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Abstract.—Accurate estimates of population size and trends are often necessary for wildlife conservation, but imperfect and variable rates of detection can lead to substantially biased counts during surveys. The influence of survey timing relative to timing of breeding on the counts recorded for five shorebird species during transect surveys at East Bay, Nunavut, Canada, from 2000 to 2010 was examined. Transect counts varied widely among species and years, and transect counts were most strongly predicted by the density of nests found during more intensive surveys. However, after accounting for this variation, survey counts were influenced substantially by survey timing. Surveys carried out shortly after the median date of nest initiation (~2 days after) corresponded most closely to the densities of found nests, and if surveys were not within several days of the median date, the discrepancy between the two estimates was large. Although neither nest densities nor transect surveys are believed to be a perfect indication of local population status, these results suggest that the nearly inevitable variation in survey timing could introduce substantial bias into density estimates. *Received 18 December 2013, accepted 11 February 2014.*

Key words.—Arctic, breeding chronology, density, detection, nesting, shorebirds, surveys.

Accurate estimates of population size and trends are often necessary for wildlife conservation, yet achieving accurate counts can be difficult. For bird surveys, there are few cases where counts are believed to be complete; due to numerous sources of potential counting error and detection bias, counts represent an index of true abundance (Rosenstock *et al.* 2002). Despite this, trends in the index are often of interest (Johnson 2008). In the absence of estimates of detection, researchers assume that detection probability remains constant through time (Williams *et al.* 2002). The bias when this assumption is violated can be significant (Thompson 2002), and accounting for variable detection is increasingly viewed as a prerequisite for meaningful inferences from bird surveys. While accounting for birds not detected during surveys is valuable, some debate remains as to whether it warrants the added logistical costs, and whether a precise correction for detection is achievable (Johnson 2008).

The terms "detection rate," "detection probability," "detection ratio," and "index ratio" (Bart *et al.* 1998; Nichols *et al.* 2000) all generally refer to some ratio of birds counted to an independent measure or estimate of birds actually using the surveyed area, but the specific definition varies among surveys. Detection can be divided into at least two components: availability and perceptibility (Marsh and Sinclair 1989). Birds are available for detection when they are present and visible or singing during the survey. Perceptibility describes the ability of an observer to detect a bird, given that it was available for detection. Disentangling the various sources of imperfect detection is challenging. Various means exist to estimate and correct for detection, including double-observer methods (Nichols *et al.* 2000), repeated sampling and n-mixture models (Royle 2004). However, these methods can increase the complexity and cost of a survey program. An understanding of the magnitude and variability of the detection rate is necessary to understand whether the additional costs to correct for imperfect detection are justified.

Shorebird surveys might detect fewer individuals than are truly present if birds are not vocal or remain hidden in vegetation. The most accurate estimates of local breeding shorebird abundance can be made during late courtship/early incubation, and birds become more difficult to detect later

in incubation (Meltofte 2001). Vocalization activity of shorebirds declines throughout the breeding season, reducing the ability of researchers to detect individuals later in the season (Nebel and McCaffery 2003). Alternatively, surveys may detect more individuals than are nesting within the plot if birds call or fly from a distance to investigate the observer, or if migrants or non-breeders are present in the area at the time of surveys.

While choosing survey dates to correspond with particular phases of the breeding cycle is desirable, it can be difficult due to environmental variation among years. Annual variation in local climatic variables such as snow cover and temperature can strongly influence timing of shorebird nest initiation (Smith *et al.* 2010). It can be prohibitively expensive or logistically challenging to have crews on the ground monitoring the progress of breeding so surveys can be optimally timed. And because species vary in their timing of breeding (Smith *et al.* 2010), the optimal time for surveys can differ across species.

Correcting for imperfect detection is less critical when the detection ratio is close to 1, or when the relationship between survey counts and true abundance of nesting birds is consistent across years (Thompson 2002; Johnson 2008). For shorebird surveys, the latter scenario is implausible if the detection rate varies strongly over the season, given the difficulties of timing surveys to coincide with the same stage of the nesting period in each year. Seasonal changes in the detectability of shorebirds have been documented rarely (Meltofte 2001; Nebel and McCaffery 2003), and, to our knowledge, the specific effect of timing of surveys relative to timing of breeding has not yet been quantified. This study evaluates the extent to which survey counts of shorebirds breeding at East Bay, Nunavut, in the eastern Canadian Arctic are influenced by survey timing. We estimated the local abundance of five shorebird species using transect surveys, as well as more intensive nest searching to establish nest densities. We then estimated the timing of surveys relative to timing of breeding and evaluated

the degree to which temporal variation of surveys influenced the correspondence between transect counts and nest densities.

