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Comparison of sampling strategies to estimate abundance of double-crested cormorants in western Mississippi

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Abstract: We compared 2 sampling strategies designed to estimate abundance of double-crested cormorants (*Phalacrocorax auritus*, hereafter cormorants) on aquaculture ponds in western Mississippi. Cormorants are a major predator of cultured channel catfish (*Ictalurus punctatus*) in this region; thus, estimating cormorant abundance is needed to better determine their economic impact. We independently designed a species-specific survey (i.e., cluster sampling) and a general survey (i.e., transect sampling) based on robust probability sampling theory to estimate abundance of this target population. During winters 2002–2003 and 2003–2004, we conducted 8 pairs of surveys and compared estimates of cormorant abundance and associated precision using conventional paired *t*-tests and complimentary equivalency tests. Abundance estimates from sampling methods did not differ given a minimum important effect size of 1,420 individuals. Precision of estimates for both survey protocols was poor (the coefficient of variation [CV] was 39.5% for cluster samples and 45% for transect samples), and we were unable to definitively conclude if precision was similar between sampling methods (due to low sample size and high variability). We found sample sizes must increase 222% for cluster sampling and 538% for transect sampling to detect a 15% change in abundance on average. Thus, neither method met our goals of detecting a given effect size at a desired level of precision. We recommend investigating additional sampling designs that may provide precise estimates of abundance more efficiently than the methods compared in this study.

Key words: abundance, aerial survey, aquaculture, bird depredation, cluster sampling, double-crested cormorant, estimation, human–wildlife conflicts, Mississippi, *Phalacrocorax auritus*, sampling design

The double-crested cormorant (*Phalacrocorax auritus*, hereafter cormorant) is considered a major avian predator of channel catfish (*Ictalurus punctatus*) raised for commercial production in Mississippi (Wywialowski 1999). In the past 20 years, cormorant abundance has increased dramatically in the United States, and its winter distribution has shifted to include western Mississippi (Hatch and Weseloh 1999). These factors and diurnal and gregarious feeding behaviors of cormorants have led to their distinction as the top nuisance species for aquaculture producers (Glahn and Stickley 1995). Past research on cormorant depredations of catfish focused on food habits, bioenergetics modeling, night-roost surveys, and extrapolation of these data to estimate potential economic losses (Stickley et al. 1992, Glahn and Brugger 1995, Glahn et al. 1996, Glahn et al. 1998). However, distribution and abundance of cormorants using aquaculture facilities have not been determined, and this information is needed to more precisely determine the economic impacts of the birds to the catfish aquaculture industry, which Dorr (2006) estimated in western Mississippi at $14 million in 2000–2001 and $10 million in 2003–2004. Furthermore, survey data could be used to evaluate management efforts designed to deter cormorants from using aquaculture ponds during winter or possibly population reduction efforts on breeding grounds.

Estimating abundance by aerial quadrat or transect sampling has an extensive history and prominent role in wildlife conservation and management (Lancia et al. 1996). Aerial survey

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practitioners must make multiple decisions regarding sampling protocols, including basic sampling design, size and shape of sample units, and method of estimation. Care must be given in choosing an appropriate sampling scheme because these decisions influence precision and bias of estimated parameters. Individuals within populations are often spatially aggregated, making precise estimation of abundance challenging, and in many instances an efficient and effective sampling method is not apparent, especially when prior knowledge of the spatial distribution of the target population is variable or unknown (Krebs 1999).

Researchers have responded by comparing sampling methods to determine the most precise and cost-effective approaches. Two common methods are to simulate a population and conduct varied sampling scenarios (Christman 1997, Brown 1999, Khaemba et al. 2001) or to analyze a data set collected in the field using multiple techniques (Hone 1988, Storm et al. 1992, Sherman et al. 1995, Walter and Hone 2003). Both methods assist in determining proper sampling methodology, but each has inherent weaknesses. Simulated populations lack realism, and only limited comparisons can be made when analyzing a data set with multiple methods. Few studies have directly tested competing methods using independently obtained samples from the same target population. This direct comparison method is advantageous for choosing a sampling protocol because it lacks the limitations of the previously described methods (Pople et al. 1998, Jachmann 2002).

