How intensive is intensive enough? Limitations of intensive searching for estimating shorebird nest numbers

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Numerous methods have been employed in an effort to accurately estimate bird numbers. For tundra-nesting shorebirds, researchers often search discrete areas for nests, and then apply these apparent nesting densities across various spatial scales in order to estimate population size. Double-sampling has recently been used in this context, but an untested assumption of this approach is that intensive nest searching yields an accurate estimate of the number of nests present on a given study plot. We test this assumption with nesting success data from a four-year study of Western Sandpipers on the Yukon-Kuskokwim Delta in western Alaska. We applied Mayfield nest success estimates to compare the number of nests found to the number of nests estimated to be present. On average, we located only 84% of first nests, despite a small study plot and high search intensity. Thus, our nest searching efforts yielded only an index of nests present, not a complete count. Model-based double-survey methodologies may better estimate shorebird population numbers when nest searching yields only an index count, but these approaches also make important assumptions. We urge shorebird researchers to carefully evaluate, and ideally test, the assumptions underlying the range of approaches being used to derive estimates of breeding population size.

INTRODUCTION

Two decades after the first symposium devoted to the estimation of terrestrial bird numbers (Ralph & Scott 1981), the task of accurately estimating population size in a particular area remains extraordinarily challenging. A spate of recent papers has addressed this issue, specifically highlighting the problems associated with using traditional index counts to monitor populations (Nichols *et al.* 2000, Bart & Earnst 2002, Rosenstock *et al.* 2002, Thompson 2002). Alternatives which generate actual density estimates include double-observer methods (Nichols *et al.* 2000), distance sampling (Buckland *et al.* 2001, Rosenstock *et al.* 2002), and double-sampling (Handel & Gill 1992, Bart & Earnst 2002).

Bart & Earnst (2002) developed a double-sampling approach to estimate the number of tundra-breeding shorebirds over large geographic areas. The method involves randomly selecting a large number of survey plots, most of which are surveyed rapidly during single visits. A subset of the plots, however, is surveyed intensively over a period of several days to several weeks, with the goal of determining the actual number of territorial males whose first nests were initiated on these intensive plots. Rapid surveys of the intensive plots (conducted by independent surveyors) are then used to generate an index ratio which reflects the proportion of birds present that was detected by the rapid surveyors. This index ratio is used to estimate actual numbers on those plots that were only surveyed rapidly. Finally, because the rapid plots were randomly selected, these data can then be expanded to generate population estimates for the area of interest.

The utility of the double-sampling approach rests on the assumption that the actual number of nests is accurately determined on the intensive plots. Because it is essential to confirm the validity of this assumption before adopting a double-sampling approach for large-scale population monitoring (Rosenstock *et al.* 2002), it is important to consider an analysis that takes into account the possibility of nests lost prior to discovery.

One such approach is based on Mayfield nest success estimates (Miller & Johnson 1978, Johnson & Shaffer 1990). In brief, the number of successful nests found on a study plot is divided by the Mayfield estimate of nest success for that study plot. The quotient represents an estimate of the actual number of nests initiated. Johnson and his colleagues recommended this approach for estimating the density of waterfowl nests; apparently, however, it has not been widely implemented. We are not aware of any study of tundra-nesting shorebirds which has used the Mayfield approach to convert an index of nest abundance (i.e., the raw results of nest searching) into an actual estimate of nest density. Instead, shorebird researchers have often assumed that their intensive searches yield not just an index but an actual count of the number of nesting birds on their plots. In this paper, we evaluate the validity of this assumption by using the Mayfield approach to estimate the percentage of sandpiper nests found on an intensively surveyed study plot in western Alaska.

STUDY AREA AND METHODS

We studied Western Sandpipers *Calidris mauri* from May to July 1999–2002 at the Kanaryarmiut Field Station, located near the Aphrewn River on the Yukon-Kuskokwim Delta, Alaska (61°21.80' N, 165°07.53'W). The 16-ha study plot was dominated by upland heath tundra; permanent water bodies bordered the plot along 85% of its perimeter. One to 3 persons searched daily for nests on the study plot from late May through late June each year. We checked the status of nests approximately every 5 days during incubation, and daily near the time of hatch. Nesting adults were captured and each was banded with an aluminum United States Fish and Wildlife Service band, as well as a unique combination of 3 colour bands. For additional details of the study area and field protocols, see Ruthrauff (2002).

