Tools and Technology Article

Evaluation of Aerial Cluster Sampling of Double-Crested Cormorants on Aquaculture Ponds in Mississippi

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ABSTRACT Concern over increasing numbers of double-crested cormorants (*Phalacrocorax auritus*) and their impacts on channel catfish (*Ictalurus punctatus*) aquaculture has resulted in increased need for quantitative information to develop and evaluate depredation management efforts. We evaluated aerial surveys in a stratified cluster sampling (SCS) design to estimate and monitor abundance of cormorants on catfish aquaculture ponds in the Yazoo River Basin of Mississippi, USA (hereafter Yazoo Basin). Twice monthly abundance estimates and coefficient of variation during winter averaged 8,128 ($n = 29$, SE $= 1,233$) and 33% ($n = 29$, SE $= 0.02$), respectively. Counts of cormorants on catfish aquaculture ponds between survey years were correlated ($r = 0.87$, $n = 28$). The correlation between diurnal counts of cormorants on ponds and cormorant night roost counts was 0.64 in 2000–2001 and 0.58 in 2003–2004 ($n = 20$ in both years). A priori estimates of sample size indicated an average increase in sampling effort of 39% during peak periods of cormorant use would be necessary to detect a ±15% change in cormorant abundance on aquaculture ponds at $\alpha = 0.05$ and $\beta = 0.80$. The sampling design we used has the potential to be an effective tool for providing quantitative information on cormorant abundance on catfish aquaculture ponds in the Yazoo Basin. However, increased sampling effort would be necessary to obtain desired levels of precision. The SCS design we evaluated represents only one of many possible survey methods, and we recommend additional evaluation of this method and related survey methods. (JOURNAL OF WILDLIFE MANAGEMENT 72(7):1634–1640; 2008)

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There has been mounting concern among catfish producers with increasing numbers of double-crested cormorants (*Phalacrocorax auritus;* hereafter cormorants) and their potential impacts on channel catfish (*Ictalurus punctatus*; hereafter catfish) aquaculture (Glahn and Stickley 1995, Glahn et al. 2000*a*). Confirmation of cormorant impacts to aquaculture has been manifest in various local and regional depredation management efforts (Glahn et al. 2000*b*). This concern has resulted in changes to management policy at the federal level, including establishment of the 1998 Depredation Order specific to aquaculture in 13 states (United States Fish and Wildlife Service [USFWS] 1998). In addition, the 1998 rule was expanded in 2003, establishing a Public Resource Depredation Order to allow various agencies to conduct cormorant control for the protection of public resources in 24 states including Mississippi, USA (USFWS 2003). Glahn et al. (2000*b*) suggested that localized controls in the Yazoo Basin were becoming less effective because of increasing cormorant numbers and that an effective management strategy would include large-scale population management. Glahn et al. (2000*b*) also suggested the necessity of efficient cost-effective population estimation techniques for monitoring and evaluating management efforts.

Monitoring status and trends of natural resources is often conducted by sample surveys because complete censuses are often not feasible (Olsen et al. 1999). Sample surveys have been developed for various species and ecological systems ranging from land-use patterns to estimating sizes of various wildlife populations (Conroy 1988, Smith 1995, Nusser et al. 1998, Link and Sauer 1999). Effective surveys link quantitative data on resource status and trends to decision-making processes for management of resources (Nichols et al. 1995). The importance of this informational link is reflected in the incorporation of surveys in large-scale conservation and management initiatives such as the North American Waterfowl Management Plan and North American Bird Conservation Initiative (International Association of Fish and Wildlife Agencies 2004, USFWS et al. 2004). Currently no survey of this scale exists to link cormorant use of aquaculture with regional level management. Our objectives were to estimate abundance of cormorants on aquaculture ponds in the Yazoo Basin using aerial surveys deployed in a random stratified cluster sampling (SCS) design. We also determined whether methods for estimating abundance of cormorants were sufficiently precise (±15%) to detect changes in cormorant abundance.

STUDY AREA

The Yazoo Basin watershed covered about 34,590 km^2 of northwestern Mississippi and was the state's largest drainage basin. Approximately 65% of the total acreage, production, and associated value of catfish produced in the United States occurred within the 16,000-km^2 Mississippi Delta portion of the Yazoo Basin (Hargreaves and Tucker 2004; Fig. 1).

