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Tools and Technology Article: Evaluation of an Aerial Survey to Estimate Abundance of Wintering Ducks in Mississippi

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Evaluation of an Aerial Survey to Estimate Abundance of Wintering Ducks in Mississippi

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ABSTRACT Researchers have successfully designed aerial surveys that provided precise estimates of wintering populations of ducks over large physiographic regions, yet few conservation agencies have adopted these probability-based sampling designs for their surveys. We designed and evaluated an aerial survey to estimate abundance of wintering mallards (*Anas platyrhynchos*), dabbling ducks (tribe Anatini) other than mallards, diving ducks (tribes Aythini, Mergini, and Oxyurini), and total ducks in western Mississippi, USA. We used design-based sampling of fixed width transects to estimate population indices ($\hat{I}$), and we used model-based methods to correct population indices for visibility bias and estimate population abundance ($\hat{N}$) for 14 surveys during winters 2002–2004. Correcting for bias increased estimates of mallards, other dabbling ducks, and diving ducks by an average of 40–48% among all surveys and contributed 48–61% of the estimated variance of $\hat{N}$. However, mean-squared errors were consistently less for $\hat{N}$ than $\hat{I}$. Estimates of $\hat{N}$ met our goals for precision (CV $\leq$ 15%) in 7 of 14 surveys for mallards, 5 surveys for other dabbling ducks, no surveys for diving ducks, and 10 surveys for total ducks. Generally, we estimated more mallards and other dabbling ducks in mid- and late winter (Jan–Feb) than early winter (Nov–Dec) and determined that population indices from the late 1980s were nearly 3 times greater than those from our study. We developed a method to display relative densities of ducks spatially as an additional application of survey data. Our study advanced methods of estimating abundance of wintering waterfowl, and we recommend this design for continued monitoring of wintering ducks in western Mississippi and similar physiographic regions. (JOURNAL OF WILDLIFE MANAGEMENT 72(6):1413–1419; 2008)

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Local, regional, and continental waterfowl surveys are critical for understanding population and habitat dynamics and for conservation of waterfowl in North America. For example, biologists use extensive surveys of breeding populations and habitat in the United States and Canada to determine annual harvest regulations (Martin et al. 1979, Williams et al. 1996, Brasher et al. 2002). Furthermore, the North American Waterfowl Management Plan expressed goals in terms of abundance and recommended researchers improve population surveys (U.S. Department of the Interior and Environment Canada 1986). Thus, considerable motivation exists for researchers to improve methods to estimate abundance of waterfowl throughout their annual range.

Currently, few surveys of wintering waterfowl are based on probability sampling, and data from these surveys have been used sparingly to monitor and manage populations and habitats (Eggeman and Johnson 1989, Heusmann 1999). Past winter surveys of waterfowl conducted from 1979 to 2001 in Mississippi, USA, have used representative or judgment samples (Lohr 1999), and results were presented as raw counts of individuals (K. Brunke, Mississippi Department of Wildlife, Fisheries, and Parks, personal communication). Scientists have questioned the validity of existing winter surveys because they do not have an explicit sampling design (Reinecke et al. 1992), do not follow similar procedures among participating agencies (Eggeman and Johnson 1989), and make tenuous assumptions (e.g., same proportions of populations are counted annually). Indeed, rigorous methods are needed to generate estimates of abundance that are reliable and comparable among areas and time periods.

Estimating waterfowl abundance during winter is challenging due to aggregated and species-specific distributions of individuals that are spatially dynamic within and among years (Nichols et al. 1983, Reinecke et al. 1992). Past research has demonstrated that aerial surveys of wintering waterfowl can provide precise estimates of population indices at large spatial scales, but such surveys generally have not been implemented annually (Conroy et al. 1988, Reinecke et al. 1992). Two critical shortcomings of previous research were imprecise estimates for key strata (e.g., states) within large physiographic regions and lack of effort or ability to estimate abundances of multiple species simultaneously and precisely (Conroy et al. 1988, Reinecke et al. 1992, Eggeman et al. 1997). Before rigorous winter surveys can become operational, research should address these and related issues such as visibility bias (Pearse et al. 2008).

