

Accuracy and variation in estimates of large numbers of birds by individual observers using an aerial survey simulator

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ABSTRACT. The accuracy of aerial estimates of avian aggregation sizes is variable across studies, and the relative importance of techniques and inter-observer error to this variation are poorly understood. Using a scaled physical model of a wading bird colony, we examined accuracy and variation in observer counts of simulated large numbers (200–6000) of densely nesting birds in vegetated situations. Observer estimates averaged 29% less than true numbers (under- and overestimates averaged together), and the mean absolute value of observer errors was 49% of true values. We found no effects of the size of the aggregation, the experience of the observer, the size of the previous aggregations surveyed by observers, the use of corrective lenses, or fatigue on degree of individual error. Over- and underestimates by individuals did not tend to cancel out in estimates by individuals of a “population” of colonies. Photographic counts of the same trials were significantly more accurate than observer estimates. We suggest that many studies using estimates of large numbers of birds may be confounded by similar errors. We urge that researchers use caution in interpreting the results of past surveys and develop ways to minimize, measure, and correct for visual estimation error within individuals and among observers.

SINOPSIS. Exactitud y variación en los estimados de grandes números de aves, por observadores individuales, utilizando simulaciones de censos aéreos

La exactitud de los estimados aéreos de agregaciones de aves es muy variable en los diferentes estudios que se han hecho. La importancia relativa de las técnicas y el error interobservador, que introducen estas variaciones, ha sido pobremente entendido. Utilizando un modelo físico a escala de una colonia de vadeadores, examinamos la exactitud y la variación en los observadores en conteos de simulaciones de densas colonias de aves anidando en vegetación, y en grandes números (200–6000 individuos). Los estimados de los observadores promediaron un 29% menos que los verdaderos números (incluidos bajo y sobre estimados juntos) y la media absoluta promedio del error del observador fue de 49% con respecto a los valores reales. No encontramos efecto en el tamaño de la agregación, la experiencia del observador, tamaño de la agregación previamente censada por el observador, el uso de lentes correctivos, o la fatiga en el grado de error del observador. Los bajo o sobre estimados por individuos no tendieron a cancelar el estimado por individuo de una “población” de colonias. Los conteos fotográficos del mismo evento fueron significativamente más exactos que los estimados de los observadores. Sugerimos que muchos estudios que han utilizado estimados de grandes agregaciones de aves pueden haber cometido errores similares. Los investigadores deben tener precaución en la interpretación de los datos obtenidos de censos originados de estimados visuales. Se deben desarrollar formas de minimizar, medir y corregir los estimados visuales dentro de grupos de individuos y entre observadores.

Key words: aerial estimation, count error, observer error, survey

Nearly all types of surveys or counts of wild-life are subject to biases and variation in estimation accuracy, stemming from imperfect abilities to detect animals that are present and

to count animals that are detected (Caughley 1974; Thompson 2002; Williams et al. 2002; Seber 2002). Surveys conducted from aircraft have frequently been used to monitor the size and status of aggregated or colonial bird populations (Custer and Osborn 1977; Runde et al. 1991; Begg et al. 1997; Kingsford et al. 1999), to use waterbird reproductive responses as biological indicators of ecosystem change (Custer and Osborn 1977; Ogden 1994; Erwin and Custer 2000), and for many other kinds of research.

Although aerial visual techniques are quite

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efficient for monitoring bird populations over large geographic areas (Buckley and Buckley 2000), estimates of the accuracy of this technique have been mixed. McCrimmon (1982) found that aerial estimates by observers were quite comparable to ground counts for nesting Great Blue Herons (*Ardea albus*), while Gibbs et al. (1988) and Dodd and Murphy (1995) found that aerial visual estimates averaged 87% and 80% of ground counts, respectively, in the same species. Aerial estimates were acceptable for detection of a 15% annual change in numbers for a statewide survey (Dodd and Murphy 1995).