METHODS

Study Area

The study area is located on the coastal wetland plain of East Bay, Nunavut, Canada, in the East Bay Migratory Bird Sanctuary (63° 59′ N, 81° 40′ W). The landscape slopes gently toward the coast; lowland areas close to shore contain brackish ponds, whereas farther inland, freshwater ponds are separated by gravel ridges and areas of drier heath (Smith *et al.* 2007). Five shorebird species, Black-bellied Plover (*Pluvialis squatarola*), Semipalmated Plover (*Charadrius semipalmatus*), Ruddy Turnstone (*Arenaria interpres*), White-rumped Sandpiper (*Calidris fuscicollis*), and Red Phalarope (*Phalaropus fulicarius*), commonly found in East Bay were studied. Work occurred in June and July, from 2000-2010 inclusive.

Transect Surveys

The transect surveys were conducted by walking along linear transects in a 2.6 km² plot that stretched from the approximate high tide mark to 1.5 km inland. This area was covered with 1.5-km long transects (*n* = 17) running north to south. Two observers walking 50 m apart observed an area of 25 m on either side of them, for a combined transect width of 100 m. Given this transect width, detection of individuals sitting tight on the nest could be low. Our method is similar to the "rapid" survey method used in the Arctic Program for Regional and International Shorebird Monitoring (Bart *et al.* 2012), except that this rapid survey method uses a 25-m spacing between observers, and surveys occur in much smaller plots (typically 0.12-0.16 km²).

Observers stopped at approximately 50-m intervals to scan for birds. Sightings, locations, and observations on whether the birds were on the ground or overflying the transect were recorded. Only individuals on the ground or flying within ~2 m of the ground were included in the analysis. Birds that flew across the transect behind the observer were not included to avoid double counting. If the same individual appeared on two adjacent transects, it was recorded only once. However, if the observer was unsure if a bird was the same individual, both observations were recorded. The plot surveys were typically conducted once per year in mid- to late June, targeting late-courtship/early incubation, but were conducted two to three times in the years 2001 and 2002. Surveys take 8-10 person-days to complete, and time constraints prevented multiple surveys in all years. Surveys were conducted between 07:00 hr and 17:00 hr, and were postponed during periods of poor weather, such as heavy fog or wind, to maximize detection and minimize disturbance to birds. Transect-based estimates of density were the number of individuals per km² counted within the plot for each species and year.

Nest Searching

Nests were found using behaviors of individuals or by opportunistically flushing incubating birds from their nests (see Brown *et al.* 2014). Nest searching at the East Bay site was conducted across a larger study area (4 km x 3 km), but we restricted analyses to nests found within the 2.6-km² plot within which transect surveys were conducted. The larger study area was divided into 1-km² grid cells and each of these was visited by different observers to avoid bias from individual searching strategies. Nest searching within the 1-km² cells typically occurred over an entire day (8-10 hr), and all grid cells were surveyed at least three times per year, with search effort allocated evenly across them.

Once discovered, the location of each shorebird nest was recorded with a GPS, and discretely marked by inserting a tongue depressor into the vegetation 5-10 m away from the nest. This approach minimized visual cues for predators. The nests were visited every 3-7 days to determine breeding success. We determined which nests were within the transect-surveyed plot using GIS (Environmental Systems Research Institute 2009), and calculated nest density as the total number of nests found within this plot for each species in each year, divided by the plot's area (2.6 km²). For some analyses, we converted nests to birds by assuming that on average each nest represents two birds. This assumption may result in an overestimate of the true abundance of breeding individuals for polygamous species (White-rumped Sandpipers and Red Phalaropes in our sample), where one individual can be associated with > 1 nest.

Timing of nest initiation was directly observed or estimated using egg floatation (Liebezeit *et al.* 2007). When nests were found before the clutch was complete, the nest initiation date was estimated assuming one egg is laid per day (Sandercock 1998). When nests were found with a full clutch, typically four eggs, the age of the nest was determined by observing the angle at which eggs floated in water and their position in the water column (Liebezeit *et al.* 2007). At least two eggs were floated, and the method provides a nest initiation date with accuracy of ± 4 days in most cases. The median nest initiation date for each year was then calculated for each of the five shorebird species.

