
Statistical Power of Presence-Absence Data to Detect Population Declines

DAVID L. STRAYER

Institute of Ecosystem Studies, Box AB, Millbrook, NY 12545, U.S.A.

Abstract: *Population declines may be inferred from a decrease in the number of sites at which a species is detected. Although such presence-absence data often are interpreted informally, it is simple to test the statistical significance of changes in the number of sites occupied by a species. I used simulations to examine the statistical power (i.e., the probability of making the Type II error that no population decline has occurred when the population actually has declined) of presence-absence designs. Most presence-absence designs have low power to detect declines of <20–50% in populations but have adequate power to detect steeper declines. Power was greater if the population disappeared entirely from a subset of formerly occupied sites than if it declined evenly over its entire range. Power also rose with (1) increases in the number of sites surveyed; (2) increases in population density or sampling effort at a site; and (3) decreases in spatial variance in population density. Because of potential problems with bias and inadequate power, presence-absence designs should be used and interpreted cautiously.*

Poder Estadístico de la Presencia-Ausencia de Datos para Detectar Disminuciones Poblacionales

Resumen: *Las disminuciones poblacionales pueden ser inferidas de una disminución en el número de sitios en los cuales una especie es detectada. A pesar de que los datos de presencia-ausencia son interpretados informalmente, es sencillo determinar la significancia de cambios en el número de sitios ocupados por una especie. Utilicé simulaciones para examinar el poder estadístico (i.e., la probabilidad de cometer un error Tipo II de que la disminución poblacional no ha ocurrido cuando en realidad la población ha disminuído) de diseños de presencia-ausencia. La mayoría de los diseños de presencia-ausencia tienen un poder bajo para detectar las disminuciones de <20–50% en poblaciones, pero tienen un poder adecuado para detectar disminuciones pronunciadas. El poder fue mayor si la población desaparece completamente de un subconjunto de sitios previamente ocupados que si disminuye homogéneamente de su distribución total. El poder también se incrementó con (1) incrementos en el número de sitios muestreados; (2) incrementos en la densidad poblacional o esfuerzo de muestreo en un sitio; y (3) disminuciones en varianza espacial de la densidad poblacional. Debido a los problemas potenciales del sesgo y poder inadecuado, los diseños de presencia-ausencia deberán ser utilizados e interpretados con cautela.*

Introduction

When determining whether the distribution or abundance of a species is declining, often the only information available is whether the species was historically present or absent at a series of sites. A common design to assess whether the population has declined is to re-

visit those sites and again determine whether the species is present or absent. Such data often are interpreted informally, by visual comparison of spot maps or by statements such as “the species was present at 18% of the sites surveyed and is now found at only 8% of the sites.” Of course, such informal tests have no statistical validity; an apparent decline in the number of sites occupied may represent random variation from sampling error or the metapopulation dynamics of a stable population. To avoid the problem of Type I errors—concluding that the population is declining when it is stable—pres-

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ence-absence data are easily tested with simple statistical tests (e.g., Snedecor & Cochran 1967).

The conclusions drawn from statistical analysis of presence-absence surveys may be incorrect because of either inadequate power (excessive probability of a Type II error concluding that the population is stable when it has in fact declined) or bias. Severe bias may arise from the inappropriate design or conduct of presence-absence surveys. This problem was addressed by Shaffer et al. (1998) and by Strayer and Fetterman (1999) and is not dealt with here. The issue of statistical power has received much attention from ecologists in the past decade (reviewed in Steidl et al. 1997) because it has become increasingly apparent that many ecological studies have unacceptably high probabilities of Type II errors. I examined the power of presence-absence surveys to detect declines in either the population density or number of sites occupied across a species' range. In addition, I explored how statistical power is affected by the mean density of the species (or, equivalently, by sampling effort at each site), by the variance around that mean density, and by the number of sites included in the data set. Because this work was inspired by a survey of unionid mussels (Strayer & Fetterman 1999), the models are parameterized for unionids. The precise, quantitative results about power thus apply only to these particular models and would differ with models that were constructed and parameterized differently. Nevertheless, the broad conclusions about the power of presence-absence surveys and the factors that affect power should be applicable to presence-absence surveys for a broad range of taxa.

