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DESIGN CONSIDERATIONS FOR EXAMINING TRENDS IN AVIAN ABUNDANCE USING POINT COUNTS: EXAMPLES FROM OAK WOODLANDS

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Abstract. We used data from two oak-woodland sites in California to develop guidelines for the design of bird monitoring programs using point counts. We used power analysis to determine sample size adequacy when varying the number of visits, count stations, and years for examining trends in abundance. We assumed an overdispersed Poisson distribution for count data, with overdispersion attributed to observer variability, and used Poisson regression for analysis of population trends. Overdispersion had a large, negative effect on power. The number of sampling years also had an especially large effect on power. In all cases, 10 years of sampling were insufficient to detect a decline in abundance of 30% over 10 years. Increasing the sampling period to 20 years provided adequate power for 56% of breeding species at one site. The number of count stations needed for detecting trends for a given species depended primarily on observer variability. If observer variability was high, increasing the number of years and visits was a better approach than increasing the number of stations. Increasing the number of stations was most beneficial for species with low abundance or low observer variability. When the number of stations is limited by the size of the area, we recommend multiple visits to stations. For most species, multiple visits per year (six or more) for 15–20 years were needed to detect a 30% decreasing trend in 10 years with adequate power. We suggest potentially useful focal species for monitoring, such as keystone species like the Acorn Woodpecker (*Melanerpes formicivorus*).

Key words: avian point counts, count data, focal species, monitoring, population trends, power, sample size.

Consideraciones de Diseño para Examinar las Tendencias en la Abundancia de Aves Usando Conteos Puntuales: Ejemplos con Datos de Bosques de Encino en California

Resumen. Usamos datos de dos sitios ubicados en bosques de encino en California, con el fin de desarrollar una guía para diseñar programas de monitoreo usando conteos puntuales. Usamos un análisis del poder de la prueba para determinar el tamaño adecuado de la muestra al cambiar el número de visitas, el número de estaciones de conteo y los años de conteo con el fin de examinar las tendencias en la abundancia. Supusimos la distribución de Poisson para el conteo, con sobredispersión atribuida a la variabilidad del observador. La sobredispersión tuvo un efecto fuerte y negativo en el poder de la prueba. El efecto del número de años de muestreo fue especialmente grande sobre el poder. En cada caso, 10 años de muestreo fueron insuficientes para detectar una disminución de la abundancia del 30% en 10 años. Al aumentar el período de muestreo a 20 años, el análisis proporcionó un poder adecuado para 56% de las especies reproductivas en uno de los sitios. El número de estaciones de conteo requeridos para una especie dada dependió principalmente de la variabilidad del observador. Si la variabilidad del observador era alta, aumentar el número de años de observación y visitas fue una estrategia mejor que aumentar el número de estaciones. Aumentar el número de estaciones fue más benéfico para especies poco abundantes o con baja variabilidad del observador. Cuando el número de estaciones es limitado por el tamaño del área, recomendamos visitas múltiples a las estaciones. Para la mayoría de las especies se requieren visitas anuales múltiples (6 o más) durante 15–20 años para detectar una tendencia de decrecimiento a una razón del 30% en 10 años con un poder adecuado. Sugerimos especies focales potencialmente útiles para monitoreo tales como la especie clave *Melanerpes formicivorus*.

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INTRODUCTION

To conserve and manage wildlife populations, we need to be able to assess the effects of land-management activities on population size and detect trends in populations. Good study design should provide adequate statistical power to detect a difference if one exists. In designing studies one must consider both Type I errors (the likelihood of incorrectly rejecting the null hypothesis) and Type II errors (the likelihood of incorrectly accepting the null hypothesis). Type II errors may have more important consequences to species' conservation than Type I errors (Verner 1983, Rotenberry and Wiens 1985, Peterman 1990, Thompson and Schwalbach 1995). Failing to detect a significant negative response may result in the use of management practices detrimental to species viability, and may be worse than not monitoring the population at all.

Most abundance data consist of counts of animals. These counts are not a complete census but rather an index of population size. The total variability in count data may arise from several sources, including variability due to imperfect detectability and other sampling problems, and variability in numbers across space and time. Previous work has shown that annual variability in count data may be high (Verner et al. 1996) and that explanatory variables such as weather, time of day, time of season, and observer variability may be responsible for perceived trends (Sauer et al. 1994, Kendall et al. 1996, Gibbs et al. 1998, Purcell et al. 2002). Study designs for count data require consideration of numbers of sampling sites, visits per year, and years needed to detect a trend or difference.

Point counts are used extensively and have become a standard method to detect trends in bird populations and to study the effects of habitat modification on bird numbers (Thompson et al. 1998). In spite of much research on the method and the availability of guidelines on its use (Ralph et al. 1993, 1995, Hamel et al. 1996), few studies have evaluated statistical power to detect trends. Most published studies have examined two-sample tests to investigate differences between treatments in space or time, but few have examined trends. Using a Type I error rate of 0.05 and power of 0.90, Verner (1983) concluded that 250 count stations were needed to detect a 25% decline in abundance for a species with a mean count of one bird per count station (one-tailed test). Thompson and Schwalbach (1995) found that, for the 21 most abundant species in their samples, the estimated total number of count stations needed to detect a 20% decline (one-tailed two-sample test) with a Type I error rate of 0.1 and a Type II error rate of 0.2 ranged from 101 to over 2000. Aigner et al. (1997) found that 14 to 920 count stations per treatment were needed to detect a 50% difference in the mean number of birds counted (power = 0.80, two-tailed test). Clearly, most studies do not achieve these sample sizes.

Point-count data are incomplete counts of bird abundance. One of the factors involved in the lack of perfect detectability is observer variability (Sauer et al. 1994, Link and Sauer 2002, Royle 2004). Other factors include weather, site characteristics, attributes of vocalizations including volume, frequency, and rate, behavioral attributes related to flight and physiological status, and factors that affect visibility such as plumage coloration and size. When the assumed model for the analysis of count data is unadjusted for detection probability, it may be unreliable due to the potential for unadjusted counts to be biased or confounded if detection probabilities vary among years or treatments. Techniques to correct estimates of abundance, that account for birds present, but not detected, are often recommended. These techniques include distance estimates to define a detection function (Burnham et al. 1980, Buckland et al. 1993, Rosenstock et al. 2002), double sampling (Cochran 1977, Bart and Earnst 2002), the double-observer approach (Nichols et al. 2000), and multiple visits to estimate the probability of detection (Royle and Nichols 2003, MacKenzie et al. 2003). To control for detection errors in part, we included overdispersion as a random effect in a Poisson generalized linear model, based on a multiple-visit sampling design. Overdispersion is common in count data and occurs when the sampling variance exceeds the theoretical variance of the distribution assumed in data analysis. Observer and site variability were assumed to be the major sources of overdispersion in our models (Link and Sauer 1997). We treated factors that influence detectability, such as observers, as random effects that influence variation in the mean count and, in this way, detectability errors were modeled indirectly as opposed to directly parameterizing a model in terms of detection probability. Others have approached the issue of detectability errors similarly (Sauer et al. 1994, Link and Sauer 1997, 2002, Royle 2004).

Our goal was to use existing data to develop guidelines for the design of bird monitoring programs in oak woodlands using point counts. An additional impetus was to incorporate these guidelines into the California Partners in Flight Oak Woodland Bird Conservation Plan (California Partners in Flight 2002). For analysis of population trends, we examined the numbers of count stations, visits, and years needed to obtain reasonable statistical power for a range of species varying in abundance and a range of effect sizes, using Poisson regression for count data. We discuss application of the focal species approach to oak-woodland bird communities and suggest potentially useful focal species for monitoring, based on geographic variability, ease of monitoring, and species ecology.