Statistical Analyses

We calculated the difference in timing between transects and median nesting date (Δt), in days, for each year and species. Δt^2 was also calculated as it is possible both early and late surveys have low detection ratios (defined here as the ratio of birds counted to birds that establish nests in the surveyed area), resulting in an optimal survey time. When more than one plot survey was conducted in a year (i.e., 2001-2002), the survey that gave the largest spread in Δt was chosen (to maximize variation in the explanatory variable).

We evaluated the relative importance of year, species, Δt, Δt^2 and nesting density in explaining variation in transect-based density estimates by comparing a series of *a priori* General Linear Models (GLMs) us-ing Akaike's Information Criterion corrected for small sample sizes (AIC_c; Table 1; Akaike 1974; Burnham and Anderson 1998). Our annual, species-specific, transect-based density estimates were treated as the response variable, and were normally distributed. First, we tested for the influence of year, species, and nesting density, and selected the best supported of these models. Next, we tested the additive effect of timing (i.e., Δt and Δt^2). Finally, we allowed for variation in the rates of detection by species and the effects of timing by species, by considering nest density by species and Δt or Δt^2 by species interactions. However, the results of these latter tests are tentative given the large number of parameters relative to our sample size. All statistical work was carried out using program R (R Development Core Team 2012). Unless otherwise noted, means are reported ± SE.

RESULTS

Variation in Density Estimates and Timing of Surveys

Transect surveys were conducted between 11 June to 2 July. Across all years, survey timing ranged from 24 days before to 13 days after the median date of nest initiation (Fig. 1). Surveys were often conducted later than median nest initiation ($n = 26$ nests) rather than earlier ($n = 18$ nests), and rarely on the same day ($n = 3$ nests). Nest density ranged from 0.0 to 5.1 nests/km² across species and years, with a mean of 1.6 ± 1.2 nests/km² (Fig. 2). Densities of birds recorded during

Table 1. Comparisons of models relating variables to transect-based estimates of shorebird density from 2000-2010 at East Bay, Nunavut. Models including species, year, nest density (nests found/km²), timing of surveys relative to the median date of nest initiation (Δt), and timing of surveys relative to the median date of nest initiation squared (Δt^2) were considered. Models were compared using Akaike's Information Criterion corrected for small sample sizes (AIC_c) and are displayed sorted by AIC_c relative to the top model (ΔAIC_c). *K* is the number of parameters in the model, and w_i is the Akaike weight.

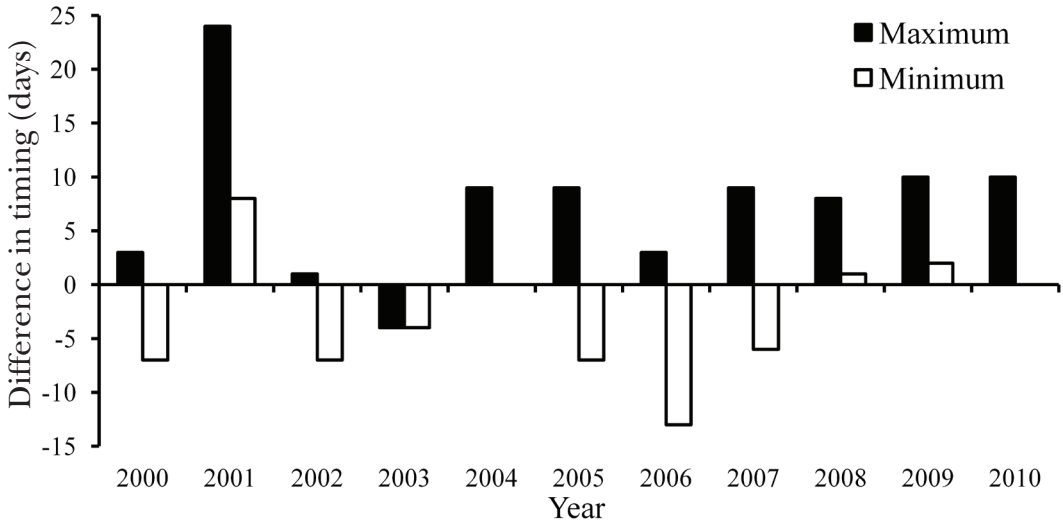| Model	ΔAIC_c	*K*	w_i
Nest Density + Δt + Δt^2	0	5	0.75
Nest Density	3	3	0.16
Nest Density + Δt	5	4	0.08
Nest Density + Species	8	7	0.01
Nest Density + Year	12	12	0.00
Species	24	6	0.00
Null	33	2	0.00
Year	49	11	0.00