ANALYSIS

Nest success estimates were derived via the Mayfield method (Mayfield 1975, Manolis *et al.* 2000). For Western Sandpipers at the Kanaryarmiut Field Station, the period length (i.e., average exposure days for a successful nest) was 25 days, 4 for the laying period and 21 for incubation (Ruthrauff & McCaffery, unpubl.). We estimated the number of nests actually present on the plot using the following equation

$$N_E = N_H / M$$

where N_E is the estimated number of Western Sandpiper nests on the plot, N_H is the number of nests that hatched on the plot, and M is the Mayfield estimate of nest success. The rationale for use of this equation is found in Miller & Johnson (1978) and Johnson & Shaffer (1990). An assumption of this approach is that all successful nesting efforts are identified. It does not require that all successful nests be found prior to hatching (if successful nests can be identified after the fact), nor does it even require that all successful nests be found. If broods from undiscovered nests are found on the plot, they can be included in N_H, as long as the researcher can determine that they hatched from a nest located on the plot.

In the double-sampling approach for tundra-breeding shorebirds, the parameter being estimated on the intensive plots is the "number of territorial males whose first nest of the season, or territory centroid for non-nesters, was within the plot" (Bart & Earnst 2002, p. 39). This is not necessarily the same as the number of nests initiated on the plot, although nests are often used as an index to, or an aid in determining, the number of breeding birds. For many shorebird populations, particularly monogamous species where re-nesting does not occur, an estimate of the number of nests on a plot is the functional equivalent of the number of pairs. At the Kanaryarmiut Field Station, however, Western Sandpipers frequently re-nest if their first nests are lost early in the season (McCaffery & Ruthrauff, unpubl.). Because the parameter of interest is the number of first nests only, we have corrected the estimate of total nests derived via the Mayfield method by incorporating the frequency of re-nesting in each year of the study. The equation for estimating the number of first nests on the study plot becomes:

$$N_F = (N_H / M)(F)$$

where N_F is the estimated number of first nests and F is the percentage of nests found that were first nests (i.e., first nests/total nests). Two additional assumptions are required for this modification of the equation: a) among nests found, first and second nests are identified correctly, and b) the rate of re-nesting among nests not found is the same as for those found.

RESULTS

Effort

Total search effort on the 16-ha plot amounted to 400 hours spread over 40 days and 340 hours spread over 30 days in 2001 and 2002 respectively. The additional effort in 2001 was necessary because a severe cold snap early in the laying period resulted in a sharp hiatus in clutch initiation; as a result, clutches were initiated (and therefore active) over a longer period than in 2002. The average numbers of search hours per ha during each 5-day period of the nesting season were 3.1 and 3.5 in 2001 and 2002 respectively. Search effort on the plot was not quantified in 1999 and 2000, but was comparable to that in 2001 and 2002.

Estimated number of nests

In 3 of 4 years, the number of first Western Sandpiper nests found on the Kanaryarmiut study site (N_O) was less than that expected (N_F) based on Mayfield nest success calculations (Table 1). The mean ratio of these values (i.e., the proportion of first nests found) was 0.84. In other words, on average, intensive surveying apparently failed to find 16% of the estimated number of first nests initiated by Western Sandpipers on the study plot.

DISCUSSION

Assumptions

The validity of this approach rests on three assumptions. The first is that all successful nests must be identified. Several factors suggest that this assumption is probably met. First, scheduling daily nest checks as hatch approaches (see Methods) ensures that the fates of known nests are almost always definitively determined. Second, if an undiscovered nest successfully hatches, the combination of comprehensive daily plot searches and parental mobbing behaviour (in response to observers ≤100 m away, once chicks hatch)

Table 1. Parameters used to estimate the number of Western Sandpiper nests actually present on a 16-ha study site at Kanaryarmiut Field Station, Yukon-Kuskokwim Delta, Alaska.