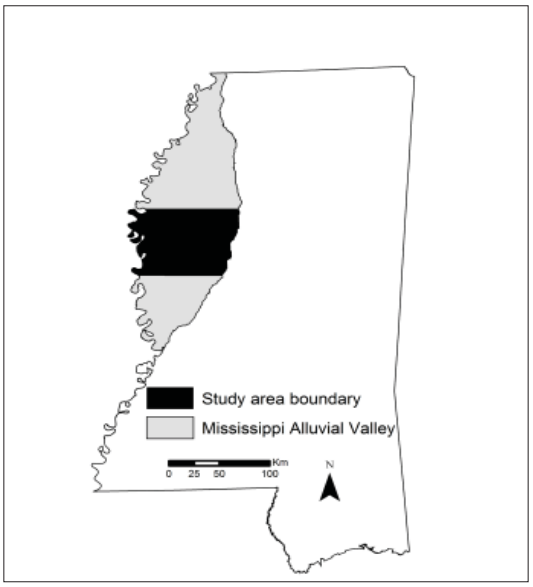

Figure 1. Study area boundary for comparison of sampling methods to estimate abundance of double-crested cormorants within the Mississippi Alluvial Valley of Mississippi, USA.

In this study, we sampled the same target population of cormorants employing 2 independent sampling strategies over multiple sampling periods. We developed a species-specific method with cormorants as the primary species of interest and integrated the spatial distribution of aquaculture ponds (the habitat of interest) into the sampling protocol. Furthermore, we developed a general survey method to estimate abundance of multiple waterbird species; thus, we incorporated all wetland types in our sampling procedure. Our objective was to compare abundance and precision estimates of these 2 survey protocols to determine if a general aerial survey could estimate cormorant abundance with similar precision as a species-specific survey. If possible, a general waterbird survey could replace numerous surveys each designed for 1 species, allowing public and private organizations to collaborate and combine resources to monitor abundances of multiple species.

Study area

We studied the winter abundance of cormorants in a 680,000-ha region in western Mississippi (Figure 1). This area is located in the Mississippi Alluvial Valley (MAV), the floodplain of the Mississippi River, and is the primary catfish aquaculture-producing area in the United States. Aquaculture began in Mississippi in 1965 and soon became a major component of the economic landscape of the region (Wellborn 1987). As of 2000, this region accounted for 70% of total catfish production in the United States (U.S. Department of Agriculture 2000). Cormorants use various types of habitats during winter in western Mississippi, including cypress swamps, oxbow lakes, and bayous for roosting, and lakes, rivers, and aquaculture ponds for foraging (Jackson and Jackson 1995).

Methods

Species-specific survey procedures

We developed a species-specific survey based on a stratified cluster sampling design (hereafter, cluster sampling; Thompson 1992). To employ cluster sampling, we partitioned the study area into 2 strata using 90.85^{0}W longitude as the delineation between east and west strata. We stratified because an additional component of the research was to compare cormorant abundance between strata. We divided the study area into square quadrats of 259 ha. All quadrats containing at least 1 catfish pond were included in the sampling frame of primary sampling

units. We designated catfish ponds as secondary sampling units; thus, if a primary sampling unit was selected, all ponds within it would be sampled. We selected a random sample of primary sampling units at the start of the project and sampled the same units for each survey.

We conducted cluster-sampling surveys using a Cessna 172, fixed-wing aircraft to sample selected primary and secondary sample units over an 8-hr survey period. Flights originated from the same location, but we chose randomly the order quadrats were flown to reduce potential bias resulting from diurnal patterns of cormorant-feeding behavior. The pilot circled primary sample units at an altitude of 100 m, and the observer counted all cormorants observed in each secondary sample unit (i.e., pond).

We used the SURVEYMEANS procedure to estimate abundance of cormorants in the study area for each survey (SAS Institute 1999). This method used sample weights derived from sample-selection probabilities to estimate abundances. We specified a stratified cluster-sampling design in the SURVEYMEANS procedure, and it used a Taylor-series expansion to estimate the variance associated with abundance estimates (SAS Institute 1999). This method also included a finite population correction factor by specifying the total number of clusters within strata.