We designed an aerial transect survey to estimate abundance of wintering ducks in western Mississippi during

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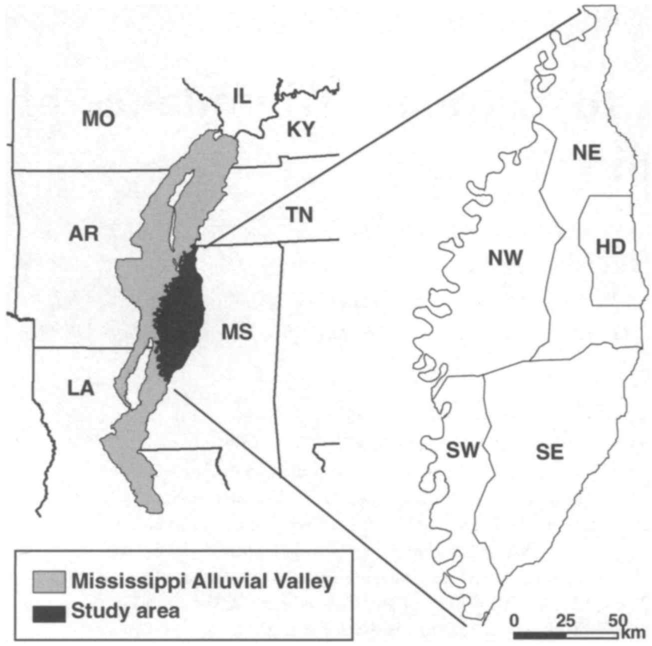

Figure 1. Major strata (NE, NW, SE, and SW) and location of a high-density stratum (HD) during surveys conducted in winter 2004 in the Mississippi portion of the Mississippi Alluvial Valley, USA, where we conducted aerial surveys of wintering waterfowl in winters 2002–2004.

winters 2002–2004. To assess survey performance, we quantified precision of estimates of duck population indices and, after using a model-based approach to correct for visibility bias, estimates of population abundance (Pearse et al. 2008). We also demonstrated application of survey results by describing and testing for temporal differences in duck abundance, comparing our estimates with those from earlier surveys, and developing methods to predict spatial distributions of ducks from survey data.

STUDY AREA

The Mississippi Alluvial Valley (MAV), a continentally important region for migrating and wintering waterfowl in North America, is the floodplain of the lower Mississippi River, and covers 10 million ha in portions of 7 states (Reinecke et al. 1989, Saucier 1994). Historically, the MAV was a bottomland–hardwood ecosystem that provided food and other resources for waterfowl and other wildlife (Fredrickson et al. 2005). Extensive landscape changes occurred during the 20th century, and large portions of the MAV were cleared of trees primarily for agricultural production. Our study area encompassed most of the MAV in Mississippi (1.9 million ha) and was bounded to the south and east by the loess hills of the lower Mississippi River Valley and to the west by the Mississippi River channel (Fig. 1).

METHODS

We conducted 14 surveys, including 3 during winter 2002 (9–17 Dec 2002, 8–13 Jan 2003, and 28 Jan–2 Feb 2003), 6 during winter 2003 (17–21 Nov 2003, 2–6 and 18–22 Dec 2003, 5–9 and 26–30 Jan 2004, and 9–13 Feb 2004), and 5 during winter 2004 (3–7 and 17–21 Dec 2004, 3–5 and 24–27 Jan 2005, and 10–12 Feb 2005). Survey methods were similar to Reinecke et al. (1992). We used a fixed wing aircraft (Cessna 172; A. Nygren, Nygren Air Service, Raymond, MS), and the pilot flew at an altitude of 150 m and navigated transects using a Global Positioning System (GPS) receiver. The observer sat in the right-front seat and determined transect boundaries with marks placed on the wing strut and window (Norton-Griffiths 1975). The observer recorded number of mallards (*Anas platyrhynchos*), other dabbling ducks (e.g., northern pintail [*A. acuta*], American wigeon [*A. americana*], northern shoveler [*A. clypeata*]), and diving ducks (e.g., lesser scaup [*Aythya affinis*], ring-necked duck [*A. collaris*], and ruddy ducks [*Oxyura jamaicensis*]) observed within each transect. We limited estimation to these groups to reduce counting errors and increase precision of estimates. The observer could not consistently differentiate diving ducks from American coots (*Fulica americana*); hence, estimates of diving ducks were biased positively but the magnitude of bias likely was limited because coots made up a small proportion of waterbirds in the study area (A. T. Pearse, Department of Wildlife and Fisheries, Mississippi State University, personal observation; Dubovsky and Kaminski 1992). Using a GPS receiver, we recorded the spatial location of each group of waterfowl observed, defined as $\geq$1 bird within a portion of a wetland.