In other situations, aerial estimation has shown poorer accuracy. Rodgers et al. (1995) found that although degree of vegetative cover had no effect on accuracy of estimates of Wood Stork (*Mycteria americana*) colony sizes, the 95% confidence intervals of aerial estimates were -75 to 206% of ground counts, and variance of aerial estimates was proportional to the square of ground counts. In Florida, aerial estimates of seven ciconiiform species in a single mixed-species colony had between 32 and 100% error by comparison with ground counts, depending on species (Kushlan et al. 1979). Kadlec and Drury (1968) found that the variance of aerial counts of photographs of Herring Gull (*Larus argentatus*) colonies (<500 pairs) were proportional to the square of ground counts, and suggested that aerial counts were not adequate for obtaining population estimates of nesting gulls. Similarly, 95% confidence intervals of aerial surveys were $\pm 140\%$ of ground counts for gulls, and $\pm 56\%$ of ground counts for Double-crested Cormorants (*Phalacrocorax auritus*). More than twice as many waterbirds (cormorants, ducks, gulls) were seen by observers on the ground as were documented by individuals from aerial surveys (Savard 1982).

These measures of accuracy are affected by the observers' abilities to count animals seen and their abilities to detect birds that were present. Some studies have focused on measuring the former source of error by removing detection of nests or birds as a potential bias. Erwin (1982) asked observers to estimate the size of floating flocks of Canvasbacks (*Aythya valisineria*) photographed at an oblique angle on a uniform background. Although there was relatively poor accuracy for daily estimates, "population

estimates" of 50 photographs over a period of five days by individuals were with one exception within 10% of the total. Although untrained observers of photographs of shorebirds in flight (range 20–3650 targets) showed high individual variation in accuracy for any photograph, the errors of multiple observers were largely cancelled by each other (Prater 1979).

This information collectively suggests that aerial visual estimates of large aggregations of birds may sometimes be associated with high variances and poor accuracy. Yet many of the historical and current large-scale surveys of colonially nesting birds in the U.S. and elsewhere have relied heavily on aerial survey techniques (e.g., Custer and Osborn 1977; Portnoy 1978; Ogden 1978, 1994; Texas Colonial Waterbird Society 1982; Frederick et al. 1996; Runde et al. 1991; Bibby et al. 2000). The use and interpretation of past and future surveys therefore depends heavily on the ability to determine absolute accuracy and the variation in accuracy that may depend on individual observer biases.

With the exception of the studies by Erwin (1982) and Prater (1979), most studies have used ground counts as a proxy for the "true" number of birds or nests, with the assumption that there is little or no bias in ground counts. While this may be true in some situations, it is especially unlikely in heavily vegetated colonies, where even experienced ground-based observers may miss hidden nests or mis-identify nests. In addition, it is often impossible to perform ground and aerial counts on the same dates, and in the studies cited, aerial and ground counts were as much as seven days apart. Since colony or aggregation occupancy is usually unstable over even short time-frames (see Kadlec and Drury 1968), this problem could introduce unwanted variation into the estimation of counting error. Finally, the ability to detect differences in absolute (not relative) accuracy among individual observers over a large range of aggregation sizes has been confined to studies using photographs of bird aggregations, in which detectability played little or no part.

In this study, we examined accuracy and variation in observer counts of large numbers (200–6000) of densely nesting birds in vegetated situations. We placed known numbers of scaled model birds on a physical model of a wading bird colony, and allowed trained biologists to repeatedly estimate bird numbers. We

also compared true numbers with photographic counts of the same trials. The use of this approach ensured that the numbers of actual targets were known with great accuracy, that estimation accuracy could be simultaneously assessed for many individuals, that a large range of aggregation sizes could be assessed, and that the effects of counting and detection ability were both included in the error estimates.

METHODS

We constructed a scaled model of a large wading bird colony, using measurements from a representative mixed-species colony in south Florida, U.S.A. We covered a 122×144 cm sheet of 19 mm thick plywood with plastic "grass" carpet painted with flat green paint and hobby modeler's shrubs and trees. "Grass" was denuded in some areas using a small handheld torch to mimic the areas of low-growing or trampled vegetation typical of many colonies. All aspects of the model (vegetation heights and densities, size of colony, size of birds) were 0.0063 times normal size. At this scale, the eye of an observer standing above the model placed on the ground would be equivalent to an observer looking at the colony from an altitude of between 240 and 320 m (depending on height of observer), which are typical fixed-wing aircraft survey altitudes.

"Birds" were represented by alfalfa seeds painted white, corresponding to the size and rough shape of an adult White Ibis (*Eudocimus albus*). We pre-counted seeds for all trials using an agricultural seed counter. The measured accuracy of this method averaged over 98% (10 trials, actual seed number between 30 and 800).