METHODS

STUDY AREAS

We analyzed data from 5-min counts using unlimited distance detections collected at two study sites. At all sites, point-count stations were placed at least 200–250 m apart. Count stations were laid out in groups that could be sampled in one morning. We refer to these as routes. Our index of abundance was calculated as the total count of each species summed over all visits for each route in each year.

San Joaquin Experimental Range, Madera County, California. The San Joaquin Experimental Range (SJER) lies in the western foothills of the Sierra Nevada, approximately 31 km northeast of Madera, California, and ranges in elevation from 215 to 520 m. This oak-woodland habitat consists of a sparse woodland overstory of blue oak (*Quercus douglasii*), interior live oak (*Q. wislizenii*), and foothill pine (*Pinus sabiniana*). An understory of scattered shrubs includes mainly wedgeleaf ceanothus (*Ceanothus cuneatus*), chaparral whitethorn (*C. leucodermis*), hollyleaf coffeeberry (*Rhamnus ilicifolia*), and Mariposa manzanita (*Arctostaphylos viscida mariposa*). SJER has been lightly to moderately grazed since about 1900, has an area of approximately 1875 ha, and is surrounded on all sides by similar habitat.

The sampling array at SJER consisted of 210 count stations, with 30 stations distributed along each of seven routes established throughout SJER. From three to seven observers counted in any year, although there were four observers in most years (10 of 16 years). Counts were performed from 1986 through 2001.

Each observer sampled all routes on seven different mornings, completing one count at each of the 210 count stations. Consequently, each station was counted each year as many times as the number of observers in that year. Recording of birds at count stations began 10 min after official sunrise and continued at successive stations at 10-min intervals, thus controlling for time-of-day variability (Verner and Ritter 1986). Following a 2-week training period, counts were performed during the last week of March through the end of April each year. To help reduce observer variability, we used the same observers over as many years as possible (Verner and Milne 1989).

Valensin Ranch, Cosumnes River Preserve, Sacramento County, California. This site (Valensin) contains a mixture of riparian forest, oak woodland, oak savannah, and grassland adjacent to the Cosumnes River, and ranges in elevation from 8 to 11 m. The dominant tree species is valley oak (*Quercus lobata*), with some black willow (*Salix goodingii*) also present. This site was grazed by livestock until the fall of 1996, and thus had relatively little understory vegetation at the start of the study. Understory cover is slowly increasing due to livestock exclusion and is composed of sparse shrubs (Himalayan blackberry [*Rubus discolor*], button bush [*Cephalanthus occidentalis* var. *californicus*], and Oregon ash [*Fraxinus latifolia*]) with a low, dense herbaceous ground cover.

The study design at this site is typical of many monitoring projects that take place in small habitat reserves. Two or three visits were made to one route consisting of 17 stations. Stations were counted for 7 years (1995–2001) beginning in late April or May and running through mid-June. Data were collected by a single observer in some years and two observers in others. Count stations were visited three times in most years ($n = 6$) and in some years some stations were visited only once or twice.

STATISTICAL ANALYSES

Because for trend analysis we felt that the risk of missing a significant change is at least as important as the risk of finding a significant difference where it does not exist, we set Type I

TABLE 1. Mean count per year, variance, and estimates of overdispersion for bird species at two oak-woodland study sites: the San Joaquin Experimental Range, California and Valensin Ranch, Cosumnes River Preserve, California. The values for sigma, the overdispersion parameter, were calculated with a model that included slope (change over time) as an explanatory variable. Data from the San Joaquin Experimental Range are based on 16 years of data from seven routes of 30 stations. Data from the Valensin Ranch are based on 7 years of data from one route of 17 stations. Missing values represent species that were absent or rare. Species marked with an asterisk are primary focal species in the California Partners in Flight Oak Woodland Bird Conservation Plan (California Partners in Flight 2002).

Species	San Joaquin experimental range			Valensin Ranch Cosumnes River Preserve		
	Mean count per route per year	Variance	Sigma	Mean count per year	Variance	Sigma[a]
California Quail (*Callipepla californica*)	37.7	351.0	0.37	1.7	1.4	0.86
Acorn Woodpecker* (*Melanerpes formicivorus*)	86.1	1167.7	0.33	13.6	49.6	0.25
Nuttall's Woodpecker (*Picoides nuttallii*)	7.1	18.7	0.33	5.9	1.5	0.00
Ash-throated Flycatcher (*Myiarchus cinerascens*)	23.3	221.1	0.54	11.3	3.2	0.00
Western Scrub-Jay* (*Aphelocoma californica*)	32.4	136.9	0.29	4.8	10.6	0.59
Yellow-billed Magpie* (*Pica nuttallii*)	–	–	–	6.3	11.7	0.72
Oak Titmouse* (*Baeolophus inornatus*)	58.4	305.9	0.25	8.4	9.6	0.46
Bushtit (*Psaltriparus minimus*)	13.6	87.9	0.53	8.4	22.3	0.96
White-breasted Nuthatch (*Sitta carolinensis*)	22.4	60.1	0.25	9.7	17.1	0.34
Bewick's Wren (*Thryomanes bewickii*)	13.3	78.3	0.51	1.0	0.7	0.46
Blue-gray Gnatcatcher* (*Polioptila caerulea*)	1.5	2.8	0.58	–	–	–
Western Bluebird* (*Sialia mexicana*)	9.1	19.4	0.32	3.1	5.8	0.65
European Starling (*Sturnus vulgaris*)	28.9	1368.0	0.30	61.7	331.3	0.42
Lark Sparrow* (*Chondestes grammacus*)	3.6	7.9	0.48	<1.0	<1.0	–

[a] Estimates of sigma may be unreliable due to low abundance and inadequate sample size.

(α) and Type II (β) errors equal. We set α and $\beta = 0.10$, and considered adequate power as 0.90. All tests were one-tailed to determine if there were significant declines in abundance.

As count data are discrete and the variance generally increases as the mean increases, we assumed a Poisson distribution. The Poisson distribution assumes that the mean is equal to the variance, but the statistical distribution of count data is not exactly Poisson because often the variance of count data is much larger than the mean. When the variance exceeds the mean the data are overdispersed. In count data, the main sources of extravariability are due to site and observer. Therefore, we corrected for this overdispersion problem by modeling the extra variability in a generalized linear model (McCullagh and Searle 2001). We used overdispersed Poisson generalized linear models to examine sample size adequacy for trend analysis using power analysis. We used data from bird species from two sites to calculate initial counts and estimates of overdispersion for the power analyses (Table 1). The study design of each particular site was used in power calculations, including the number of stations, routes, visits, and years but changing the parameter values as appropriate for each question. For model input, four visits were assumed for SJER and three visits for Valensin (except in analyses conducted specifically to explore the effects of various numbers of visits on power).