Year	N_H[1]	M[2]	N_E[3]	F[4]	N_F[5]	N_O[6]	N_O/N_F[7]
1999	16	0.25	64	0.87	56	46	0.82
2000	19	0.35	54	0.87	47	46	0.98
2001	12	0.22	55	0.91	50	50	1.00
2002	8	0.11	73	0.79	58	33	0.57

[1] N_H = number of nests hatched
[2] M = Mayfield nest success estimate
[3] N_E = estimated number of total nests on plot, or N_H/M
[4] F = first nests found/total nests found
[5] N_F = estimated first nests, or $(N_E)(F)$
[6] N_O = observed first nests
[7] N_O/N_F = estimated proportion of total first nests found

virtually assures detection of an unknown brood within 24 hours of hatching. Third, the extensive water barriers around the plot and the limited mobility of day-old chicks makes it very unlikely that there is either emigration or immigration of broods hatched on or off the plot, respectively, within the first 24 hours after hatching. Finally, the purpose of this analysis was to evaluate how effective intensive plot surveys are in locating sandpiper nests. If this first assumption is actually violated (i.e., if there are undetected but successful nests), then N_F is underestimated, and N_O/N_F is overestimated. In other words, the 0.84 detection rate for nests on the plot is a maximum; if the first assumption is violated, the true nest-finding efficiency is lower (and, conversely, the percentage of nests *not* found is higher).

The second and third assumptions relate to the correction for re-nesting. One is that, among nests found, first and second nests are identified correctly; the other is that the re-nesting rate among discovered nests can be applied to the pool of nests not located. Regarding the former assumption, the high percentage of banded birds on the plot (~50% of banded birds are re-sighted each year; banding of previously unbanded birds begins within days of clutch completion) suggests that most nests can be correctly identified as first or second nests (Ruthrauff & McCaffery, unpubl.). Unbanded pairs that lose their nest during laying or early incubation, however, could produce a second clutch that might be misidentified as a first clutch. This would result in an overestimate of both F, the proportion of first nests among the pool of discovered nests, and N_O, the observed number of first nests. The net result if this assumption is violated, however, is no change in the estimated proportion of nests found on the plot.

The final assumption, that the re-nesting rate among undiscovered nests is the same as among nests that have been located, may be violated at our study site. Although many nests are found simply by flushing incubating birds, some nests are found by keeping track of individuals (in effect, focal sampling) until they return to the nest. Investment in, and the pay-off from, this latter strategy is greatly enhanced when working with colour-marked birds; as a result, there may be a bias toward finding nests (and re-nests) of this subset of the population. These birds were all banded at nests on the plot in previous years and thus comprise a cohort of known, experienced breeders. Unbanded birds, on the other hand, include birds that have nested previously on the plot but were never captured and banded, birds that have previously nested off the plot, and first-time breeders. If this cohort of unbanded birds re-nests at a lower rate (which might be expected for a group including young birds or those lacking local experience), then the plot-wide application of a re-nesting rate derived just from experienced plot breeders may be inappropriate. If the re-nesting rate is overestimated (i.e., the assumption is violated), then F is underestimated, N_F is underestimated, and the proportion, N_O/N_F is biased upward. Overall, therefore, violation of any of the three assumptions results in either an upward bias, or no bias, in the estimate of N_O/N_F. In other words, if the first or third assumptions were violated, we actually found a smaller proportion of the nests present than the calculations indicate.

Effort

Effort, as measured by hours spent searching/ha, was extremely high at our study site relative to many other shorebird surveys and studies. We averaged 3.1–3.5 search hr/ha in each 5-day period in 2001 and 2002; overall, we searched for nests for 21–25 hr/ha over the course of the field season. By comparison, on their plots in northern Alaska, Bart & Earnst (2002) spent 1.2–1.4 hr/ha in each of three 5-day periods, for a seasonal total of 3.6–4.2 hr/ha.

Implications

Despite a level of search effort considerably higher than that generated in most studies of tundra-nesting shorebirds, we apparently failed to find, on average, ≥16% of the first nests initiated on the study plot. Our findings are not unequivocal, because the number of nests actually found each year (N_O) always fell within the 95% confidence interval about the estimate derived from the Mayfield approach (N_F). The frequency and magnitude of difference between these two measures (found in 3 of 4 years; N_F up to 75% > N_O), however, lead us to conclude that we usually missed nests during our intensive surveys. These results have both theoretical and practical (i.e., methodological) implications. On the theoretical front, one would draw very different conclusions about annual variation in Western Sandpiper population size at Kanaryarmiut Field Station depending on the data set considered. Based on the raw search data (i.e., N_O), 2002 had by far the lowest apparent density of nesting pairs, but based on the Mayfield approach (i.e., N_F), 2002 was the year of highest density. If one were analyzing short-term trends in abundance, or trying to correlate environmental phenomena with population size, it would be easy to misinterpret the data and draw incorrect conclusions.