We tested the abilities of 18 biologists from state, private, and federal natural resource agencies to estimate randomly-determined numbers of targets spread on the model. Participants were contacted directly, and were under no obligation to us or to their employers to participate in the study. Participation in the study was by informed consent only, and anonymity of results was guaranteed through our procedures (below). All participants had estimated numbers of animals on one or more occasions as part of their professional duties. Since our model could not accommodate 18 viewers at once, we conducted the experiment over three sessions between 17 November 2000 and 10 Au-

gust 2001. All sessions were identical and did not offer different treatments. Each session consisted of 20 trials each, presenting a different number of seeds for each trial. Seeds were scattered in an approximately uniform density of 10 seeds/cm² by over-laying a temporary grid of 10 cm² sections; the grid was removed before observers viewed the model. The order of presentation of trials was randomly determined, but all sessions on the different dates had the same order of presentation. One trial was omitted in Session 1 due to spillage of seeds during loading, and the last four trials were omitted from Session 3 due to deteriorating lighting conditions. All trials were conducted outdoors under shaded, ambient light.

Prior to each trial, observers were allowed to "calibrate" by viewing labeled, randomly-spaced groups of black dots on white paper representing 50, 100, 500 and 1000 targets for 2–7 min. All observers (range 5–9 per session) viewed the model by slowly walking together around it for 60 s (1 bout), to mimic actual conditions while surveying from a fixed-wing aircraft. Each trial consisted of three 60-s bouts, and observers wrote down their estimates after each bout on a standardized data sheet. Following the third bout of each trial, observers then wrote down a final, "best guess" estimate for the trial, with instructions that the final number did not need to have any relationship with the preceding three bout estimates. During each bout, we asked observers to continuously move slowly around the model; observers were also allowed to alter their "altitude" by adjusting their posture.

Following the observer sessions (range 1.75–2.50 h), all observers were asked to fill out a questionnaire concerning prior experience, and personal information such as highest education level, corrective lens use, and age. We categorized variables related to prior experience based on observer responses. The largest aggregation of animals previously surveyed was classified as small (1–900 individuals), medium (1000–9000 individuals), or large (more than 10,000 individuals). We also categorized the amount of time since last survey as recent (within 6 months), moderate (1–2 yrs), or later (more than 2 yrs). Finally, the number of previous surveys conducted by an observer was classified as few (1–50), some (100–500), or many (more than 500).

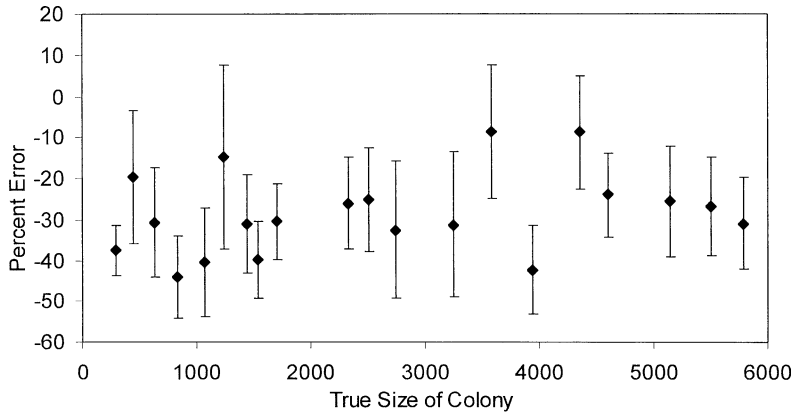


Fig. 1. Mean percent error (± 1 SE) among observers ($N = 18$) estimating sizes of simulated avian aggregations on a physical scaled model of a vegetated wading bird colony.

The "colony" was photographed following each trial in the first two sessions using a 28–200 mm zoom lens on a single-lens reflex camera with slide film. We made the aggregation of seeds fill the frame, regardless of the area occupied by the aggregation. Slides were counted at a later date by a single individual by projecting the image onto a large piece of paper (cf. 10×200 cm), counting with a single category handheld counter, and circling each dot as it was counted.