METHODS

We sampled at randomly selected clusters of catfish ponds in approximately 258,000 ha of the primary aquaculture producing area of the Yazoo Basin (Fig. 1). We established

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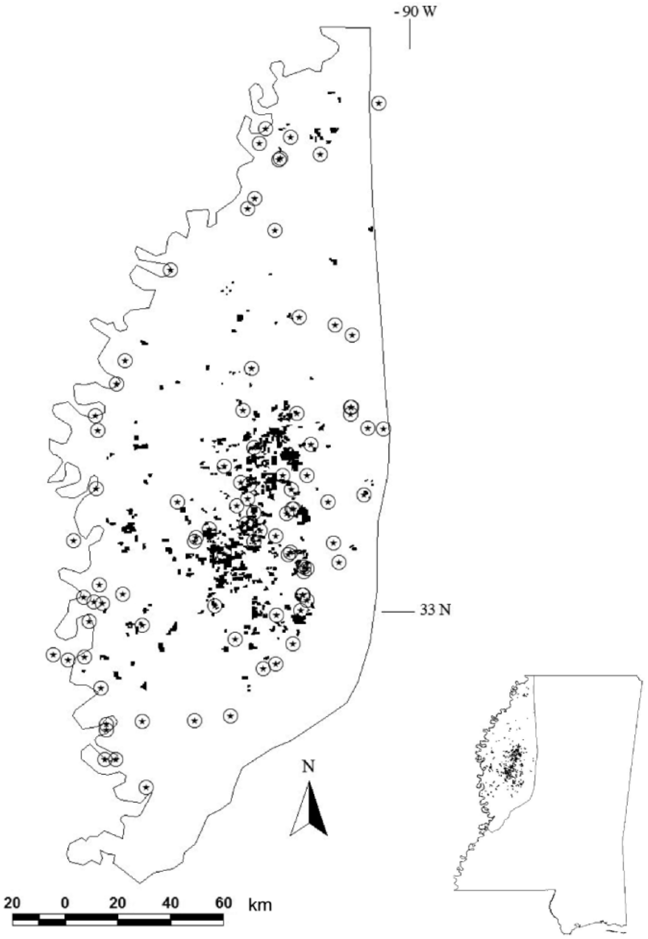

Figure 1. Yazoo River Basin of Mississippi, USA. Black shapes represent known extent of catfish aquaculture and centered circles represent known double-crested cormorant night roost locations surveyed during the winters (Oct–Apr) 2000–2001 and 2003–2004.

Figure 2. Study area for estimating distribution and abundance of double-crested cormorants in the primary aquaculture producing area of the Yazoo River Basin of Mississippi, USA. Bounded areas represent river and interior regions; shaded areas represent clusters of catfish aquaculture sampled in winter (Oct–Apr). Vertical bars represent clusters sampled in winter 2000–2001; horizontal bars represent clusters sampled in winter 2003–2004; cross-hatched areas represent clusters sampled in both winters.

aerial surveys to provide an estimate of mean and total number of cormorants on clusters. We used SCS to estimate cormorant occurrence and abundance within the sample frame (Christopher et al. 1986). The sample frame contained approximately 67% of the total water surface area in production (National Agriculture Statistics Service [NASS] 2004). We defined clusters (primary sampling units) as all aquaculture ponds within a given United States Geological Survey (USGS) land survey section (Fig. 2). We determined clusters by overlaying USGS land survey section polygons (1993; 7.5-minute quadrangle) over a Geographic Information System (GIS) coverage of ponds in the Yazoo Basin (Landsat L7, Enhanced Thematic Mapper, ortho-rectified, terrain corrected, ±15-m resolution) provided by Ducks Unlimited Inc. (Memphis, TN). We considered a pond (secondary sampling unit) within a cluster if >50% of the pond was within the section. We assumed clusters of ponds to be representative of ponds on individual aquaculture farms. During aerial surveys, the pilot circled selected clusters at an altitude of 100–150 m above ground level. The observer counted and recorded all cormorants observed in each pond and we surveyed all ponds in each cluster. Cormorants typically respond to the aircraft by cessation of foraging and alert behavior until the aircraft has passed. Thus undercounting due to diving behavior was not expected.