Methods

Because presence-absence surveys merely report whether a species was encountered in the survey area and rarely include information on actual population densities, I used encounter rate as a measure of population density. In this context, an encounter might be the sighting or collection of a single individual or, in the case of gregarious or colonial species, the sighting or collection of a single flock or colony that contains many individuals. Advantages to using encounter rate rather than actual population density as a measure of population density are that the former is readily related to the probability of detecting a population (Green & Young 1993; Strayer et al. 1996) and often is simple and inexpensive to obtain. Presumably, higher encounter rates indicate higher population densities. In the specific case of unionids, limited studies suggest that density is a nearly linear function of encounter rate (Hornbach & Deneka 1996; Strayer et al. 1997, and unpublished data; Obermeyer 1998). Survey sites were assumed to be far enough apart, relative to the scale of demographic processes, to be statistically independent.

I modeled the distribution of encounter rates at specific sites across a study area as any of several lognormal distributions (Fig. 1). Encounter rates of unionid mussels at sites in the upper Susquehanna River basin in New York that contained any mussels typically were roughly lognormal, with mean encounter rates of 0.1–14/hour and variances of 1.5–2 ln units (Fig. 2). In this model I assumed that the species was present, even if at very low numbers, at all sites surveyed. If surveys included sites at which the species did not occur at all, as is the case for many real-world surveys, then statistical power would be lower than calculated by my model.

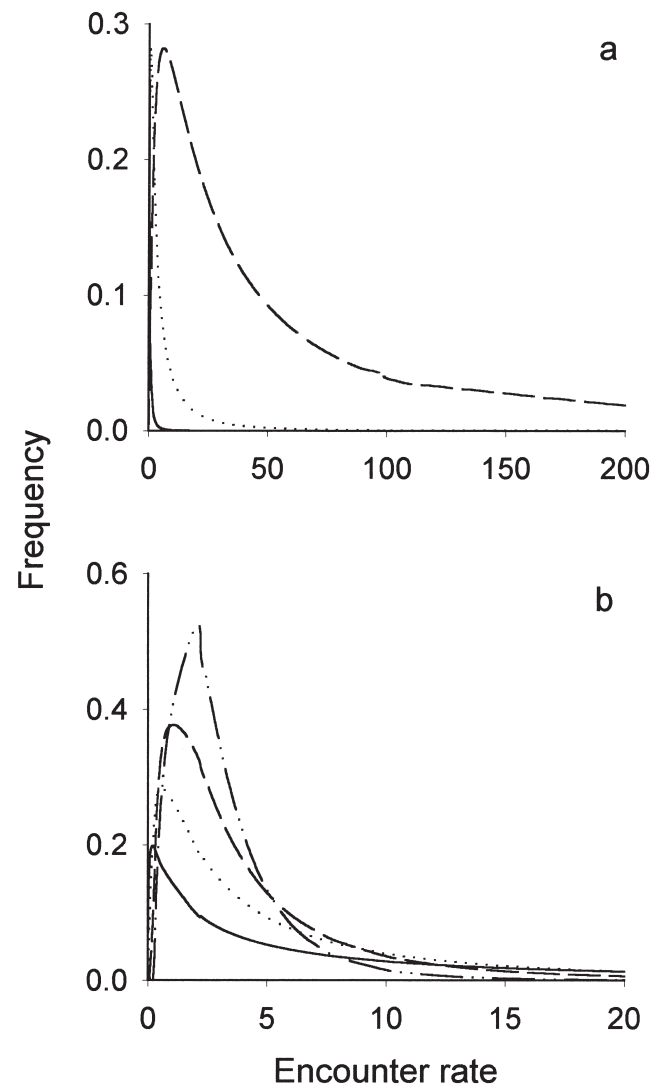


Figure 1. Distribution of encounter rates used in the power calculations: (a) different mean encounter rates (20 encounters, 2 encounters, 0.2 encounters), all with variance of 2 ln units, and (b) different variances (0.5, 1, 2, and 4 ln units), all with the same mean encounter rate (2 encounters).