A route regression procedure was used as an approach to trend analysis. We modeled point count data using a Poisson regression model with random effects due to overdispersion, and route as a fixed effect (Link and Sauer 1997, 1999, McCulloch and Searle 2001). The statistical model for the SJER design with multiple routes is described as follows:

Let $count_{ijk}$ be the number of birds observed by observer k on route j in year i, and assume that the expected count, conditioned to the overdispersion error ϵ_{ik}, is Poisson distributed

$$count_{ijk} | \epsilon_{ik} \sim Poisson(e^{a_j + b\ year_i + \epsilon_{ik}}), \qquad (1)$$

where parameter a_j is the baseline site effect due to route j, b is the slope or annual trend, and ϵ_{ik}, is the random effect (overdispersion error) that accounts for the extra variability due to observer variability. In addition, we assumed that the error term (ϵ_{ik}) is normally distributed with mean zero and variance σ^2. The mean count is

$$\lambda_{ijk} = e^{a_j + b\ year_i + \epsilon_{ik}},$$

or equivalently,

$$\log(\lambda_{ijk}) = a_j + b\ year_i + \epsilon_{ik},$$

for year i, on route j and counted by observer k. We assumed that each year a different observer sampled the route, and each observer visits all the routes. If observer variability is zero, we could assume that the counts are perfectly Poisson distributed and, therefore, the only source of variability would be that from the Poisson distribution. But previous work has shown that the main source of variability in count data is due to differences in the abilities of observers (Bart 1985, Verner and Milne 1989, Sauer et al. 1994). Therefore, the observed count was assumed to have two sources of error: the Poisson error and the overdispersion error. The statistical model for the Valensin site is simply a particular case of the above design, with only one route.

The null hypothesis for the trend model was that no trend was observed or that the slope (b) was zero. Because our model assumes that all routes have the same slope, the null hypothesis was that no trend was observed on any route. The alternative hypothesis for a decline in abundance was that the slope was less than zero. It is possible to assume a different slope for each route, but for the purpose of elucidating power consideration, we chose this simple case that happens to fit the SJER data quite well. The minimum sample size to detect a change of interest was obtained by calculating the power of the test of the null hypothesis against the alternative of interest. Power analyses were performed on simulated data (based on 5000 simulations) using the SAS GENMOD procedure (SAS Institute, Inc. 2000) that uses Maximum Likelihood Estimation (McCullagh and Nelder 1991) and Generalized Estimating Equations approaches (Liang and Zeger 1986, Link and Sauer 1994). The proportion of times the null hypothesis is rejected yields an approximate value of the power of the test. The simulations were run using Maximum Likelihood Estimates (MLE) of initial count and the overdispersion variance based on existing data for specific bird species from the two study sites. The MLEs for the initial parameters were obtained with SAS NLMixed procedure (Whittemore and Gong 1991, SAS Institute, Inc. 2000).

Where route can be regarded as a random effect, we simulated the data for two independent random effects, one due to route (site) and the other due to observer. Therefore, we used the extra-variability Poisson regression as follows:

$$\text{count}_{ijk} | \delta_i, \epsilon_{ik} \sim \text{Poisson}(e^{a + \delta_j + b\ \text{year}_i + \epsilon_{ik}}), \qquad (2)$$

where a is constant (mean route effect), and δ_i is the route random effect normally distributed with mean 0 and variance τ^2. The rest of the notation in the regression model is defined as in Equation 1. Again, the minimum sample size to detect a change of interest was obtained by calculating the power of the test of the null hypothesis against the alternative of interest. A range of values of overdispersion due to route were calculated as the variance of the estimated a_i from the model in Equation 1 for species in our study areas and were used in power analysis. Power analyses were performed on simulated data (based on 3000 simulations) using a SAS experimental procedure called GLIMMIX (SAS Institute, Inc. 2003). This procedure, besides estimating a and b, can estimate the two variance components for observer and route (σ^2 and τ^2) and allows us to examine the relative contributions of these two sources of overdispersion.

RESULTS

EFFECT OF OVERDISPERSION ON POWER

To construct the datasets for the simulated data, the overdispersion variance, σ^2, was estimated

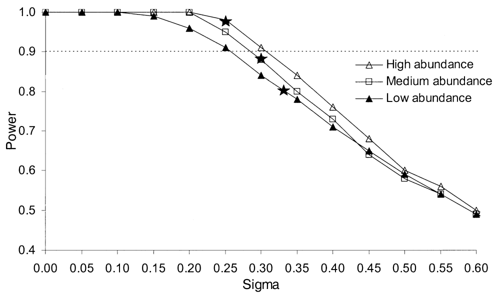

FIGURE 1. Power for trend analysis in relation to overdispersion (σ), based on data for species with high abundance (unfilled triangle represented by Oak Titmouse with an average of 1.9 birds per station), medium abundance (unfilled square, represented by European Starling with 1.0 birds per station), and low abundance (solid triangle, represented by Nuttall's Woodpecker with 0.2 birds per station) from the San Joaquin Experimental Range. Overdispersion was estimated from a model that included year as an explanatory variable. Stars show the estimated values of σ (0.25, 0.30, and 0.33, respectively) for the three species and the curves show the effect of varying hypothetical values of σ. Calculations examine a decreasing trend of 20% over 10 sampling years based on a one-tailed test with $\alpha = 0.10$. Dotted line shows power at 0.90 ($\beta = 0.10$).

from existing data by assuming that the overdispersion was due to observer variability. The overdispersion variance was estimated using models that included intercepts for route and year as explanatory variables for power analysis of trends, assuming route as fixed effect. Counts for most species were overdispersed. Variances exceeded mean counts by an average of nine times across all species and sites (Table 1). The magnitude of the overdispersion factor had a large effect on power. Power declined rapidly as overdispersion increased (Fig. 1).

When route was modeled as a random effect in a model that included error terms for both route and observer, observer variability again had a large effect on power (Table 2). If observers count for several years their variance could be modeled, reducing to some degree the effect of observer variability on power. The magnitude of the route variance had negligible influence on power (see also Urguhart and Kincaid 1999).

DESIGN CONSIDERATIONS

Using data from the San Joaquin Experimental Range, we examined three species of varying abundance with similar estimated values for the overdispersion parameter: Nuttall's Woodpecker (*Picoides nuttallii*) with low abundance, European Starling (*Sturnus vulgaris*) with medium abundance, and Acorn Woodpecker (*Melanerpes formicivorus*) with high abundance. Varying the magnitude of the trend had a large effect on power, especially as the number of sampling years increased (Fig. 2). Varying abundance had some influence on effect size, but not as much as might have been expected. Results from models assuming route as a random effect showed that, even with low abundance, power can be high if overdispersion due to observer variability is low (Table 2)

Results based on initial parameters for nine oak-woodland species varying in abundance and the study design from Valensin Ranch showed that increasing the number of visits from three to six improved power for all species (Fig. 3). Even the maximum number of visits ($n = 6$ visits) provided inadequate power with only 10 years of sampling (Fig. 3a) and 15 sampling years resulted in adequate power for only the most abundant species, Acorn Woodpecker, with three visits, and for two species with six visits (Fig. 3b). Twenty years were required to attain adequate power for two of nine species with three visits and four species with four visits (Fig. 3c).

Data from the San Joaquin Experimental Range showed modest increases in power from increasing the number of visits from two to six (Fig. 4). Even with 6 visits, only the most abundant species approached adequate power with 10 sampling years (Fig. 4a, b). Sampling for 20 years improved power noticeably, especially when combined with multiple visits to stations (Fig. 4c, d).