Glahn et al. (1995) reported cormorants that roosted on or near the Mississippi River had a lesser percentage of catfish in the diet than cormorants that roosted in the interior of the Yazoo Basin. Because these factors could influence abundance estimates, we stratified cluster sampling by river and interior regions (Fig. 2). We considered all clusters west of longitude 90.85°W to be in the river region and we considered clusters east of this longitude to the Loess Bluffs to be in the interior region (Shelford 1963, Mott et al. 1998, Tobin et al. 2002). From the GIS coverage of these ponds in the Yazoo Basin we randomly selected 20% of identified clusters from each region for sampling. During surveys, we counted the total number of cormorants on all catfish ponds within each cluster. We determined a visibility correction factor by taking a sample ($n = 34$) of digital photographs of ponds with cormorants present. We used the mean of the ratio of paired verified to observed counts to adjust observed counts. We spatially sampled clusters between regions to maximize independence and reduce double-counting of cormorants between regions by separating stratified regions by mean foraging distance (24.2 km) as reported by King et al. (1996).

We flew 2 surveys per month from October 2000 to April 2001 and October 2003 to April 2004, except for October 2000 in which we flew an additional pilot survey (Dubovsky and Kaminski 1987, Dubovsky et al. 1988). This October to April period encompassed most of cormorant winter movements through the Yazoo Basin. Each flight took approximately 8 hours to complete. Flights were limited to <8 hours to complete counts in one day due to logistics and to minimize double counting of cormorants within the survey area. Sunrise varied by <1 hour over the study area between 1 October and 30 April so we began each survey at approximately 0800 hours, weather permitting, and shifted it 1 hour for daylight saving time.

We used PROC SURVEYMEANS (SAS Institute 1999) to estimate survey mean, sum, and coefficients of variation for each survey flown. For cluster sampling, PROC SURVEYMEANS uses Taylor series linearization to estimate variances, which obtains a linear approximation for the estimator and then uses the variance estimate for this approximation to estimate variance of the estimate (Woodruff 1971, SAS Institute 1999). We derived sample weights from sample selection probabilities to estimate parameters for survey data (SAS Institute 1999). In this case, the sample weight was the inverse of the probability of selection (i.e., 1/0.20) within each region. We used the domain option in PROC SURVEYMEANS to generate mean counts per cluster for each region averaged over all surveys within a given year.

We evaluated the SCS aerial survey design with respect to design effects and generated a priori the sample size necessary to achieve a target level of precision with a given allowable error. Efficiency of complex sample designs is typically compared to the performance of simple random sampling (SRS; Kish 1965). We evaluated the design effect (*dêff*) of the SCS design to SRS by calculating a *dêff* ratio (Kish 1965, Cochran 1977). The *dêff* is the ratio of the variance of the estimated parameter (e.g., cormorant counts) of the implemented design to the variance expected with SRS (Kish 1965). A *dêff* coefficient ≤1.0 means the sampling design is equivalent to or more precise than SRS. A *dêff* for cluster sampling ranging from 1 to 3 is considered reasonable (Shackman 2003). We calculated the *dêff* ratio for SCS using the variance of the estimated mean from PROC SURVEY MEANS and variance of the mean for SRS using PROC MEANS with observations weighted to account for effects of clustering and stratification (Verma et al. 1980). We could then use the *dêff* to adjust sample size estimation from simpler formulas to account for design effects (Kish 1965, Cochran 1977).

Criteria for precision commonly set for large-scale surveys of waterbirds suggest coefficients of variation of 15% (Conroy et al. 1988, Reinecke et al. 1992). Therefore, we estimated a priori sample sizes necessary to detect a 15% change in total numbers of cormorants at $\alpha = 0.05$ and $\beta = 0.80$ (Cohen 1977) for each survey period as given by:

$$c = d\hat{e}f\!f\,[(Z_{\alpha/2} + Z_{\beta})^2(\sigma_0^2 + \sigma_1^2)]/(\lambda_0 - \lambda_1)^2 \qquad (1)$$

where c is the number of clusters required; *dêff* is the design effect; $Z_{\alpha/2}$ and Z_{β} are the a priori desired levels of significance and power $(1 - \beta)$, respectively; ${\sigma_0}^2$ and ${\sigma_1}^2$ are the baseline and expected standard deviations, respectively; and λ_0 and λ_1 are the baseline and expected estimated numbers of cormorants, respectively (Magnani 1997, Hayes and Bennet 1999). We used the average of the 2 years of sampling effort as the baseline total and standard deviation for estimating sample size of future surveys. Because variation in future surveys is unknown, we used the ratio of variation in counts to total counts from observed surveys as the estimated variation for future surveys. We calculated the expected standard deviation as the ratio of the observed total to observed standard deviation applied to the expected change (i.e., ±15%) in estimated total (Magnani 1997, Hayes and Bennet 1999).