General survey procedures

We developed a second, more general survey based on a stratified random sampling design with transects as sampling units (hereafter, transect sampling) to compare with the cluster sampling approach. We divided the study area into 5 strata based on expected distribution of an abundant duck species (i.e., mallard [*Anas platyrhynchos*]). Initially, the entire MAV within Mississippi was our study area for this sampling design, but we removed all transects sampled outside of the current study area to allow for comparison with the cluster-sampling methodology (Figure 1). Thus, transects used in this study were flown nonsequentially over multiple days (Table 1). We designated transects as the sample unit, positioned transects in an east-west orientation, and placed them 250 m apart throughout the entire study area. Before each survey, we randomly selected transects with replacement and probability proportional to transect length (Caughley 1977, Reinecke et al. 1992). We allocated sampling effort (i.e., cumulative length of transects) to strata using the Neyman method (Thompson 1992). We constrained adjacent transects from being selected to reduce the chance of double counting individuals (Reinecke et al. 1992).

During aerial surveys, the pilot navigated transects using a global positioning system (GPS) receiver. While the observer collected data, the pilot did not deviate from preselected transects and maintained an altitude of 150 m. The observer was seated in the front seat next to the pilot and recorded all cormorants within a 250-m transect band delineated with markers on windows and wing struts (Norton-Griffiths 1975). We estimated cormorant abundance by inputting transect-specific counts and sampling weights for each transect into SURVEYMEANS (SAS Institute 1999). We specified stratification to facilitate variance calculations and did not include finite population correction because sample units were chosen with replacement.

Data analysis

We estimated cormorant abundance, a standard error (SE), and a coefficient of variation (CV) for each sampling method and survey period. We paired estimates from sampling methods by dates surveys were conducted (Table 1) and compared estimates of abundance and CV using paired *t*-tests. We analyzed CV instead of variance estimates because the CV provides a measure of the relative variability of an estimate regardless of the estimate itself. Further, we derived a sample correlation coefficient for transect- and cluster-sampling estimates of abundance to determine if both detected a similar trend in population dynamics of cormorants in western Mississippi (CORR procedure, SAS Institute 1999). Due to our relatively small number of paired surveys ($n = 8$), we established an a priori α-value of 0.10 to increase the statistical power of tests (Tacha et al. 1982).

Table 1. Dates aerial surveys were conducted to estimate abundance of double-crested cormorants using cluster and transect sampling in western Mississippi, winters 2003–2004 and 2004–2005.

Survey	Year	Dates	
		Cluster sampling	Transect sampling
1	2003	November 11	November 19–21
2	2003	December 8	December 2–6
3	2003	December 27	December 18–22
4	2004	January 11	January 5–9
5	2004	January 20	January 26–30
6	2004	February 3	February 8–13
7	2005	February 4	January 26–30
8	2005	February 18	February 8–13

Complementary to traditional paired *t*-tests, we performed equivalency tests if we failed to reject null hypotheses of no difference. Equivalency tests reverse traditional null and alternative hypotheses where the null hypothesis represents a difference between the observed value at a predetermined level set by the researchers to describe practical equivalence or biological significance (Parkhurst 2001). Conversely, the alternative hypothesis corresponds to the situation where the observation is within the bounds of the predetermined level or sufficiently equivalent to zero. Equivalency tests paired with traditional hypothesis tests allowed us to determine if estimates from survey techniques were statistically different, similar, or uncertain due to high variability and low sample size (Parkhurst 2001).