Survey Design

We used stratified random sampling to estimate duck numbers and defined an a priori goal of precision at coefficient of variation $\leq$15% (Conroy et al. 1988). First, we delineated 4 strata using selected highways as boundaries with the joint objective of satisfying reporting needs of management agencies and separating areas differing in mallard abundance and available habitat (Fig. 1). Next, we delineated selected areas of expected mallard concentrations as a fifth stratum that we would sample with greater intensity to increase precision of estimates. The fifth stratum included noncontiguous portions of the 4 other strata. We allowed location, size, and shape of the fifth stratum to vary and determined its final configuration before each survey relative to wetland conditions and expected mallard densities (Pearse 2007). We used the distribution of mallards for stratification because they were the most abundant species (Table 1), and their population status often is used to guide conservation of other duck species (Reinecke and Loesch 1996, Johnson et al. 1997).

We designated fixed width transects as sample units and used Geographic Information System technology to create a sample frame by orienting transects east to west and spaced 250 m apart across the study area. We selected new sets of transects for each survey to avoid the possibility that an individual sample was not representative, reduce serial correlation among surveys, and increase coverage of the study area and best represent the spatial distribution of ducks (Reinecke et al. 1992, Eggeman et al. 1997). We selected transects randomly, with replacement, and with probability proportional to length (Caughley 1977). We

Table 1. Abundances ($\hat{N}$), standard errors, and coefficients of variation of mallard, other dabbling duck, diving duck, and total duck populations estimated from aerial surveys conducted in western Mississippi during winters 2002–2004.

			Mallards			Other dabbling ducks			Diving ducks			Total ducks		
Survey[a]	Time[b]	n[c]	$\hat{N}$	SE	CV	$\hat{N}$	SE	CV	$\hat{N}$	SE	CV	$\hat{N}$	SE	CV
1	E	146	118,317	19,068	0.16	153,101	32,309	0.21	104,242	19,615	0.19	375,660	54,048	0.14
2	M	178	321,299	33,677	0.10	231,514	25,023	0.11	99,019	17,559	0.18	651,832	57,069	0.09
3	L	103	343,218	40,990	0.12	212,084	27,517	0.13	71,020	15,674	0.22	626,322	67,582	0.11
4	E	80	127,612	52,984	0.42	116,417	22,486	0.19	70,352	18,652	0.27	314,381	73,141	0.23
5	E	108	109,013	20,479	0.19	65,048	12,372	0.19	91,509	29,851	0.33	265,570	43,788	0.16
6	E	117	120,936	15,704	0.13	119,144	19,139	0.16	83,643	18,451	0.22	323,723	40,678	0.13
7	M	84	121,228	22,481	0.19	97,963	22,555	0.23	77,286	16,697	0.22	296,477	47,399	0.16
8	L	125	183,998	18,163	0.10	124,752	16,575	0.13	59,573	13,853	0.23	368,323	36,269	0.10
9	L	118	336,309	45,927	0.14	168,270	20,087	0.12	67,846	13,272	0.20	572,425	59,934	0.10
10	E	84	101,938	18,991	0.19	138,096	32,140	0.23	67,308	17,505	0.26	307,342	52,188	0.17
11	E	123	131,416	18,014	0.14	183,492	28,922	0.16	83,733	18,492	0.22	398,641	48,755	0.12
12	M	83	203,719	34,718	0.17	169,275	34,310	0.20	106,505	29,126	0.27	479,499	71,597	0.15
13	L	100	80,074	12,189	0.15	283,663	55,578	0.20	116,398	21,922	0.19	480,135	70,668	0.15
14	L	89	72,839	12,099	0.17	251,228	33,295	0.13	110,115	23,124	0.21	434,182	52,331	0.12

[a] Dates conducted: survey 1 9–17 Dec 2002; survey 2, 8–13 Jan 2003; survey 3, 28 Jan–2 Feb 2003; survey 4, 17–21 Nov 2003; survey 5, 2–6 Dec 2003; survey 6, 18–22 Dec 2003; survey 7, 5–9 Jan 2004; survey 8, 26–30 Jan 2004; survey 9, 9–13 Feb 2004; survey 10, 3–7 Dec 2004; survey 11, 17–21 Dec 2004; survey 12, 3–5 Jan 2005; survey 13, 24–27 Jan 2005; survey 14, 10–12 Feb 2005.

[b] Time period during winter: E = early winter; M = midwinter; L = late winter.

[c] No. of transects sampled.

constrained adjacent transects from being selected to reduce the chance of multiple counting of ducks (Reinecke et al. 1992). To determine effects of sample size on precision of estimates, we partitioned samples of transects so that they represented 2 levels of survey effort (i.e., 3 and 5 survey days). We nested these 3- and 5-day surveys such that the 3-day survey consisted of the first 3 days of a 5-day survey period.

For the initial survey in December 2002, we allocated sample effort (i.e., cumulative length of transects) to the first 4 strata proportionally and to the fifth or high-density stratum at twice the proportional rate. In subsequent surveys, we used the Neyman method to allocate sample effort (Cochran 1977).