To measure observer accuracy we calculated the percent error as ((observers final colony size estimate – true bird number) / true bird number) * 100. Because over and underestimates cancel each other, we also report the absolute value of the error. To examine the relationship between colony size and ability to estimate bird number we classified the true number of "birds" in each trail as small (1–2000 birds), medium (2001–4000), and large (4001–6000). We then performed a repeated measures analysis of variance (ANOVA) with observer as a within-subject factor and colony size as a between-subject factor. Fatigue effects were examined in a correlation analysis by comparing average absolute errors for each trial against trial number.

We used the absolute value of error as a response variable to investigate the effects of previous experience, education, and corrective lenses. We performed multiple one-factor repeated measures ANOVA with observers as the within-subject factor and experience, education, and lens use as between-subject factors. We

compared age and average individual error in a correlation analysis. If variables did not meet test assumptions (i.e., normality and homoscedasticity), we used equivalent nonparametric tests. Analyses were performed with SAS software.

RESULTS

Estimation of error among observers.

The overall tendency among observers was to undercount (81% of all estimates). The mean underestimate ($N = 255$) varied from the true values by -48.61% ($SE = 1.41\%$). The mean overestimate ($N = 59$) varied from the true values by 54.92% ($SE = 7.15\%$). When total overestimates and underestimates were combined, the mean error for all estimates by all observers was -29.16% ($SE = 0.57\%$; Fig. 1). These results demonstrated that the average tendency by observers was to underestimate. Because there was canceling of over- and underestimates, we also examined the average absolute value of total observer error (49.80% , $SE = 7.54\%$; Fig. 2). This result illustrates that the average estimation of colony size was off by approximately 50%, as either an overestimate or an underestimate of the true number. For all trials, there was great variation among observers, as well as within a single observer (Figs. 1, 2). Within individuals, we also compared the sum of all true values in the series to the sum of all trial estimates. Two of the 18 individuals had "population" estimates that were greater than the sum of true values, and 16 were small-

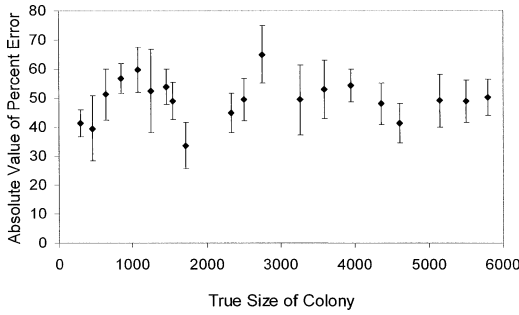


Fig. 2. Mean percent absolute value of error (± 1 SE) among observers estimating sizes of simulated avian aggregations on a physical scaled model of a vegetated wading bird colony.

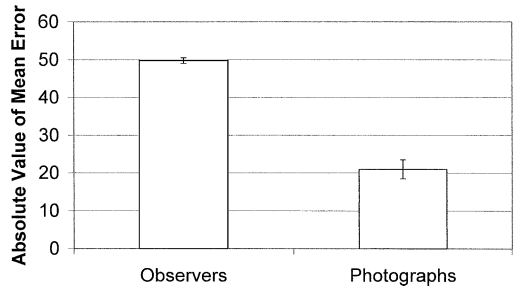


Fig. 3. Comparison between mean absolute value of estimation error using direct observation ($SE = 0.75$) and counts of photographs ($SE = 2.51$). Both kinds of estimates were derived from a physical scaled model of a vegetated wading bird colony.

er than the true values. Individual mean “population” errors over the entire trial series (mean = -27.8% of true values, $SE = 9.67\%$) were similar to those of the mean of all estimates lumped (-29.6%).

We expected that estimation error would increase as aggregation size increased (Prater 1979), but aggregation size did not have a significant effect on error, at least within the range of 250–6000 “birds” ($F_{2,262} = 0.21, P = 0.81$). Estimation ability did not significantly decrease as the trial number increased within sessions, suggesting that fatigue did not have a significant effect on estimation ability.

We found no significant effects of largest number of animals previously surveyed, date when the observer last conducted a survey, total number of surveys previously conducted, highest education level, or the use of corrective lens on estimation error (Table 1).