The number of sampling years was clearly important to the ability to detect population trends. In most cases, ten years were not long enough to detect a significant decrease in abundance with adequate power, and even then, only the most abundant species could be examined. For three species representing low, medium, and high abundance at SJER, 10 sampling years yielded adequate power to detect decreases of 38% to 43% per 10 years, 15 sampling years resulted in the ability to detect 23% to 26% decreases per 10 years, and 20 sampling years were needed to detect 16% to 18% decreases per 10 years (Fig. 2). Results for all breeding species at SJER showed that, with 210 count stations visited four times, 10 sampling years did not

TABLE 2. Power to detect a 30% decrease in avian abundance in 10 years, for 10 and 15 years of sampling, comparing two levels of abundance (high = 2.0 birds per station, low = 0.2 birds per station), number of routes, number of stations per route, and overdispersion variability due to route and observer. The range of values selected for abundance and the two types of overdispersion were based on data from the San Joaquin Experimental Range, California. Analysis was based on four observers using one-tailed tests, with $\alpha = 0.1$.

		Number of routes = 5		Number of routes = 10	
Route overdispersion	Observer overdispersion	10 stations per route	20 stations per route	10 stations per route	20 stations per route
10 sampling years, high abundance					
0.2	0.3	0.84	0.86	0.86	0.87
0.2	0.6	0.46	0.47	0.48	0.49
0.5	0.3	0.81	0.85	0.85	0.86
0.5	0.6	0.45	0.47	0.46	0.47
10 sampling years, low abundance					
0.2	0.3	0.62	0.70	0.70	0.79
0.2	0.6	0.38	0.42	0.42	0.46
0.5	0.3	0.59	0.71	0.72	0.81
0.5	0.6	0.40	0.43	0.44	0.47
15 sampling years, high abundance					
0.2	0.3	1.00	1.00	1.00	1.00
0.2	0.6	0.81	0.83	0.82	0.82
0.5	0.3	1.00	1.00	1.00	1.00
0.5	0.6	0.81	0.82	0.80	0.82
15 sampling years, low abundance					
0.2	0.3	0.92	0.98	0.99	1.00
0.2	0.6	0.72	0.76	0.76	0.81
0.5	0.3	0.92	0.98	0.98	1.00
0.5	0.6	0.69	0.75	0.76	0.80
Total number of stations		50	100	100	200

provide adequate power to examine a 30% declining trend over 10 years for any species (Table 3). Increasing the sampling period to 20 sampling years improved our ability to examine trends of this effect size, with 56% of breeding species having adequate power (Table 3). Results based on data from Valensin showed that 10 years did not result in adequate power for any of the nine species examined, with 20 years still not providing adequate power for most species (Fig. 3). Finally, results from analyses assuming route as a random effect were similar, with 15 years required for adequate power, but only when observer variability was low (Table 2).

Sample size appeared to be less important for power than some other design considerations. Data from the Valensin site showed that the number of stations needed for adequate power depended largely on the amount of overdispersion in the count data, but abundance, the number of sampling years and visits, and effect size were also important. The optimal combination of parameter values differed across species. Species with low overdispersion (Acorn Woodpecker, Ash-throated Flycatcher, Nuttall's Woodpecker) benefited most from increasing the number of count stations, regardless of relative abundance (Fig. 5). With low overdispersion, 20–35 stations visited at least six times a year for 10 years were needed to detect a 30% decline (Fig. 5). When overdispersion was high or moderate (as in Yellow-billed Magpies, Western Bluebirds, and European Starlings), increasing the number of stations was not as effective as increasing the number of sampling years and the number of visits (Fig. 5). With high overdispersion, 20–60 stations visited 6 times for 20 years were needed (Fig. 5e, f). Species with low abundance (e.g., Western Bluebirds) tended to benefit most from increasing the number of stations (Fig. 5f). Results from the model assuming route as a random effect were similar, with increases in both the number of routes and the number of stations per route resulting in rather small increases in power (Table 2).

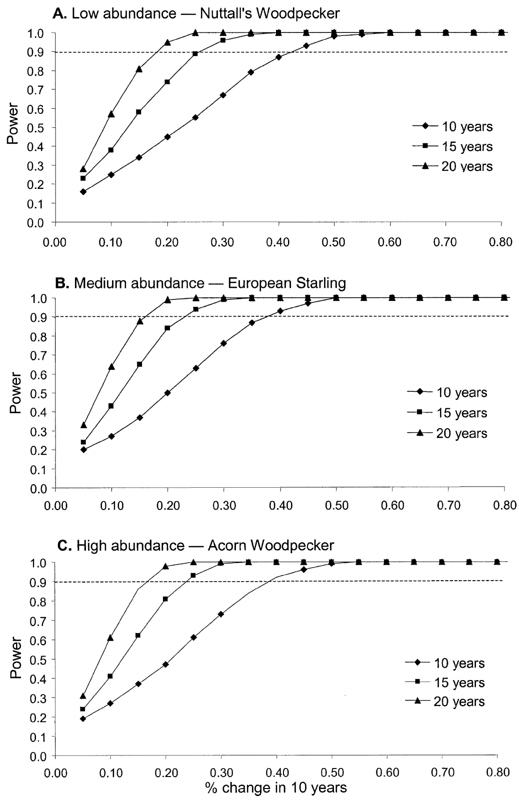

FIGURE 2. The influence of effect size and the number of sampling years on power for three species breeding at the San Joaquin Experimental Range, California, that vary in abundance but have similar overdispersion parameters (σ): A) the Nuttall's Woodpecker (*Picoides nuttallii*) typifies low abundance (0.23 birds per station, σ = 0.33), B) the European Starling (*Sturnus vulgaris*) represents medium abundance (0.96 birds per station, σ = 0.30), and C) Acorn Woodpecker (*Melanerpes formicivorus*) represents high abundance (2.85 birds per station, σ = 0.33). Results based on one-tailed tests with α = 0.10. Dotted line shows power at 0.90 (β = 0.10).

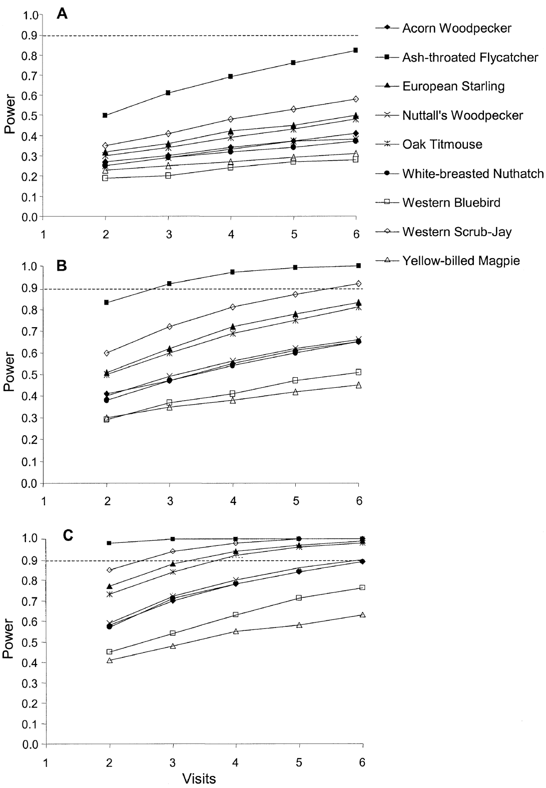

FIGURE 3. The effect of the number of visits to count stations on power to detect a decreasing trend based on count data for nine species breeding at the Valensin Ranch, California. Effect size is a 30% decrease per 10 years with A) 10 sampling years, B) 15 sampling years, and C) 20 sampling years. Note that an effect size of −30% per 10 years with 15 sampling years is equal to a 41% decrease over the 15 years and an effect size of −30% per 10 years with 20 sampling years is equal to a 50% decrease over 20 years due to the assumption of a non-linear Poisson distribution for count data. Model input was based on one route of 17 stations. Results based on one-tailed tests with α = 0.10. Dotted line shows power at 0.90 (β = 0.10).