We used the two 1-sided test procedure (Schuirmann 1987) and set the equivalency interval value at ±11.0% for the CV test and ±1,420 individuals for difference in estimates of abundance (see justification below). We calculated 100(1-2α)% confidence intervals about expected mean differences, and if these intervals were completely contained within the bounds of our equivalency value, we rejected the null hypothesis of inequivalence (McBride 1999). Determination of an equivalence interval value can be interpreted as a minimum important effect size and is a decision investigators must make based on their knowledge of the subject matter (Parkhurst 2001). Our choice of an interval for the test of cormorant abundance was derived from our initial inspection of precision of the abundance estimates. Specifically, we knew estimates were relatively imprecise; thus, we decided on a value that corresponded to the average abundance of both survey methods across all survey time periods (mean abundance = 6,173) and the mean of the most precise survey from each method (mean CV= 23.0%). We determined that the product of these values (i.e., 1,420) would represent our most optimistic margin of error and should be used to describe practical equivalence. To determine critical limits for precision (as measured by CV), we employed a procedure using a value relative to the standard deviation of the mean difference in CV (SD = 22.0%). Welleck (2003) recommended for a paired *t*-test that a value of 50% of the SD could be used to represent a liberal critical value (i.e., 11.0%). Due to our small sample size, we decided to use this recommendation as the critical value for this test.

For all surveys, we determined sample sizes necessary to detect a 15% change in abundance with α-level of 0.05 and β = 0.80. Sample size calculations for complex designs are challenging; thus, we employed a multi-step procedure for determining needed sample sizes (e.g., Stafford et al. 2006). First, we determined the design effect (*dêff*) for the specific sampling design. The design effect is the variance of an estimate derived from the sampling design of interest divided by the variance derived from simple random sampling (Cochran 1977). We used the *dêff* and information from specific surveys to determine estimated sample sizes by:

$$n = \hat{deff}\ [(z_{\alpha/2} + z_{\beta})^2\ (\sigma_0^2 + \sigma_1^2)\ /\ (\lambda_0 - \lambda_1)^2]$$

where n is the number of clusters or transects required, *dêff* is the design effect, $z_{\alpha/2}$ and z_{β} are standard normal values corresponding with the a priori desired levels of significance and power, respectively, σ_0 and σ_1 are the baseline and expected standard deviations, and λ_0 and λ_1 are the baseline and expected estimated numbers of cormorants, respectively (Hayes and Bennet 1999). The expected standard deviation (σ_1) for future surveys was calculated as the ratio of the observed total to observed standard deviation applied to the expected 15% change in estimated total (i.e., expected λ_1; Cochran 1977, Hayes and Bennet 1999).

Results

We conducted 6 cluster- and 6 transect-sampling surveys between November 2003 and February 2004 and completed 2 cluster- and 5 transect-sampling surveys between November 2004 and February 2005. Inclement weather caused fewer completed surveys in winter 2004–2005; hence, we used the 8 completed pairs of surveys across both years as our sample. We conducted paired surveys as close together

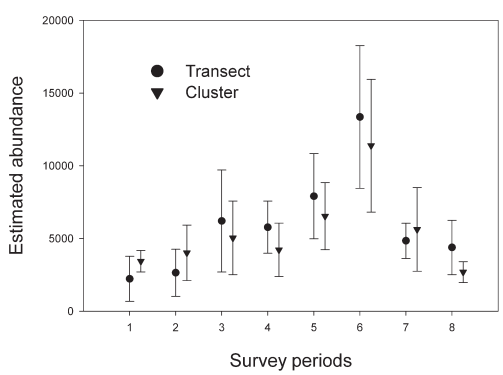

Figure 2. Comparison of abundance estimates (±1 SE) of double-crested cormorants from stratified transect sampling and stratified cluster sampling for 8 survey periods in western Mississippi during winters 2003–2004 and 2004–2005.

in time as weather conditions allowed, and mean time interval between pairs of surveys was 4.8 days (SD = 2.0) with a maximum separation of 8 days (Table 1). Using transect sampling, we estimated between 2,224 (SE = 1,545) and 13,353 (SE = 4,907) cormorants on catfish ponds in our study area during winters 2003–2004 and 2004–2005 (Figure 2). Overall, transect-sampling estimates were relatively imprecise with an average CV of 44.6% (SE = 5.9%), and CVs generally decreased with increasing cormorant abundance. We estimated between 2,685 (SE = 720) and 11,380 (SE = 4,563) cormorants on catfish ponds using cluster sampling, and CV generally did not decrease as cormorant abundance increased. Estimates of abundance from cluster sampling also were imprecise (mean CV = 39.5%), but precision was slightly less variable than transect sampling (SE = 4.2%).