Error from photographic counts of seeds on the model. Counts of photographs taken of each trial during the first two sessions resulted in a mean aggregate error (over- and underestimates combined) of -13.17% ($SE = 3.65\%$). Approximately 51% of the photo

counts were underestimates. The absolute value of the mean error in photographic counts was 20.98% ($SE = 3.94\%$). Using a Spearman rank correlation test, we found a negative correlation between true seed number per trial and the percentage error of seed estimates from photographs ($r_s = -0.55, P = 0.0002$). As the colony size increased, the degree of underestimation also increased. Absolute values of mean photographic counts had a significantly lower mean error (20.98%) compared to absolute values of mean observer estimates (49.80% ; $F_{1,18} = 5.66; P = 0.03$; Fig. 3).

DISCUSSION

These results indicate that there is likely to be considerable variation among trained biologists in their ability to estimate large numbers of birds. This variation was not attributable to any of the human characteristics that we tested for, including past experience or visual impairment. This suggests that the accuracy of individual observers is inherently unpredictable, at least based on human attributes, and that direct

Table 1. Effect of experience, education, and corrective lenses on ability of biological observers to estimate simulated numbers of birds.

Factor	Categories	df	F	P
Largest number of animals counted	100's, 1000's, 100,000's	2,14	1.16	0.34
Last survey conducted	<6 months, 1–2 yrs, >2 yrs	2,15	0.22	0.80
Total number of surveys conducted	1–50, 100–500, >500	2,15	0.10	0.91
Highest education level	Ph.D., M.S., B.S.	2,15	3.17	0.07
Use of corrective lens	yes, no	1,16	0.98	0.34

measurement of bias is required to establish the accuracy of any individual.

Our results indicate that undercounts by observers were by far the most common type of error, and that averaged estimates that take into account over- and under-counts also were consistently underestimates. This is consistent with virtually all studies of human estimation abilities (Prater 1979; Erwin 1982; Kemp 1984). We therefore suggest that counts of aggregated birds in vegetated habitats from aerial or photographic surveys should usually be treated as underestimates unless evidence to the contrary can be provided.

The absolute value of the mean error among trials demonstrated that even experienced observers miscounted by 50% on average. Several studies have suggested that within individuals estimating a population of counts, canceling of over- and underestimates may occur (Prater 1979; Erwin 1982; Rodgers et al. 1995). However, our results indicate that estimates of a "population" of colonies by individual observers are virtually the same as group population estimates (-30%). This clearly suggests that biologists should not rely on canceling in large samples to reduce estimation errors.

It is important to realize that the mean errors we have expressed would be equivalent to having 18 observers each count all of the 20 colonies in our simulated survey. It is more likely that one or only a handful of observers will be involved in most real-world surveys. The variation and range in estimation error among individuals therefore becomes more interesting than the mean error. For example, our results suggest that estimates of single colonies by experienced, individual observers could have been off by as much as 70%.

These results also suggest that counts of aerial photographs may reduce estimation error by over half in comparison with aerial observer estimation. While we believe this is true, researchers should be aware that aerial photographs still yield considerable bias—in our study, an overall error of approximately -13% (with canceling effects) or 21% (mean absolute value of errors). The efficacy of aerial photography is also probably highly dependent on the situation. For example, Dolbeer et al. (1997) found that aerial photos and ground counts of Laughing Gull (*L. atricilla*) nests in New York differed by means of only 1–9%. In that study,

aerial videography was also shown to be both accurate and more cost effective than aerial photography.

Another way to reduce the effect of estimation error on survey results would be to develop a corrected estimate based on modeling the error (Dolbeer et al. 1997). We have demonstrated that much of the error in estimates is likely to be due to variation in estimation ability among observers, and it seems that a correction factor would therefore have to be derived from estimates of individual bias. This means that the bias of observers would need to be measured individually through some technique that both mimics the field situation, and allows some true numbers of targets to be compared with the estimates. It is unclear, however, whether the estimation abilities of individuals are stable over time. This would be a key assumption for observers that perform a series of surveys. As far as we are aware, there have been no tests of this assumption over any time scale.

The use of a time series of surveys may be a powerful tool for identifying trends in population fluctuations and for measuring population responses to environmental change or management. However, observers are quite likely to have changed over time, especially if the series spans many years. Deriving estimation errors for those past observers may not be possible, and assuming an average error for them may be indefensible given the level of individual variation we have demonstrated. The magnitude of individual differences in estimation error therefore seems to offer a strong potential to confound the apparent trends in a time series (Cobb et al. 1995). For this reason, we recommend caution when comparing surveys done by different individuals, and urge that researchers devote more attention to measuring observer error.

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