We flew aerial surveys within 24 hours of United States Department of Agriculture (USDA) Wildlife Services-Mississippi (WS-MS) night roost surveys (weather permitting) to evaluate distribution of cormorants relative to active night roosts. Cormorant night roost counts provided a total count of cormorants for the entire Yazoo Basin. Counts of cormorants on ponds provided a measure of the total number of cormorants within the region that may be using aquaculture. We conducted simple Pearson correlations between counts of cormorants in night roosts and on catfish ponds within and between years to determine whether abundance estimates of cormorants on catfish aquaculture ponds and cormorant roost counts were correlated.

RESULTS

We flew 15 aerial surveys from 10 October 2000 to 17 April 2001 and 14 surveys from 15 October 2003 to 20 April 2004. In 2000–2001, we sampled 66 clusters, 58 from the interior and 8 from the river region. We dropped one cluster in the interior region because ponds were not in production. In 2003–2004, we sampled 65 clusters, 58 from the interior and 7 from the river region. We dropped one cluster each in the interior and river regions because ponds were not in production. We adjusted sample weights accordingly. In both survey years clusters averaged 19 ponds per cluster. Twenty total aerial night roost surveys were flown by WS-MS, 10 in each year.

Total counts of cormorants from night roost surveys conducted by WS-MS over both years for the Yazoo Basin ranged from 1,248 to 81,873 ($n = 20$, $\bar{x} = 33{,}874$, SE = 5,230; Fig. 3). Verification of observed cormorant pond counts from aerial photos indicated observed counts underestimated actual numbers verified by digital photography by a mean ratio of 1.15 ($n = 34$ pairs, SE = 0.07). We adjusted individual cormorant pond counts upward accordingly. Total estimated counts of cormorants on catfish ponds within the sample frame ranged from 903 to 24,569 ($n = 15$,

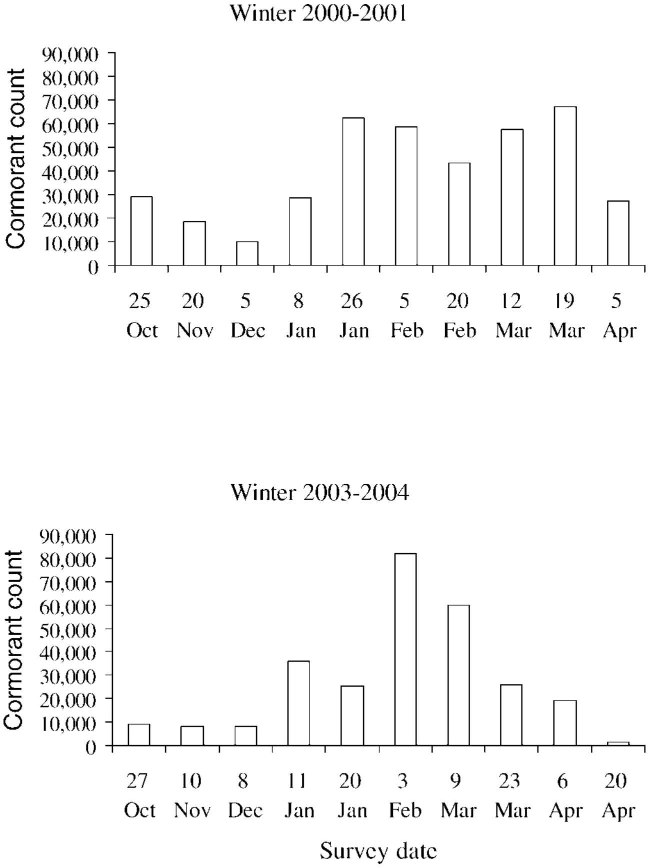

Figure 3. Survey date and counts of double-crested cormorants from United States Department of Agriculture, Wildlife Services, Mississippi, USA, aerial census of all known night roosts ($n = 80$) in the Yazoo River Basin of Mississippi, winters 2000–2001 and 2003–2004.