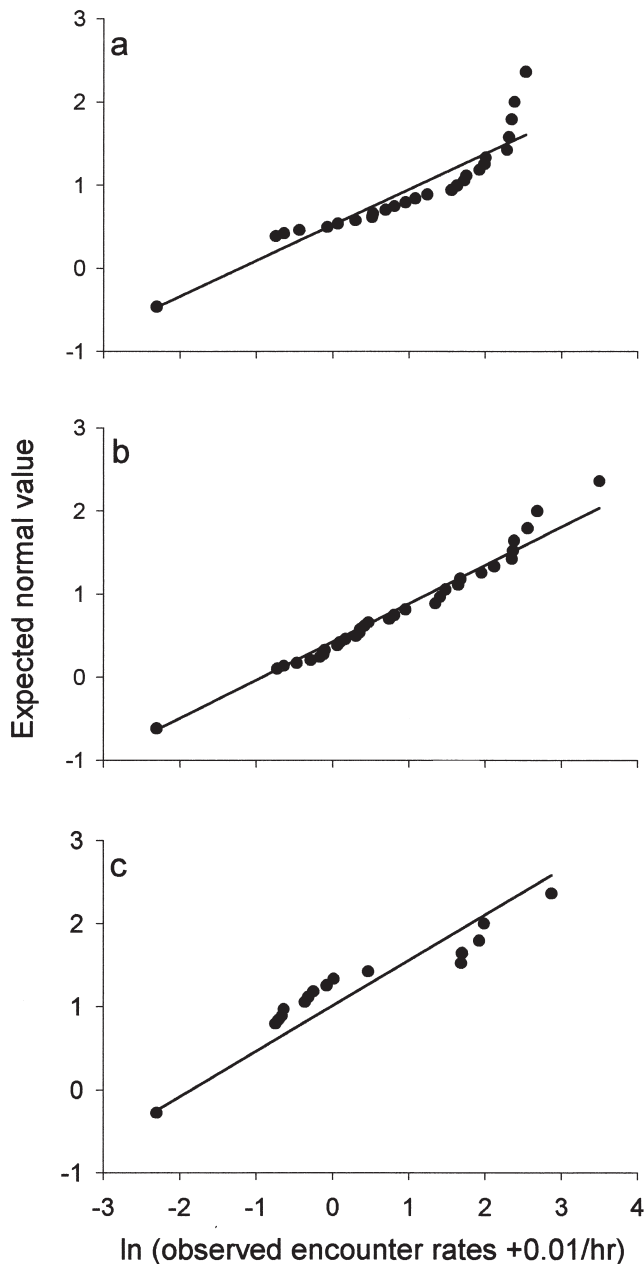


Figure 2. Distribution of encounter rates of three rare species of mussels at sites in the upper Susquehanna basin compared to lognormal distributions. The x-axes show actual encounter rates (as number/hour, after \ln -transformation) for sites at which the species was encountered, and the y-axes show the expected value if the data followed a normal distribution. Each point represents a study site. The species are (a) *Alasmidonta marginata*, (b) *Lampsilis cariosa*, and (c) *Lasmigona subviridis*. Data are from Strayer and Fetterman (unpublished).

I considered two kinds of population declines: (1) a uniform decline of 10, 30, 50, 70, or 90% in encounter rates across all sites and (2) a complete loss of populations at 10, 30, 50, 70, or 90% of sites that formerly con-

tained the species. The former model might represent the effects of widespread environmental degradation or the effects of a widely distributed alien species, whereas the latter was intended to represent local extinctions from habitat destruction, locally severe pollution, or a locally distributed alien species. These two models represent extremes of the kinds of spatial declines that a population might experience.

To estimate power, I compared the probabilities of detecting a series of populations before and after an imposed decline. First, I drew population encounter rates from the chosen distribution (Fig. 1) and estimated the probability (p) of detecting each of these populations as $p(\text{detection}) = 1 - e^{-R}$, where R is the encounter rate at the site (Green & Young 1993; Strayer et al. 1996). I determined whether each population had been detected by comparing this probability with a random integer from a uniform distribution between 1 and 1000 (which was divided by 1000 to bring it to the same scale as detection probabilities). If the random number was less than the detection probability, I scored the population as detected; otherwise, I scored the population as undetected. Then, I diminished encounter rates by either of the methods described in the preceding paragraph and calculated how many of the populations from the diminished distribution were detected. I compared the data from the original and diminished populations using a chi-square test for paired samples (Snedecor & Cochran 1967) to determine whether the difference in the number of populations detected was significant. Because I was testing whether the population had declined, not simply changed, I used a one-tailed test at $\alpha = 0.05$. Calculations were made with Resampling Stats (Bruce et al. 1995) with 1000 trials for each scenario.