Figure 1. Maximum and minimum difference in timing between plot surveys and median nest initiation dates (days) from 2000-2010 for five shorebird species pooled in East Bay, Nunavut.

the transect surveys varied greatly among years as well as among species (Fig. 2).

Factors Explaining Variation in Transect Density Estimates

We found strong support for a model relating transect-based estimates of density to estimates derived from nest searching. Inclusion of the nest density variable reduced AIC_c by 29 units over the null model, and nest density was by far the strongest single predictor of transect density (Table 1). Our best supported model included nest density, survey timing relative to the date of median nest initiation (Δt), and survey timing relative to the date of median nest initiation squared (Δt^2), and was an improvement of three AIC_c units over the model including only nest density ($w_i = 0.75$, $R^2 = 0.57$; Table 1). Parameter estimates for this top model appear in Table 2. We found no support for the model that included a species and nest density interaction ($\Delta AIC_c = 15$ units over the best supported model), suggesting no strong evidence for differences in rates of detection among species. However, we found some support for different patterns of detectability throughout the nesting season among species. The AIC score was five units lower than that of our top model with only

main effects, but because of the large number of parameters relative to the sample size, this model was not supported on the basis of AIC_c; we acknowledge that this model is over-parameterized but suggest interspecific differences in detectability as an area of future study.

We used the parameter estimates and values of 1, 2 and 5 nests/km^2 (corresponding to the range observed in our data) to evaluate variation in the detection rate across values of Δt (Fig. 3). Transect counts always exceeded nest densities, but the lowest predicted discrepancy occurred when transects were surveyed shortly after the median nest initiation date. Discrepancies were lower for positive vs. negative values of Δt, and lower when densities of nests found were high.

DISCUSSION

Both our transect-based counts and our density estimates derived from nest searching varied widely among years. This variation could reflect true variation in local abundance among years and/or differences in the rate of detection during surveys. Nest densities were the strongest single predictor of densities estimated during transect surveys, suggesting that the variation in large
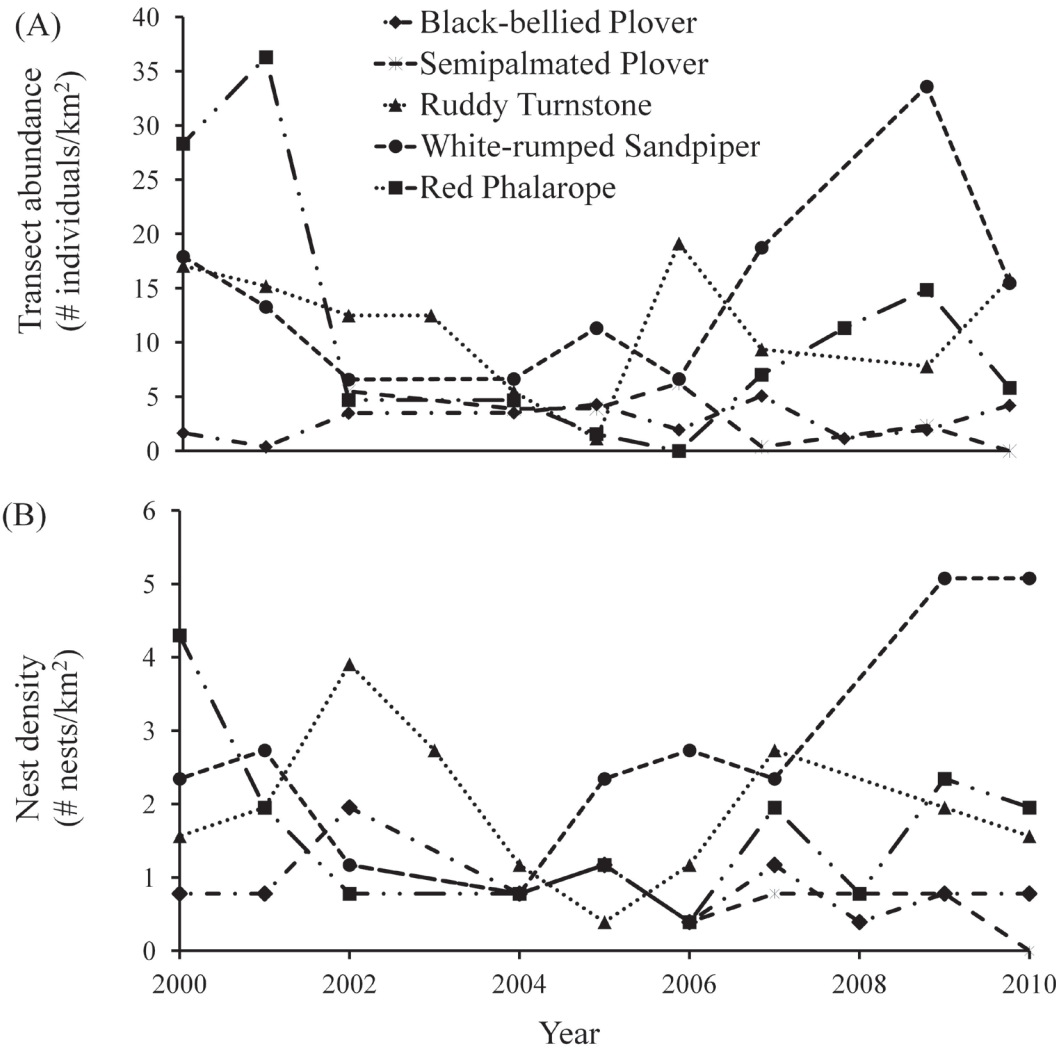
Figure 2. (A) Transect abundance (number of individuals/km²) and (B) nest density (number of nests/km²) of five shorebird species surveyed from 2000 to 2010 in East Bay, Nunavut.