DISCUSSION

Our results show that adequate study design is important when monitoring bird species to ensure that declining trends are detected and that appropriate management responses can be taken. Our results further point out that species with low abundance or high variability cannot be effectively monitored in most cases, even with large sample sizes, unless the trend is strong. It is important to realize prior to the implementation of studies that it will not be possible to examine trends for many species.

NUMBER OF YEARS

We found that 10 sampling years were insufficient to detect a 30 percent decrease with adequate power and that, even with 20 sampling years, declining trends could only be examined for fairly abundant species. A previous study by Verner et al. (1996) found similar results for bird species breeding at SJER. Examining coefficients of variation for annual variability, they concluded that 11–22 years would be needed to obtain baseline data for the 34 species with counts of at least 10 detections per year. Population declines not only take a very long time to

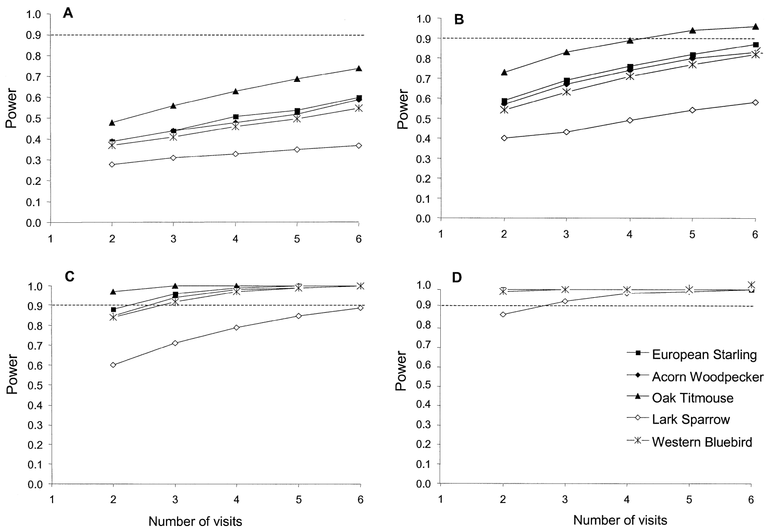

FIGURE 4. The effect of the number of visits to count stations on power to detect a decreasing trend based on point-count data for five species breeding at the San Joaquin Experimental Range, California, with an effect size of (A) 20% decrease per 10 years with 10 sampling years, (B) 30% decrease per 10 years with 10 sampling years, (C) 20% decrease per 10 years with 20 sampling years, and (D) 30% decrease per 10 years with 20 sampling years. Note that an effect size of −20% per 10 years with 20 sampling years is equal to a 36% decrease over 20 years and an effect size of −30% per 10 years with 20 sampling years is equal to a 51% decrease over 20 years. Model input was based on four visits to 210 stations along seven routes. Based on one-tailed tests with $\alpha = 0.10$. Dotted line shows power at 0.90 ($\beta = 0.10$).

detect, but there is also the risk that such long-term declines may be difficult to reverse, especially if the cause of the decline is not known.

NUMBER OF STATIONS

One of the first considerations when designing a monitoring program is the number of stations to sample. We found that species with low overdispersion in count data responded strongly to increasing the number of stations, while those with high overdispersion responded weakly. The level of overdispersion is usually unknown prior to beginning a study and, even if it can be estimated from pilot data, it will differ across species. Because the optimal combination of parameter values differs across species, achieving an adequate study design, even for a small number of species, is difficult. It is important to remember that, with limited visits and sampling years, the power of tests of significance of trend will never be adequate, regardless of the number of stations. The most important consideration and limitation when deciding on the number of count stations is likely the size of the area to be sampled and how many stations will fit within the study area without risk of double-counting individuals at different stations. Another consideration is the species whose trends are of greatest interest. Low abundance did not necessarily mean that trends or treatment effects could not be examined. Increasing the number of count stations improved power for species with low abundance faster than for more abundant species. If, however, the objective of the study is simply to assess species richness at a site or identify the species present within a specific habitat, maximizing the number of stations will likely be a more appropriate choice (Ralph et al. 1993).

NUMBER OF ROUTES

Count stations are usually laid out in groups of stations that can easily be sampled in one morning (i.e., routes). Although one approach to increasing sample size to achieve adequate power is to increase the number of stations per route, this is generally not feasible above a given number of stations, as detection probabilities drop off significantly after the morning hours. Generally, therefore, increasing sample size is more logically accomplished by increasing the number of routes, provided more routes can be in-

TABLE 3. Power to detect a declining trend in avian abundance with an effect size of 30% over 10 years, after 10 and 20 years of sampling for 52 species breeding at the San Joaquin Experimental Range. Results are based on 5000 simulations, using one-tailed tests for a decrease with $\alpha = 0.10$. Initial values were from existing data from point counts conducted on seven routes of 30 stations with 4 visits each year. Note that an effect size of -30% per 10 years with 20 sampling years is equal to a 51% decrease over 20 years under a Poisson distribution.

Common name	Scientific name	10 years	20 years
Wood Duck	*Aix sponsa*	0.27	0.47
Mallard	*Anas platyrhynchos*	0.26	0.50
Wild Turkey	*Meleagris gallopavo*	0.30	0.67
California Quail	*Callipepla californica*	0.62	1.00
Turkey Vulture	*Cathartes aura*	0.54	0.99
Cooper's Hawk	*Accipiter cooperi*	0.29	0.64
Red-tailed Hawk	*Buteo jamaicensis*	0.72	1.00
Golden Eagle	*Aquila chrysaetos*	0.27	0.56
American Kestrel	*Falco sparverius*	0.45	0.95
Killdeer	*Charadrius vociferus*	0.36	0.84
Mourning Dove	*Zenaida macroura*	0.84	1.00
Greater Roadrunner	*Geococcyx californianus*	0.26	0.53
Great-horned Owl	*Bubo virginianus*	0.24	0.52
Anna's Hummingbird	*Calypte anna*	0.62	1.00
Acorn Woodpecker	*Melanerpes formicivorus*	0.70	1.00
Nuttall's Woodpecker	*Picoides nuttallii*	0.56	1.00
Hairy Woodpecker	*Picoides villosus*	0.30	0.66
Northern Flicker	*Colaptes auratus*	0.46	0.97
Black Phoebe	*Sayornis nigricans*	0.31	0.74
Ash-throated Flycatcher	*Myiarchus cinerascens*	0.42	0.93
Western Kingbird	*Tyrannus vociferans*	0.56	1.00
Loggerhead Shrike	*Lanius ludovicianus*	0.26	0.49
Hutton's Vireo	*Vireo huttoni*	0.37	0.87
Western Scrub-Jay	*Aphelocoma californica*	0.79	1.00
Common Raven	*Corvus corax*	0.66	1.00
Violet-green Swallow	*Tachycineta thalassina*	0.72	1.00
Cliff Swallow	*Petrochelidon pyrrhonota*	0.27	0.32
Oak Titmouse	*Baeolophus inornatus*	0.83	1.00
Bushtit	*Psaltriparus minimus*	0.46	0.96
White-breasted Nuthatch	*Sitta carolinensis*	0.84	1.00
Rock Wren	*Salpinctes obsoletus*	0.43	0.94
Canyon Wren	*Catherpes mexicanus*	0.65	1.00
Bewick's Wren	*Thryomanes bewickii*	0.47	0.97
House Wren	*Troglodytes aedon*	0.35	0.78
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.38	0.88
Western Bluebird	*Sialia mexicana*	0.69	1.00
American Robin	*Turdus migratorius*	0.34	0.76
Wrentit	*Chamaea fasciata*	0.24	0.42
California Thrasher	*Toxostoma redivivum*	0.24	0.50
European Starling	*Sturnus vulgaris*	0.73	1.00
Phainopepla	*Phainopepla nitens*	0.28	0.56
California Towhee	*Pipilo crissalis*	0.46	0.96
Rufous-crowned Sparrow	*Aimophila ruficeps*	0.35	0.78
Lark Sparrow	*Chondestes grammacus*	0.47	0.97
Red-winged Blackbird	*Agelaius phoeniceus*	0.27	0.50
Western Meadowlark	*Sturnella neglecta*	0.79	1.00
Brewer's Blackbird	*Euphagus cyanocephalus*	0.32	0.71
Brown-headed Cowbird	*Molothrus ater*	0.48	0.97
Bullock's Oriole	*Icterus bullockii*	0.55	0.99
House Finch	*Carpodacus mexicanus*	0.45	0.96
Lesser Goldfinch	*Carduelis psaltria*	0.61	1.00
Lawrence's Goldfinch	*Carduelis lawrencei*	0.33	0.78