In terms of methodology, our inefficiency at finding nests is even more notable when one considers that we limited our searching to nests of a colour-marked population of just one species on a very small plot. This suggests that intensive surveying alone, even when augmented by additional techniques such as rope-dragging, may be unlikely to produce accurate estimates of the numbers of nesting shorebirds on tundra study plots.

Are the findings with Western Sandpipers at Kanaryarmiut Field Station applicable across the Arctic? It is possible that the relatively low proportion of Western Sandpiper nests found on the plot (i.e., 84%) was a function of the extremely high densities (mean annual density >300 pairs/km^2) at the study site. In other words, at such high densities, it might not be unexpected that some nests were missed, or that the complexity of sandpiper social interactions precluded an accurate determination of density. Although this may actually have been the case in our study, researchers must resist the temptation to therefore conclude *a priori* that the problem identified here does not apply to other species, other sites, other habitats, or other densities. All of these variables are likely covariates affecting the proportion of nests detected on a plot. The solution, however, is not to ignore the potential problem (i.e., significant underestimates of total nests), but rather to test it quantitatively under a variety of circumstances to determine if the results from western Alaska are typical or anomalous.

If such results are typical, then at best, intensive surveying generates an index that approaches the total number of nesting pairs present on a plot. How close must such an index be in order to satisfy the assumption of double-sampling that "all" nests have been found? Depending upon the magnitude of change one wishes to detect in shorebird numbers (across time, space, habitats, etc.), the assumption that all nests must be found can be relaxed somewhat (J. Bart, pers. comm.). Nonetheless, one must still have an estimate of the ratio of discovered nests to those actually present, and that estimate cannot be derived simply by searching more intensively.

Several alternatives exist for estimating the number of nests actually present on a plot. One is the Mayfield approach used here, but it may not be the most appropriate in most situations. In this study, we have used estimates of nest density derived with the Mayfield method to demonstrate that a significant fraction of nests are probably missed even on a very intensively searched plot. When the method is actually used for statistical comparisons, however, the precision of the estimates must be taken into account. The confidence intervals about Mayfield nest success estimates are often quite large, particularly when the sample size of nests is small. The relative imprecision of the estimates with small sample sizes may preclude the use of the Mayfield method for generating density estimates in many regions where shorebirds occur at relatively low densities. In addition, the Mayfield method may not generate an unbiased estimate of nest survival if visited nests suffer a higher mortality rate than nests that are not visited (Rotella *et al.* 2000; H. Schekkerman, pers. comm.).

Additional alternatives for estimating actual numbers include variations of double-surveys (e.g., Anthony *et al.* 1999), in which different surveyors or different methods are used independently to sample the same area. Double-observer studies (e.g., Nichols *et al.* 2000) form a subset of double surveys in which the two observers are using the same approach at the same time. Double surveying differs from double sampling (e.g., Bart & Earnst 2002) in that the former approach makes no assumptions that either survey locates all of the items of interest in the study area, while the latter approach assumes that intensive surveyors do find all of the items of interest in a randomly selected subsample of plots (see Introduction). For plot-based studies of tundra-nesting shorebirds, double survey approaches could involve either a second observer independently estimating numbers on an intensive plot or periodic rope-dragging. Rope-dragging is often thought of as a supplemental technique to find nests not found by typical intensive surveying; from that perspective, however, it merely produces a more accurate index. In the context of a double survey, rope-dragging should be considered the second survey. A model-based statistical analysis of survey type one (e.g., typical intensive surveying) and survey type two (rope-dragging) can then generate a valid estimate of density with associated measures of precision. By rigorously evaluating the assumptions of the double-sampling approach through an exploration of options for estimating the actual numbers of shorebird nests present on study plots, researchers can avoid the risk of being "left with an expensive index estimate" (Thompson 2002, p. 20).

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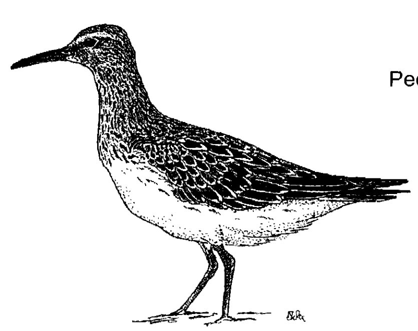

Pectoral Sandpiper by Hans Schekkerman