$\bar{x} = 8{,}524$, SE = 1,847) in year 1 (Table 1) and from 1,614 to 20,214 ($n = 14$, $\bar{x} = 7{,}700$, SE = 1,677) in year 2 (Table 1). Coefficients of variation for aerial cluster surveys ranged from 15% to 73% in year 1 and from 18% to 50% in year 2 (Table 1). Peak counts from cluster surveys occurred on 20 February 2001 and 23 March 2004 (Table 1). In year 1, mean cormorant counts per cluster (95% CI) were 25 (16–35) for interior region and 28 (6–50) for river region. In year 2, mean cormorant counts per cluster were 22 (14–30) for interior region and 32 (5–60) for river region. Month of peak cormorant roost counts reported from WS-MS aerial surveys coincided with peak cormorant pond counts (Fig. 1 and Table 1). The Pearson correlation coefficient for total cormorant pond counts between survey periods and years was 0.87 ($n = 28$, $P \leq 0.01$). Cormorant pond counts were correlated with cormorant roost counts in both years (yr 1: $r = 0.64$, $n = 20$, $P = 0.04$; yr 2: $r = 0.58$, $n = 20$, $P = 0.08$).

Design efficiencies for SCS versus SRS for both years averaged 1.48 ($n = 29$, min. = 0.81, max. = 3.39, SE = 0.12; Table 2). A priori estimates of cluster sample sizes necessary for aerial surveys using the SCS design to detect a ±15% change in number of cormorants had a mean of 132 ($n = 14$, min. = 43, max. = 416; Table 3). During February–April, coinciding with peak cormorant counts, a priori sample sizes had a mean of 89 ($n = 6$, min. = 43, max. = 143; Table 3).

DISCUSSION

Counts of cormorants on ponds indicated a correlation between sample periods and between cormorant roost counts and counts on ponds, which indicate a consistent seasonal pattern of abundance and a significant association between the night roosts targeted for management and use of aquaculture at a regional scale. However, on average we subsequently found only 24% of the total count for night roosts in the Yazoo Basin on catfish ponds at any point in time during the day. This level of use may be explained by the behavior of cormorants. Cormorants typically forage for only 1 hour each day (King et al. 1995), so a larger percentage of cormorants would be expected to be in areas other than aquaculture (i.e., loafing in day roosts, flying) than on aquaculture ponds at any given point during the day. Also, the sampling frame of about 25,000 ha of water

Table 1. Survey date, estimated abundances ($\hat{N}$), maximum per cluster (min. = 0 for all surveys), and coefficients of variation of double-crested cormorants derived from aerial sampling 66 clusters of aquaculture ponds in the Yazoo River Basin of Mississippi, USA, winter 2000–2001 and 65 clusters of aquaculture ponds in winter 2003–2004.

2000–2001					2003–2004				
Date	$\hat{N}$	SD	Max.	CV	Date	$\hat{N}$	SD	Max.	CV
10 Oct	903	373	63	0.41					
17 Oct	1,654	352	40	0.21	15 Oct	3,342	1,168	209	0.35
25 Oct	3,648	1,141	202	0.31	27 Oct	2,142	536	83	0.25
11 Nov	4,714	1,389	190	0.29	10 Nov	1,614	499	93	0.30
20 Nov	3,057	1,070	145	0.35	22 Nov	3,433	734	110	0.21
5 Dec	3,924	2,194	472	0.56	8 Dec	4,008	1,907	380	0.48
17 Dec	3,272	2,387	518	0.73	27 Dec	5,036	2,529	491	0.50
8 Jan	6,175	2,481	460	0.40	11 Jan	4,217	1,835	358	0.44
26 Jan	11,409	3,939	676	0.35	20 Jan	6,530	2,309	439	0.35
5 Feb	11,437	3,579	654	0.31	3 Feb	11,380	4,563	968	0.40
20 Feb	24,569	7,897	1,658	0.32	22 Feb	14,758	3,485	585	0.24
12 Mar	20,824	4,255	569	0.20	9 Mar	18,224	4,122	565	0.23
19 Mar	15,211	2,582	306	0.17	23 Mar	20,214	5,304	836	0.26
5 Apr	11,595	1,711	183	0.15	6 Apr	10,861	2,009	263	0.18
17 Apr	5,465	1,078	155	0.20	20 Apr	2,040	824	158	0.40

Table 2. Survey date, number of ponds subsampled (n_p), variance of the mean [$\widehat{Var}$(mean)], and design effects ($\widehat{deff}$) for estimates of mean number of double-crested cormorants counted from stratified cluster sampling (SCS) 66 clusters of aquaculture ponds in the Yazoo River Basin of Mississippi, USA, winter 2000–2001 and 65 clusters in winter 2003–2004, compared to hypothetically sampling the same ponds using simple random sampling (SRS).