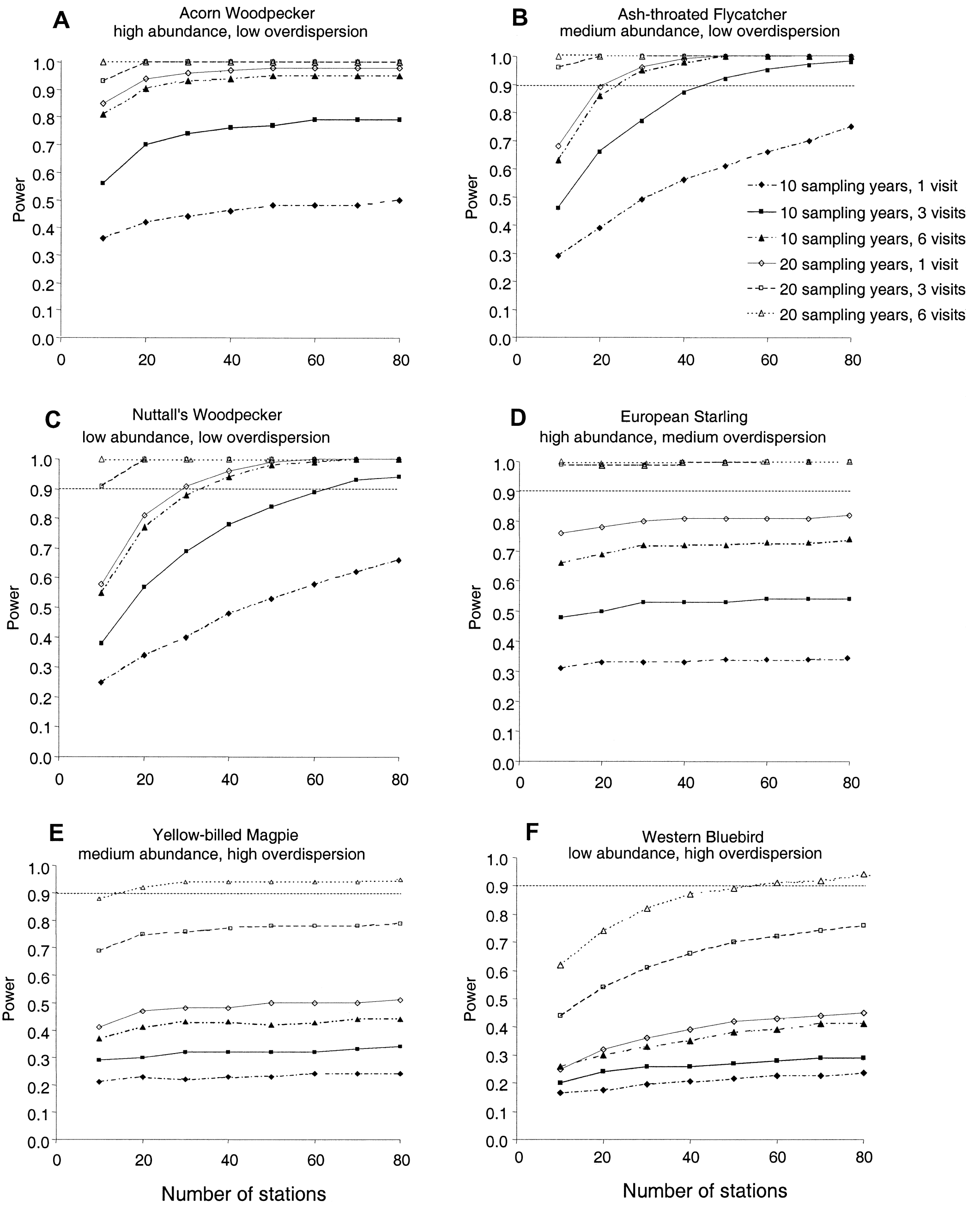

FIGURE 5. The number of count stations to achieve adequate power for trend analysis depended on the amount of overdispersion in the count data, abundance, the number of sampling years, and the number of visits. Based on data from the Valensin Ranch, California for the (A) Acorn Woodpecker, (B) Ash-throated Flycatcher, (C) Nuttall's Woodpecker, (D) European Starling, (E)Yellow-billed Magpie, and (F) Western Bluebird. Power is based on an effect size of a 30% decreasing trend over 10 years. Results based on one-tailed tests with α = 0.10. Note that an effect size of -30% per 10 years with 20 sampling years is equal to a 50% decrease over 20 years. Dotted lines indicate power at 0.90 (β = 0.10).

cluded within the study area. SJER accommodated seven routes of 30 stations each, with a minimum spacing of 200 m in an 1875-ha area, avoiding structures and atypical habitat. Thirty stations per route are probably close to the maximum that can be completed in one morning, and optimal spacing between count stations is often considered 250 m to avoid counting birds recorded at a previous count station (Ralph et al. 1993). The area needed to fit the desired numbers of stations and routes, and the sizes of the proposed treatments, should be considered when designing studies to examine the effects of treatments.

EVALUATING FOCAL SPECIES

California Partners in Flight has compiled focal species lists for each major terrestrial habitat in California, to provide focus for avian conservation planning, management, and monitoring efforts. In general, these lists include both a suite of species representing various habitat elements and processes in the ecosystem, and a number of species that are good indicators for monitoring (Chase and Geupel, in press). The Oak Woodland Bird Conservation Plan contains a list of focal species that have a range of life-history characteristics and require a variety of habitat elements in oak woodlands (California Partners in Flight 2002). In general, this type of focal species approach attempts to meet the needs of as many species as possible by identifying those species in a region that are most demanding of resources and then targeting them for management (Chase and Geupel, in press). Thus, the use of such a focal species list is based on the hypothesis that a ''landscape designed and managed to meet the focal species' needs encompasses the requirements of other species'' (California Partners in Flight 2002). The list is intended to be modified as the results of adaptive conservation research and monitoring are used to test this hypothesis.

