
5.2	13.7		6.7	25.0		10.4	32.6		13.0	47.6	
0.7	1.7	NP	0.7	1.2	NP**	1.1	2.9	NP**	1.6	4.4	NP**
1.4	1.9		1.9	2.3		2.9	3.4		3.7	5.3	
0.6	1.4	NP	1.1	2.9	NP	1.4	3.4	NP	1.8	5.3	NP
0.9	1.2		1.4	1.2		1.8	4.7		2.6	6.3	

sample sizes with the expectation that the bias in variables will average out is overly optimistic (Johnson 1981, Verner 1985). A poorly designed study that employs an adequate sample size and appropriate sample area is not necessarily better than a design that controls for biases, but does not have a large sample size. For example, collecting large numbers of samples during the relatively short breeding season would require many observers, which contributes observer bias to the estimate. If fewer observers are used, sampling would take longer, thus contributing bias due to variation in breeding phenology and weather conditions. In addition, variation due to habitat will be greater if larger samples are used regardless if sites are stratified by habitat (see Niemi and Hanowski 1984). The relative amount of variation contributed by each of these factors will not be the same for every study. However, we recommend that the amount of bias contributed by each factor be equally divided among treatment groups (for impact studies) or controlled annually. Although this will not reduce the bias in any design, it will ensure that bias is equal among groups or between years.

Monitoring studies should also be designed to ensure that data collected meet assumptions of statistical tests. The most critical in the original design is that samples are independent. This can be a problem because study areas should be close to each other to make efficient use of counting time available each day; travel time or noncount time should be minimized. We separated all study sites by 50 m and insured "biological independence" because no bird was counted in more than one study area. This separation agrees with

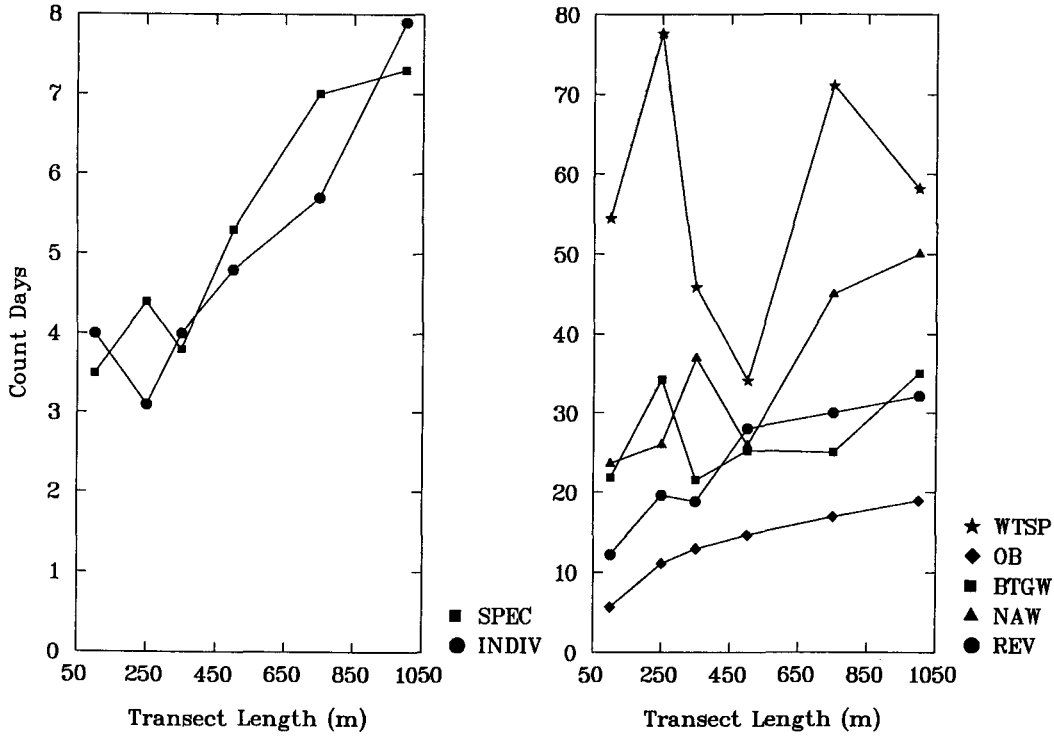

FIGURE 3. Number of counts required to obtain samples to detect a 15% difference between means for number of individuals and species and a 25% difference for numbers of five individual species for six transect lengths.

that recommended for point counts; Verner (1988) recommended that points from point counts with radii of 100 m should be 300 m apart to avoid recording the same bird on adjacent points. Although separating sample areas with an appropriate distance ensures that an individual is not counted more than one time, study sites arranged in this fashion are not truly statistically independent (e.g., all randomly selected). However, because of the large number of sites required in breeding bird counts, it is probably not feasible logistically or monetarily to randomly select all sites. Our data indicate that segments separated by 50 m were statistically independent (e.g., no autocorrelation was detected between adjacent segments). Therefore, although each site was not randomly located, data from this design met assumptions of statistical tests (e.g., independent error terms).

Based on parameters analyzed here, it is more costly to use transects longer than 500 m. In addition, using transects that are shorter than they are wide is probably not advisable due to the large proportion of edge related to the total area sampled. In no case did the shortest transect (100 m) provide a significantly better design for detecting differences between means for any one parameter. Our data suggest that an efficient transect length (e.g., 250 m) corresponds to the area counted with point counts (e.g., 100 m radius around center). Some investigators prefer to use point counts because time spent counting birds can be closely controlled (Verner and Ritter 1986). Point counts may be preferred in areas that are difficult to traverse (e.g., wetlands) because bias may be added to bird counts with line transects if observers traverse various habitats.

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