part reflected changes in local abundance. There was also substantial variation in the timing of transect surveys relative to median nest initiation dates, and this variation in timing influenced detection rates. While surveys were conducted as close to the late courtship/early incubation period as possible, the timing of this phase varied among years. Median nest initiation dates varied by up to 2 weeks across species at this site (Smith *et al.* 2010); therefore, there was no one ideal date for all species.

The nearly unavoidable variation in survey timing across species and years has important implications for interpretation of survey results. Transect survey counts were higher relative to nest densities when surveys were conducted away from the median date of nest initiation, suggesting that overestimation of nesting abundance may be a larger concern than underestimation at this site. We also found tentative support for differing temporal patterns in this relationship among species. This is consistent with the

Table 2. Parameter estimates, standard error, and 95% Confidence Intervals (CI) for the top model describing variation in shorebird transect abundance from 2000-2010 in East Bay, Nunavut. The top model included nest density (nests found/km²), timing of surveys relative to the median date of nest initiation (Δt), and timing of surveys relative to the median date of nest initiation squared (Δt^2).

Variable	Estimate	Standard Error	95% CI	
Intercept	-0.22	1.46	-3.07	2.64
Nest Abundance	4.77	0.71	3.38	6.17
Delta T	-0.13	0.15	-0.42	0.15
Delta T Squared	0.03	0.01	0.01	0.05

findings of the Arctic Program for Regional and International Shorebird Monitoring which found that transect surveys overestimated nest densities by a factor of 1.27 (± 0.22) to 1.00 in Canadian tundra habitats (Bart and Smith 2012a). Nonetheless, most detection rate studies focus on a failure of observers to detect birds (Bart and Smith 2012b). While neither transect surveys nor our estimates of nest density are perfect estimates of local breeding abundance (see below), the temporal variation in the relationship between the two is suggestive of bias that may be problematic.