We failed to reject the null hypothesis of no difference in precision between sampling methods (mean CV_{diff} = 5.1%, t_7 = 0.66, P = 0.531). The confidence interval for the corresponding equivalence test was -5.9 – 16.1%; thus, we also failed to reject the null hypothesis of inequivalence (i.e., 16.1% ≥ 11.0%).

Abundance estimates from cluster sampling generally were less than those from transect sampling (mean difference = 549), but the null hypothesis that the difference was due to random variation could not be rejected (t_7 = 1.10, P = 0.308). We rejected the null hypothesis of inequivalence because the confidence interval for our equivalence test (-156–1,259) was inside the bounds of our critical values for abundance (i.e., -1,420–1,420). Abundance estimates from both methods were positively correlated (r = 0.920, P = 0.001; Figure 2).

Transect-sampling effort varied among surveys, and mean number of transects flown was 32 (SD = 5.6). Given a flight speed of 160 km/hr, transects located within the study area were completed in an average of 7.7 (SD = 0.9) hours, and the number of transects flown was positively correlated with flight time (r = 0.889, P = 0.003). We failed to reject null hypotheses of no correlation between the number of transects flown (r = 0.062, P = 0.883) or flight time (r = -0.155, P = 0.713) and CV for given surveys. Hence, differences in survey effort did not influence precision over the range of effort in our study. In comparison, we sampled 65 sample units during each cluster-sampling survey and completed surveys in an average of 6.9 (SD = 0.2) hours.

Sample sizes needed to detect a 15% change in cormorant abundance varied among surveys and between sampling designs. We determined that 209 clusters on average should be sampled to detect this change. This number was a 222% increase in sampling effort compared to the 65 clusters sampled during each flight. For transect sampling, we needed to sample 204 transects on average to detect a 15% change (i.e., 538% increase in sampling effort).

Discussion

We generated similar estimates of cormorant abundance using both cluster and transect sampling in western Mississippi. Additionally, abundances estimated by each method were positively correlated in time; hence, both surveys revealed the same pattern of seasonal use of catfish ponds by cormorants (Figure 2). Therefore, cluster or transect sampling could be used to discern seasonal fluctuations of cormorant abundance.

Demarcation of sampling units to construct a sampling frame is a primary decision when sampling parameters of a population (Caughley 1977). In survey protocols that we contrasted, sampling units were of differing sizes and shapes. Other studies have compared sampling protocols with differing sample-plot shapes and determined transect-shaped units produced biased results. Johnson et al. (1999) simulated samples of wetlands in the Prairie Pothole Region in South Dakota using both square quadrats and transects. Estimates of pond abundance from transect sampling were positively biased compared to those from square quadrats because of the increased probability of double counting wetlands with transect sampling. Pojar et al. (1995) reported that sampling pronghorns (*Antilocapra americana*) with fixed-width transects produced lower density estimates of pronghorn than did square quadrats. They attributed this difference to greater observer bias associated with transect sampling. We found no bias between square quadrats and transects in our study. We potentially reduced incidences of double counting individuals with transect sampling by not sampling adjacent transects. As with all aerial surveys, we believe visibility bias occurred during surveys regardless of methodology; thus, we speculate this bias was equivalent between survey methods. However, we cannot assess absolute bias of either method because we did not know true abundances of cormorants.

We anticipated cluster sampling would outperform transect sampling with respect to precision because we designed the cluster-sampling protocol to specifically target cormorants

occupying catfish ponds, whereas we designed the transect-sampling protocol to estimate abundance of multiple waterbird species. We were unable to determine if precision was significantly different or similar based on our results. Specifically, we failed to reject either a null hypothesis of no difference or difference between sampling methods due to the small sample size and relatively large variation in paired differences in precision. From the equivalency test, we could conclude precision was similar if we selected a critical value >16.1% (i.e., upper bound of 95% CI of mean CV_{diff}), but we believe this difference was too great to be determined sufficiently similar.