Using this basic procedure, I examined the effect on statistical power of various mean encounter rates (0.2, 2, and 20 encounters), numbers of survey sites (30, 100, and 300 sites), and intersite variances in encounter rates (0.5, 1, 2, and 4 \ln units). I chose these ranges of parameter values to encompass typical conditions in unionid survey work, but they should apply to a wide range of taxa.

Results

Under most circumstances, presence-absence designs had low to moderate power to detect changes in populations that were declining uniformly across all sites, unless the decline was severe ($>50\%$; Fig. 3a-c). Power increased modestly as encounter rates rose from low to moderate, due to either denser populations or increased search effort, but then plateaued (Fig. 3a). Increasing the number of sites surveyed greatly increased power (Fig. 3b), so that surveys that used 300 sites had power >0.5 for declines as small as 25%. Conversely, surveys based on 30 sites had low power for all but the most se-

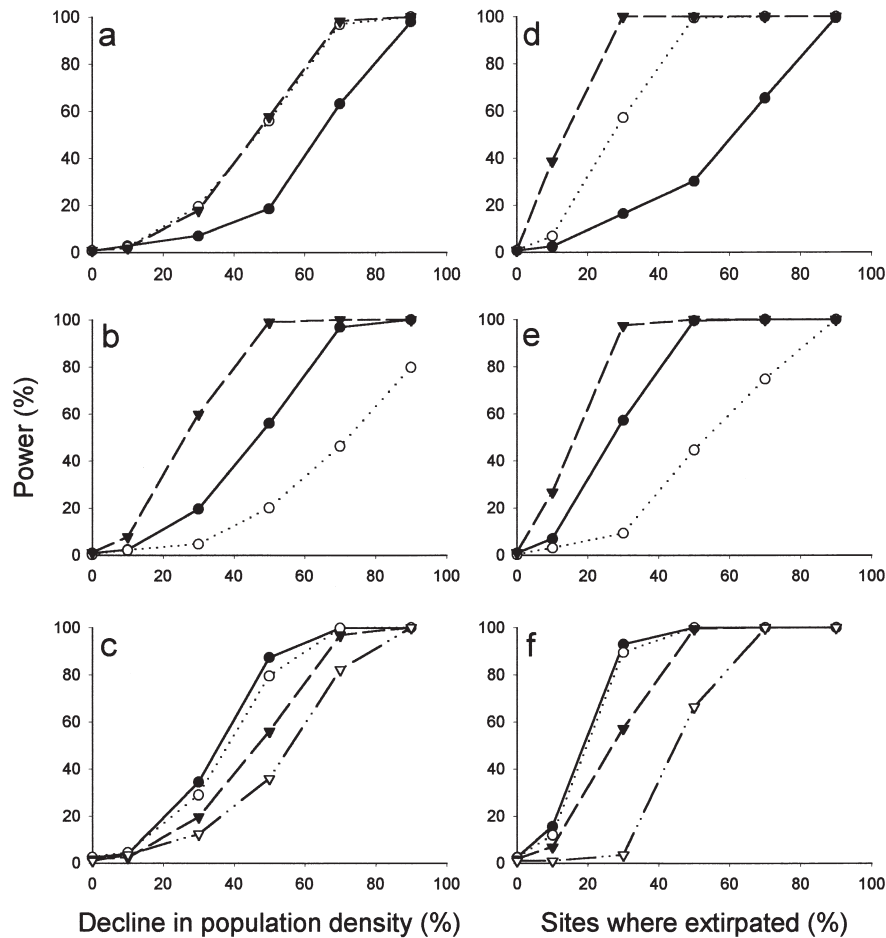


Figure 3. Statistical power (at $\alpha = 0.05$) of presence-absence designs to detect declines in populations in various situations: (a-c) populations declining uniformly across all sites; (d-f) populations disappearing entirely from parts of their ranges; (a, d) effect of mean number of encounters on statistical power (from top to bottom, curves show mean encounter rates of 20, 2, and 0.2, all with variance of 2 ln units [cf. Fig. 1a]); (b, e) effect of number of sites surveyed on statistical power (from top to bottom, curves show 300, 100, and 30 sites and populations have mean encounter rate of 2 and variance of 2 ln units); (c, f) effect of variance in encounter rates on statistical power (from top to bottom, curves show variances of 0.5, 1, 2, and 4 ln units, all with the same mean encounter rate [2 encounters; cf. Fig. 1b]).

vere ($\geq 70\%$) declines. Finally, the details of the distribution of population densities across the survey sites did influence the power to detect uniformly declining populations, but only modestly (Fig. 3c). Specifically, power was enhanced a little if population densities were not very variable spatially.