2000–2001					2003–2004				
Date	n_p	$\widehat{Var}$**(mean) SCS**	$\widehat{Var}$**(mean) SRS**	$\widehat{deff}$[a]	**Date**	n_p	$\widehat{Var}$**(mean) SCS**	$\widehat{Var}$**(mean) SRS**	$\widehat{deff}$[a]
10 Oct	1,160	0.0042	0.0051	0.824					
17 Oct	1,160	0.0036	0.0035	1.039	15 Oct	1,194	0.0385	0.0386	0.997
25 Oct	1,160	0.0377	0.0178	2.118	27 Oct	1,197	0.0072	0.0058	1.241
11 Nov	1,160	0.0591	0.0548	1.078	10 Nov	1,198	0.0060	0.0040	1.500
20 Nov	1,160	0.0330	0.0355	0.929	22 Nov	1,201	0.0111	0.0107	1.037
5 Dec	1,160	0.1387	0.1360	1.020	8 Dec	1,193	0.0945	0.0699	1.352
17 Dec	1,160	0.1638	0.2025	0.809	27 Dec	1,198	0.1667	0.0784	2.126
8 Jan	1,160	0.1836	0.1217	1.509	11 Jan	1,193	0.0876	0.1038	0.844
26 Jan	1,161	0.4417	0.4448	0.993	20 Jan	1,194	0.1429	0.0841	1.699
5 Feb	1,161	0.3657	0.2994	1.221	3 Feb	1,193	0.5976	0.6411	0.932
20 Feb	1,165	1.6549	0.9399	1.761	22 Feb	1,193	0.2427	0.0989	2.454
12 Mar	1,162	0.4991	0.3249	1.536	9 Mar	1,196	0.3716	0.1359	2.734
19 Mar	1,162	0.1809	0.1241	1.458	23 Mar	1,199	0.5792	0.1709	3.389
5 Apr	1,161	0.0730	0.0495	1.475	6 Apr	1,195	0.0921	0.0389	2.368
17 Apr	1,163	0.0325	0.0321	1.012	20 Apr	1,195	0.0186	0.0137	1.358

[a] The ratio of the variance of the estimated parameter of the implemented design to the variance expected with SRS (Kish 1965). A $\widehat{deff} \leq 1.0$ or >1.0 means the sampling design is equivalent to or more precise than SRS or less precise than SRS, respectively.

surface area in our study represents approximately 67% of the total water surface ha in the Yazoo Basin (NASS 2004). In addition, the frame represents only 16% of the total 16,000-km^2 area of the Yazoo Basin encompassed by the night roost surveys, which suggests that counts of use on catfish aquaculture may underestimate total use by cormorants. Increasing the geographic area and possibly habitats covered by the surveys would likely increase abundance estimates.

Our coefficients of variation for estimated abundances of cormorants ranged between 15% and 72% and averaged 33%, which was similar to both the SRS method used and the post hoc SCS method described by Christopher et al. (1986). Christopher et al. (1986) suggested SCS sampling may improve overall sampling efficiency but might not provide consistent increases in precision. Despite information suggesting cormorants may forage more in natural habitats nearer the Mississippi River, our evaluation of design effects indicated reduced efficiency for SCS versus a hypothetical SRS design with respect to precision of estimates. This reduced efficiency suggests that stratification may not improve the precision of estimates. However, logistical constraints for SRS sampling could prove limiting on obtaining an effective sample size.

Estimated a priori sample sizes suggested, on average, over the period October–April, a considerable (97%) increase in sampling effort would be needed to meet the ±15% detection goal at a given level of precision. However, precision was typically greater during peak periods of cormorant activity in February–April. Focusing survey effort during periods of peak cormorant activity, which concomitantly had the least variation, and a priori estimates of sample size could improve monitoring efficiency. Additionally, if a larger effect size or lesser level of precision were acceptable, then fewer cluster samples would be necessary.

Current surveys of 67 clusters maximized the Federal

Table 3. Hypothetical biweekly survey period (survey period), a priori design effect ($\widehat{deff}$), estimated double-crested cormorant abundance (λ_0), and estimated standard deviation (SD_0) averaged from aerial surveys of aquaculture ponds in the Yazoo River Basin of Mississippi, USA, winters 2000–2001 and 2003–2004. Expected abundance (λ_1), and standard deviation (SD_1) given a 15% change in observed estimates, and the a priori sample size necessary to detect that effect size at $\alpha = 0.05$ and $\beta = 0.80$ are also given. Actual sample sizes in winters 2000–2001 and 2003–2004 were 66 and 65 clusters, respectively.