Regardless, estimates of cormorant abundance from both methods did not meet a criterion commonly set for large-scale surveys of waterfowl and other waterbirds (i.e., CV ≤ 15%; Conroy et al. 1988, Reinecke et al. 1992). Our sample-size simulations suggested a considerable increase in sampling effort was needed to detect a 15% change in cormorant abundance for either survey. This sampling intensity may not be logistically or economically feasible; hence, we suggest other sampling protocols be considered. Adaptive sampling is a potential solution for estimating cormorant abundance (Thompson 1992). Based on a simulation study, Khaemba et al. (2001) reported adaptive sampling was the most efficient sampling design for aggregated distributions of African elephants (*Loxodonta africana*) and Burchell's zebras (*Equus burchelli*). Similarly, Christman (1997) determined adaptive cluster sampling was most efficient for simulated populations with a high degree of aggregation, whereas balanced sampling excluding contiguous units was more efficient under a variety of spatial aggregations. Researchers should conduct field evaluations of these and other sampling designs to determine efficient and effective sampling alternatives. While other sampling techniques could be more efficient, we recognize that high variability may be inherent to cormorants aggregated on catfish ponds in western Mississippi during winter. Therefore, no method may significantly improve precision of estimates, and the only options would be to relax conditions for detectable effect size, set more liberal Types I and II error probabilities, or select some acceptable combination of these factors that meets management or research goals.

Direct comparison of point and precision estimates was a useful tool for comparing survey strategies, but we must acknowledge certain limitations. For example, we did not estimate visibility bias for either sampling method. Visibility bias arises from failure to observe all animals within sampled areas and is a primary source of error in aerial surveys (Pollock and Kendall 1987). We believe our comparison between survey methods was valid because estimates from each method were not corrected; thus, each estimate can be regarded as a conservative estimate of abundance or an index (e.g., Conroy et al. 1988, Reinecke et al. 1992). Different observers conducted each survey method; hence, observer differences and sampling protocol were confounded. Further, paired surveys were not conducted simultaneously, and slight temporal differences in abundance during paired surveys would have introduced unexplained variation or possibly biased results. Finally, sampling effort for transect sampling was not the same for all surveys. We found this difference did not influence precision but may have introduced uncontrolled variation potentially leading to inconclusive results about the comparison of precision between sampling methods.

Cormorants over a pond.

Management implications

Of the 2 methods compared in our study, both generated comparable estimates of abundance and had similar costs (expressed as flight time). We recommend cluster sampling to estimate cormorant abundance on catfish ponds, assuming it is the only parameter of interest. Comparison tests of precision between methods were inconclusive; therefore, we make this recommendation because observed precision of cluster sampling was less variable (i.e., SE was 40% greater for transect than cluster sampling). If transect-sampling surveys were conducted to estimate waterbird abundances, cormorant numbers within transects should be noted and abundance estimates incorporated into management planning. This extra information could be recorded without additional cost and would be the preferred method if transect-style surveys were planned to estimate abundance of other species. However, managers should not

use either method during the time period of our study (i.e., late November to early February) unless sampling effort is increased based on our sample size estimates. Other research on this cormorant population suggested abundance estimates were more precise during late February to April compared to late November to early February; thus, a species-specific survey could be conducted at this time if abundances of other waterbird species are of little interest (B. S. Dorr, U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, unpublished data).

More generally, our results have implications for sampling practitioners interested in estimating parameters of spatially clumped populations. Specifically, should habitat-specific or general survey methods be employed? In this study, we considered cluster sampling as habitat specific because only sample units with catfish ponds were included in the sampling frame. Populations inhabiting islands of habitat would represent a similar sampling challenge. We found abundance estimates between protocols were similar; hence, either method could be used to index abundance. This similarity between estimates is an important conclusion because a habitat-specific survey might not be an option for a spatially clumped population if locations of habitat patches are unknown or habitat patches are too small and numerous. Further, there may be an opportunity to collapse multiple existing surveys into a single multi-species survey; thus, a more general survey integrating multiple goals and species distributions would be needed (Olsen et al. 1999). Our results suggested abundance estimates would not be biased, but overall sampling effort may need to be increased to facilitate a general survey strategy.

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