The best focal species are those that can be monitored with an affordable level of survey effort. Here we evaluated which oak woodland bird species can be effectively monitored in multi-species monitoring programs, with special attention to focal species listed in the conservation plan. Affordable survey efforts may only allow monitoring of the most abundant or least variable species, or species that respond in a strong or consistent manner to alteration of key habitat attributes. With 210 point-count stations at SJER visited four times each year, we were not able to detect a 30% decreasing trend after 20 years for 44% of breeding species. This means that a large proportion of the bird community cannot be monitored cost-effectively, at least without the addition of explanatory variables. These less-abundant species are likely to be of concern precisely because of their low numbers. Monitoring programs designed to sample whole bird communities, such as these reported here, are likely to be of little value for these species.

Species that can be monitored effectively will differ by site and region, as species abundant in one area may be rare or absent from other areas. Even within California oak-woodland habitats, differences among sites in the presence and abundance of bird species are to be expected due to variation in dominant tree species, geographical location, and elevation. Of the seven primary focal species listed in the plan, each of our study sites lacks one (Yellow-billed Magpies [*Pica nuttallii*] are absent at SJER, and the Valensin site lacks Blue-gray Gnatcatchers [*Polioptila caerulea*]) and many focal species are present in low numbers at one or both sites and are therefore difficult to monitor (e.g., Lark Sparrows [*Chondestes grammacus*] at Valensin). While SJER and Valensin had relatively similar species compositions, oak woodlands closer to the Pacific coast of California may support rather different bird communities. For example, the Dark-eyed Junco (*Junco hyemalis*) is one of the most common and easily detected breeding species in coastal oak woodlands (Tietje et al. 1997, PRBO Conservation Science unpubl. data), but does not breed at more inland sites such as Valensin and SJER. For coastal oak woodlands, the Dark-eyed Junco would likely be a good focal species for monitoring.

Because different species can be effectively monitored at different locations, a statewide list of focal species should include a diversity of species that can be easily monitored and are sensitive to environmental change. Keystone species believed to influence the associated assemblage out of proportion to their abundance are ideal candidates for focal monitoring species. When the abundance of keystone species decreases, we expect a cascading effect through the community. Cavity-nesting birds comprise a large proportion of the breeding birds in oak woodlands and excavator species are likely keystone species by virtue of providing nest sites for other cavity-nesting species of birds and mammals (Purcell 1995, Verner et al. 1997). The Acorn Woodpecker's practice of storing acorns in granary trees also provides an available food source for many wildlife species. However, the use of focal species lists is based on numerous hypotheses and assumptions, and thus these should be made as explicitly as possible and tested in ongoing monitoring studies as part of an adaptive management program (Chase and Geupel, in press).

CAVEATS AND OTHER CONSIDERATIONS

In many respects our analyses were conservative. We analyzed data from unlimited-distance point counts. Fixed-distance counts are appropriate for many analyses and objectives and are believed to help control for certain types of bias, including detectability across species and habitats (Ralph et al. 1995), although it is important to consider the potential of fixed-distance counts to add problems of distance estimation to the other sources of observer variability. We must keep in mind that limiting observations to a fixed distance results in lower counts and therefore lower power. To simplify the number of models tested and the number of simulations, we used one-tailed tests to examine a decreasing trend. One-tailed tests for an increase result in slightly lower power, and two-tailed tests yield substantially lower power in most cases. While we considered the level of adequate power to be 0.90 instead of the more traditional 0.80 (raising β from 0.20 to 0.10), we also relaxed the traditional alpha level from 0.5 to 0.10 (see also Gibbs et al. 1998).

For trend analysis, one-tailed tests for decreasing trends are generally advisable and often appropriate, as a decrease is generally of most concern (Verner 1983). Certainly increases are of concern for particular species, such as in areas where European Starlings (*Sturnus vulgaris*) potentially compete for nesting cavities with native species, and in these cases the *a priori* alternative hypothesis can be adjusted as needed.

Our results are based on statistical models and are limited to the extent to which the data fit the assumed distribution (overdispersed Poisson in this case), the limited ability of current statistical models to include more than two random effects, and other assumptions. For example, our models assumed that all visits were the same, based on an initial mean count and overdispersion parameter for each site and species, yet counts of a species from different visits during a year vary due to differences in singing rate and detectability—another reason why multiple visits during the targeted census period are important. Our analysis matched the sampling scheme for the data we analyzed, which were unadjusted for detection probability other than through the inclusion of factors that influence detectability as random effects that induce variability in the mean count. This variability was modeled indirectly in our Poisson regression models rather than being directly parameterized in the model. We assumed that the overdispersion found in our data (see Table 1) was due to observer and site variability as these were the largest sources of variability. This approach has been used for other sample designs, such as North American Breeding Bird Survey data, however for this type of data, variability due to route (site), observer, and abundance per route per year are confounded, and cannot be assessed separately (Sauer et al. 1994, Link and Sauer 1997, 2002) unless observer and visit are replicated.

We are not advocating for or against the use of density estimates based on distance estimation and detection probabilities. We are advocating rigorous and appropriate analysis of count data using statistical models appropriate to the data at hand—Poisson regression corrected for overdispersion and controlling for observer and site variability, as well as other appropriate explanatory variables.

RECOMMENDATIONS

For trend analysis of abundance data, it is important to continue data collection for at least 15 years, especially if stations are visited less than six times per season. Twenty years will be necessary for many study designs (number of count stations and visits taken together) and will allow trend analysis for a greater number of species. Studies of this duration are rare and should be encouraged.

Our results and those of other studies have shown that the number of sampling stations needed to detect a treatment effect is often prohibitively large. For a small site with limited space, we advise visiting stations as often as possible. When funding is lacking or when a study site is small, allowing the placement of only a small number of count stations, increasing the number of visits may allow adequate power to be achieved. Many studies simply aren't worth doing because of limited plot size, inadequate funding to hire the needed number of observers, or time to complete the number of visits needed. The end result will be low power to detect statistically and biologically significant differences.

While power analyses are most appropriately done following a pilot study to determine optimal study design, the power of analyses done after completion of data collection can usually be improved with the addition of explanatory variables to statistical models. This will reduce the error term and the amount of variability left unexplained. Explanatory variables may include: observer (included in the overdispersion parameter in the models examined here), route (included as a fixed or random factor in our models), time of year (date), time of day, habitat variables, presence of other bird species that are potential competitors or predators, and weather variables. Weather variables have been shown to explain significant variability, and the addition of year as an explanatory variable may increase power appreciably, as high annual variability appears to be common. In some cases, apparent population trends may simply be the result of response to weather variables (Purcell et al. 2002).

Due to statistical software limitations, unless we used beta or experimental versions such as the SAS GLIMMIX procedure for estimating more than one variance component for overdispersed Poisson regression, we were limited to models including only one random effect, which we assigned to observer variability. This constraint precluded us from simulating the effect of varying the number of routes on power unless we examined fewer routes, and results of simulations examining fewer routes would vary, depending on which routes were dropped. These software limitations, however, do not present a problem for analysis of data following data collection. When we used the GLIMMIX procedure, we assumed route as a random effect so that we could vary the number of routes. In most cases, we believe that routes cannot properly be viewed as randomly selected from a population of potential sites and therefore should be modeled as fixed effects (Sauer et al. 2004). While there is some cost to power associated with using fixed effects due to the increased number of parameters to be estimated and the associated reduction in degrees of freedom, we recommend the appropriate specification of models.