Survey period	$\widehat{deff}$	λ_0	SD_0	λ_1	SD_1	**A priori sample size**
1 Oct	1.01	2,498	760	2,873	874	76
2 Oct	1.68	2,895	839	3,329	965	114
1 Nov	1.30	3,164	944	3,639	1,085	93
2 Nov	0.98	3,245	902	3,732	1,037	61
1 Dec	1.19	3,966	2,050	4,561	2,358	257
2 Dec	1.47	4,154	2,458	4,777	2,826	416
1 Jan	1.18	5,196	2,158	5,976	2,482	164
2 Jan	1.35	8,970	3,124	10,315	3,593	132
1 Feb	1.08	11,409	4,071	13,120	4,681	111
2 Feb	2.11	19,664	5,691	22,613	6,545	143
1 Mar	2.13	19,524	4,188	22,453	4,817	80
2 Mar	2.42	17,713	3,943	20,369	4,535	97
1 Apr	1.92	11,228	1,860	12,912	2,139	43
2 Apr	1.18	3,752	951	4,315	1,094	62

Aviation Administration 8-hour flight limit for low-level flying. Sampling additional clusters would require >1 day, which would present both challenges and opportunities. By splitting the sample over 2 days, it may be possible to cover a greater geographic area of the Yazoo Basin. Increasing the sample frame size also may improve abundance estimates relative to cormorant roost counts and factors affecting distribution and abundance of cormorants. However, changing the sampling in this way may alter the estimated variances due to sampling outside of the sample frame we used.

The sampling design we evaluated represents one of many possible designs. Given the patchy distribution of cormorants on aquaculture sites, adaptive sampling is one potential solution for estimating cormorant abundance (Thompson 1992). Christman (1997) found that adaptive cluster sampling was most efficient for simulated populations with a high degree of aggregation. Simulations and field evaluations of this and other sampling designs should be conducted to determine if there is a more efficient design than the one we used. Increasing design efficiency with respect to precision is a desirable goal; however, tradeoffs with survey cost are also an important consideration. Survey cost is a function of variable and fixed costs, with variable costs depending on sampling effort and fixed costs assumed equal between candidate designs (Cochran 1977). Alternative designs should be evaluated with respect to considerations of cost of implementation. Although alternative sampling techniques may be more efficient, it is possible the level of variation in estimates may be inherent to the population of cormorants within the sample frame we evaluated. If so, it is unlikely that any method would significantly improve the precision of estimates over SCS.

Current management paradigms in the Yazoo Basin include region-wide roost harassment to move birds to night roosts along the Mississippi River (Mott et al. 1998). Underlying this strategy is the assumption that the lesser density of aquaculture relative to available natural habitat will minimize depredation losses. These data suggest that abundance of cormorants on aquaculture sites may not be influenced by proximity to the Mississippi River. However, large variation in our estimates may preclude determination of biologically or economically relevant differences by this method. We suggest further evaluation of differences in these regions with respect to use of aquaculture by cormorants.

MANAGEMENT IMPLICATIONS

The distribution and abundance of cormorants on aquaculture facilities in the Yazoo Basin have not been studied at scales larger than a few farms (Stickley et al. 1992). Our study demonstrates that it is possible to describe, evaluate, and monitor cormorant numbers using aquaculture facilities in the Yazoo Basin. However, an increase in sampling effort of 39%, during periods of peak cormorant activity, would be necessary before managers could detect a ±15% change in numbers of cormorants with an acceptable level of certainty. Cost is always an important consideration when conducting surveys. The mean cost of each survey in 2003–2004 was US$691. All else being equal a 39% increase in effort and an additional fueling stop (30 min) would increase the cost of each survey by approximately US$322. With respect to estimating abundance of cormorants on aquaculture ponds in the Yazoo Basin, it appears that stratification is unnecessary. Eliminating stratification would serve to simplify survey methods; possibly allowing sampling more clusters within a given time frame, reduced design complexity, and possibly more precise abundance estimates. The SCS design we evaluated represents only one of many possible survey methods. We recommend further evaluation through both simulation and field trials of this method and additional methods that may prove more efficient with respect to logistics, cost, and precision.

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