Birds are much easier to detect during transect surveys when they exhibit conspicuous courtship and nesting behaviors such
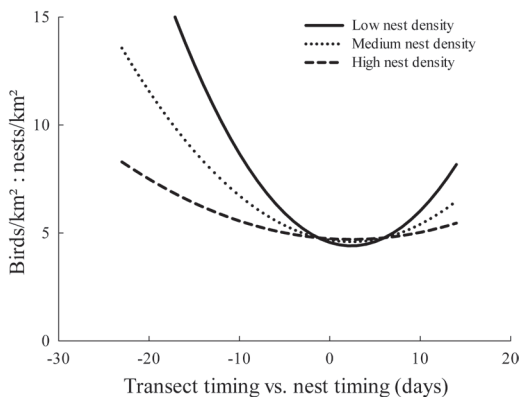

Figure 3. The ratio of predicted transect density (birds/km²) to the density of nests found (nests/km²) vs. the difference between transect timing and the date of median nest initiation (Δt) for low (1 nest/km²), medium (2 nests/km²) and high (5 nests/km²) nest densities. The nest densities and values for Δt used represent the range observed in our data.

as flight displays and vocalization (Meltofte 2001; Nebel and McCaffery 2003). Detection becomes more difficult as birds begin to incubate their nests, exhibit cryptic behaviors to evade predators, and limit their time foraging (e.g., Smith et al. 2012a). As the season progresses, individuals again become more conspicuous as nests fail or hatch. In addition, detectability patterns might vary among species. For example, the incubating sex of uniparental incubators that flush at small distances, such as White-rumped Sandpipers or Red Phalaropes, might easily be missed during transect surveys. In contrast, many biparental species such as Ruddy Turnstones and Black-bellied Plovers defend their nests aggressively, and increasingly so as nests age (Smith and Wilson 2010); these species may be less difficult to detect during incubation. Even within species, differences in territorial behavior among sexes or ages can lead to variation in availability for detection (Plissner et al. 2000). For example, post-laying females of the polyandrous Red Phalaropes aggregate in ponds in search of new males, making them easy to count. Detectability can also vary among individuals throughout the breeding season or in response to variation in resource availability (Plissner et al. 2000; Lorenz and Sullivan 2010; Calladine 2011). All of these factors can impact detectability during nesting and transect surveys.

We used nest densities as an independent measure of local abundance with which to evaluate the potential bias in transect surveys. Ideally, nest densities would be derived from extremely intensive surveys that locate all nests (Bart and Smith 2012b). Given the scale over which we searched for nests (i.e., 2.6 km²), it is unlikely that we located all nests. Smith et al. (2009) demonstrated that the probability of finding nests during a 3-8 hr single-observer visit to a 400-m by 400-m plot ranged from 21% to 64% across the species and sites they studied, with a mean of 46%. If we assume the detection rate in our larger plot was at least equal to the minimum rate observed in Smith et al. (2009), and that nests were active during at least three visits to the plot, we detected a minimum of 0.5 (i.e., $1-(1-0.21^3)$) nests. Assuming this minimum

rate of nest detection, one nest found corresponds to up to two nests initiated, or up to four nesting birds. Thus, transect counts are more likely to be overestimates of breeding abundance when the ratio of transect counts:nest density exceeds 4:1. Our results indicate that in many cases more than four birds were seen for each nest found. Thus, unless we grossly underestimated nest density, our results suggest that the high densities seen during transects carried out too early in the season represent overestimates of true local abundance. For surveys carried out early in the season, some of the observed birds may be birds that will be migrating farther north to breed (Bart and Smith 2012b).

We present the above discussion as an indication that detection rate is variable and potentially problematic, and do not suggest that our models might be usefully applied to correct for the rate of detection *post hoc*. While there are a variety of model-based approaches to correct for rates of detection in surveys (Buckland *et al.* 1993; Nichols *et al.* 2000; Royle 2004; Alldredge *et al.* 2007), most of these methods are difficult to apply given the logistical difficulties of working in the Arctic and shorebird ecology. If precise estimates of nesting density are required, our results suggest methods such as double-sampling may be the most promising means of calibrating indices derived from transect surveys. Alternatively, repeated counts of plots and N-mixture models (Royle 2004) might address some of the issues surrounding imperfect detection, but these methods are just now being tested for shorebirds in Arctic tundra.

While transect surveys can provide a useful index of the local breeding population, our results suggest that nearly unavoidable variation in survey timing might bias the results and should be taken into consideration. Estimates of population status from surveys are among the most critical pieces of information for wildlife management, and for many shorebirds breeding in the Arctic reliable estimates of population status are lacking (Ross *et al.* 2012; Smith *et al.* 2012b). However, unreliable estimates of status can lead to misdirection of limited conservation resources, and understanding sources of bias in population surveys is therefore critical.

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