Based on the low power to detect trends for many of the species and design factors considered here, meta-analysis of regional data might be the best approach, as long as methods are standardized among studies (Johnson 2002). For example, data from 5-min counts cannot be compared with data from 6-min counts, just as data from unlimited-distance counts cannot be compared with data from fixed-distance counts. The advantages of combining data from several small studies include the ability to detect smaller effect sizes or moderate effect sizes for less common or more variable species, and more confidence in the generality of results compared to those from a single, large, and presumably definitive study from a single study area (Johnson 2002).

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LITERATURE CITED

AIGNER, P. A., W. A. BLOCK, AND M. L. MORRISON. 1997. Design recommendations for point counts of birds in California oak-pine woodlands: power, sample size, and count stations versus visits, p. 431–439. *In* N. H. Pillsbury, J. Verner, and W. D. Tietje [TECH. COORDS.], Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. USDA Forest Service General Technical Report PSW-GTR-160.

BART, J. 1985. Causes of recording errors in singing bird surveys. Wilson Bulletin 97:161–172.

BART, J., AND S. EARNST. 2002. Double sampling to estimate density and population trends in birds. Auk 119:36–45.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM, AND J. L. LAAKE. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, London, UK.

BURNHAM, K. P., D. R. ANDERSON, AND J. L. LAAKE. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1–202.

California Partner's in Flight. 2002. The oak woodland bird conservation plan: a strategy for protecting and managing oak woodland habitats and associated birds in California. Version 2.0. Point Reyes Bird Observatory, Stinson Beach, CA, USA.

Chase, M. K., and G. R. Geupel. In press. The use of avian focal species for conservation planning in California. *In* C. J. Ralph and T. D. Rich [eds.], Bird conservation implementation and integration in the Americas: proceedings of the third international Partners in Flight Conference 2002. USDA Forest Service, General Technical Report PSW-GTR-191.

Cochran, W. G. 1977. Sampling techniques, 3rd ed. John Wiley and Sons, New York.

Gibbs, J. P., S. Droege, and P. Eagle. 1998. Monitoring populations of plants and animals. Bioscience 48:935–940.

Hamel, P. B., W. P. Smith, D. J. Twedt, J. R. Woehr, E. Morris, R. B. Hamilton, and R. J. Cooper. 1996. A land manager's guide to point counts of birds in the southeast. USDA Forest Service General Technical Report SO-GTR-120.

Johnson, D. H. 2002. The importance of replication in wildlife research. Journal of Wildlife Management 66:919–932.

Kendall, W. L., B. G. Peterjohn, and J. R. Sauer. 1996. First-time observer effects in the North American Breeding Bird Survey. Auk 113:823–829.

Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal analysis using generalized linear models. Biometrika 73:13–22.

Link, W. A., and J. R. Sauer. 1994. Estimating equations estimates of trends. Bird Populations 2:23–32.

Link, W. A., and J. R. Sauer. 1997. Estimation of population trajectories from count data. Biometrics 53:488–497.

Link, W. A., and J. R. Sauer. 1999. Controlling for varying effort in counting surveys—an analysis of Christmas Bird Count data. Journal of Agricultural, Biological and Environmental Statistics 4:116–125.

Link, W. A., and J. R. Sauer. 2002. A hierarchical analysis of population change with application to Cerulean Warblers. Ecology 83:2832–2840.

MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84:2200–2207.

McCullagh, P., and J. A. Nelder. 1991. Generalized linear models. Chapman & Hall, New York.

McCulloch, C. E., and S. R. Searle. 2001. Generalized, linear, and mixed models. John Wiley & Sons, Inc., New York.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393–408.

Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences 47:2–15.

Purcell, K. L. 1995. Reproductive strategies of open- and cavity-nesting birds. Ph.D. dissertation, University of Nevada, Reno, NV.

Purcell, K. L., J. Verner, and S. R. Mori. 2002. Factors affecting the abundance and distribution of European Starlings (*Sturnus vulgaris*) at the San Joaquin Experimental Range, p. 305–321. *In* R. B. Standiford, D. D. McCreary, and K. L. Purcell [tech. coords.], Oaks in California's changing landscape. USDA Forest Service General Technical Report PSW-GTR-184.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Handbook of field methods for monitoring landbirds. USDA Forest Service General Technical Report PSW-GTR-144.

Ralph, C. J., S. Droege, and J. R. Sauer. 1995. Managing and monitoring birds using point counts: standards and applications, p.161–168. *In* C. J. Ralph, J. R. Sauer, and S. Droege [tech. eds.], Monitoring bird populations by point counts. USDA Forest Service General Technical Report PSW-GTR-149.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering, and M. F. Carter. 2002. Landbird counting techniques: current practices and an alternative. Auk 119:46–53.

Rotenberry, J. T., and J. A. Wiens. 1985. Statistical power analysis and community-wide patterns. American Naturalist 125:164–168.

Royle, J. A. 2004. *N*-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108–115.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777–790.

SAS Institute, Inc. 2000. SAS procedures guide. Version 8.2. SAS Institute, Inc., Cary, NC.

SAS Institute, Inc. 2003. The GLIMMIX procedure (experimental). Version 9.1. SAS Institute, Inc., Cary, NC.

Sauer, J. R., W. A. Link, and J. A. Royle. 2004. Estimating population trends with a linear model: technical comments. Condor 106:435–440.

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American Breeding Bird Survey. Auk 111:50–62.

Thompson, F. R., and M. J. Schwalbach. 1995. Analysis of sample size, counting time, and plot size from an avian point count survey on Hoosier National Forest, Indiana, p. 45–48. *In* C. J. Ralph, J. R. Sauer, and S. Droege [tech. eds.], Monitoring bird populations by point counts. USDA Forest Service General Technical Report PSW-GTR-149.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, New York.

Tietje, W. D., J. K. Vreeland, N. R. Seipel, and J. L. Dockter. 1997. Relative abundance and habitat associations of vertebrates in oak woodlands in Coastal-Central California, p. 391–400. *In* N. H.

Pillsbury, J. Verner, and W. D. Tietje [TECH. COORDS.], Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. USDA Forest Service General Technical Report PSW-GTR-160.

VERNER, J. 1983. An integrated system for monitoring wildlife on the Sierra National Forest. Transactions of the North America Wildlife and Natural Resources Conference 48:355–366.

VERNER, J., AND K. A. MILNE. 1989. Coping with sources of variability when monitoring population trends. Annales Zoologica Fennici 26:191–199.

VERNER, J., AND L. V. RITTER. 1986. Hourly variation in morning point counts of birds. Auk 103:117–124.

VERNER, J., K. L. PURCELL, AND J. G. TURNER. 1996. Monitoring trends in bird populations: addressing background levels of annual variability in counts, p. 1–7. *In* M. L. Morrison and L. S. Hall [EDS.], Transactions of the Western Section of The Wildlife Society. The Western Section of The Wildlife Society, Oakland, CA.

VERNER, J., K. L. PURCELL, AND J. G. TURNER. 1997. Bird communities in grazed and ungrazed oak-pine woodlands at the San Joaquin Experimental Range, p. 381–390. *In* N. H. Pillsbury, J. Verner, and W. D. Tietje [TECH. COORDS.], Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. USDA Forest Service General Technical Report PSW-GTR-160.

WHITTEMORE, J. A., AND G. GONG. 1991. Poisson regression with misclassified counts: application to cervical cancer mortality rates. Applied Statistics 40:81–93.