Generally, the power of presence-absence designs to detect declines from local extinctions responded qualitatively in the same way as their power to detect uniformly declining population densities (Figs. 3d-f). Thus, power rose with encounter rates (Fig. 3d), number of sites surveyed (Fig. 3e), and more spatially uniform population densities (Fig. 3f). Given the same survey design and encounter rates, though, presence-absence designs often had much higher power to detect local extinctions than uniform population declines (compare adjacent panels in Fig. 3). Further, power was much more sensitive to survey design and population characteristics if the species was being locally extirpated than if it was declining across all sites. Thus, power to detect local extinctions was satisfactorily high in many situations, unless a species was rarely encountered or patchily distributed or the number of sites surveyed was small.

Discussion

Presence-absence designs can detect changes in populations that are either declining uniformly across their ranges or disappearing entirely from some sites. Nonetheless, the power of such designs often is low, especially if population declines are modest ($< 20\text{--}50\%$). Thus, if an investigator is specifically interested in modest declines, presence-absence designs may not be sufficiently strong. Further, if a study using a presence-absence design fails to detect a significant difference between surveys taken at two different times, this evidence usually cannot be used to rule out the possibility of a small to modest decline in population density or range.

The low power of presence-absence designs is especially problematic if a small number of sites is surveyed (Fig. 3b & 3e), if encounter rates are low (i.e., if the population is sparse or survey effort is low; Fig. 3a & 3d), if the population is highly variable spatially (Fig. 3c & 3f), or if the population decline is widespread across many sites rather than concentrated at a subset of sites. Unfortunately, all of these circumstances are commonly encountered in surveys of the rare species that are of most conser-

vation interest. On the other hand, if the species is at least moderately common (more than one encounter per site-visit, on average), if a large number of sites are included in the survey, or if the population decline consists chiefly of the local extirpation of subpopulations, the statistical power of presence-absence designs may be adequate.

Several options are available to an investigator if the power of a presence-absence design is low. First, the investigator may choose to use a response variable that is based on local abundance instead of simple presence-absence. This option may not be feasible because often it is the absence of quantitative information on historical population density or the excessive cost of gathering quantitative data that leads an investigator to a presence-absence design in the first place. Second, the investigator may be able to increase the power of the presence-absence design. Of the factors responsible for the low power of presence-absence designs, only the effort per site and the number of sites surveyed are readily under the control of the investigator. My analysis suggests that increasing the number of sites surveyed is generally a better approach than increasing the effort per site to increase power. Third, the investigator may choose to work with an α level more liberal than 0.05. Using $\alpha = 0.10$ or even 0.25 will increase the power of a program to detect declines, but it will also increase the frequency of Type I errors and may not meet with approval from colleagues and critics. Finally, the investigator may simply accept the inadequacy of the sampling design to detect declines of <20–50%, even if those declines are of biological significance.

In the specific case of unionid mussels, the group that inspired this study, presence-absence designs as applied often have inadequate power to detect declines of conservation interest. I examined 19 mussel surveys published since 1990 and found that they included a mean of 69 sites (range = 16–156 sites). Mean encounter rates often were less than one individual per species-site, exceeding 10 individuals per site for only the most abundant species. Most of these data sets thus have low to modest power to detect declining populations. Historical data sets, which must be used to test for population declines, often included even smaller numbers of sites (e.g., Vaughn 1997). Furthermore, no other monitoring design commonly used for freshwater mussels has adequate power to detect declines of <50%, except for the most abundant species (Downing & Downing 1992; Strayer et al. 1997). The inability of monitoring designs

to detect declines of <50% is a serious weakness of programs to monitor and manage unionid populations because declines in the range of 10–50% certainly are of interest to scientists and managers.

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