Estimation and Analysis

We estimated population indices ($\hat{I}$; abundance not corrected for visibility bias) for mallards, other dabbling ducks, diving ducks, and total ducks for each survey. We calculated population indices, standard errors, and coefficients of variation for each species or species group from transect sums of individuals observed and transect sample weights (i.e., [probability of selecting a transect from the sampling frame]$^{-1}$) using the SURVEYMEANS procedure in SAS (SAS Institute, Cary, NC).

To estimate population abundances ($\hat{N}$) for each survey, we used a model-based approach to correct observations from aerial surveys for visibility bias (Pearse et al. 2008). These corrections accounted for group detection rates and errors counting individuals and were a function of habitat structure (i.e., open vs. forested wetlands) and group size. Generally, bias was greater when ducks occurred in forested wetlands or in small groups (e.g., <15 birds). Because an explicit variance estimator was not available (Smith 1993, Cogan and Diefenbach 1998), we calculated standard errors of abundance estimates from 1,000 bootstrap samples (Pearse et al. 2008). Bias correction increased variances and potentially rendered estimates of $\hat{N}$ less accurate than estimates of $\hat{I}$ (Little 1986). To compare accuracy of estimates, we calculated mean-squared errors (MSE) of estimates for mallards and other duck groups for each survey as

$$\mathrm{MSE}(\hat{\theta}) = \mathrm{var}(\hat{\theta}) + \mathrm{bias}(\hat{\theta})^2,$$

where var(θ) and bias(θ) were the variance and bias of an estimate θ (Cochran 1977). We assumed estimates of abundance were unbiased (i.e., MSE[$\hat{N}$] = var[$\hat{N}$]) and calculated the bias of indices as bias ($\hat{I}$) = $\hat{I} - \hat{N}$.

We used z-statistics to compare abundance estimates between surveys (Reinecke et al. 1992). We tested whether mean abundances of surveys conducted in November and December (hereafter early winter) differed from surveys conducted in early January (hereafter midwinter) or late January and February (hereafter late winter) for mallards and other duck groups. We also compared mean abundances for midwinter and late winter. Last, we compared mean population indices of mallards from December and January surveys conducted during our study with estimates from similar surveys in winters 1987–1989 (i.e., stratum 1 in Reinecke et al. 1992). We used the Bonferroni method to control experiment-wise Type I error rate of tests at α = 0.05/9 = 0.006.

We interpolated locations of mallards and total ducks to depict their spatial distributions within the study area. We followed a 3-step procedure to create a spatial data layer needed for interpolation. First, we compiled observed locations of groups of mallards and total ducks by survey. Next, we created a spatial data layer to represent the portion of the study area sampled during each survey. This spatial data layer consisted of points spaced 1,000 m apart along

Table 2. Coefficients of variation for estimated abundances of mallard, other dabbling duck, diving duck, and total duck populations estimated from aerial surveys with 3 or 5 days of sampling effort in western Mississippi, USA, winters 2002–2004.

	Mallards			Other dabbling ducks			Diving ducks			Total ducks		
Survey[a]	3-day	5-day	Diff[b]	3-day	5-day	Diff[b]	3-day	5-day	Diff[b]	3-day	5-day	Diff[b]
1	0.18	0.16	0.02	0.25	0.21	0.04	0.19	0.19	0.00	0.17	0.14	0.03
2	0.16	0.10	0.06	0.15	0.11	0.04	0.22	0.18	0.04	0.12	0.09	0.03
6	0.16	0.13	0.03	0.18	0.16	0.02	0.28	0.22	0.06	0.14	0.13	0.01
8	0.12	0.10	0.02	0.16	0.13	0.03	0.28	0.23	0.05	0.12	0.10	0.02
9	0.14	0.14	0.00	0.14	0.12	0.02	0.20	0.20	0.00	0.10	0.10	0.00
11	0.15	0.14	0.01	0.19	0.16	0.03	0.26	0.22	0.04	0.14	0.12	0.02
$\bar{x}$			0.02			0.03			0.03			0.02

[a] Dates conducted: survey 1, 9–17 Dec 2002; survey 2, 8–13 Jan 2003; survey 6, 18–22 Dec 2003; survey 8, 26–30 Jan 2004; survey 9, 9–13 Feb 2004; survey 11, 17–21 Dec 2004.
[b] Diff = CV(3-day) − CV(5-day).

transects sampled during surveys. Finally, we combined the duck locations and transect layers to create a vector data set representing numbers of observed mallards or total ducks within the sampled portion of the study area during each survey.

To estimate relative abundances in the entire study area, we interpolated the data layer described above using the Geospatial Analysis extension in ArcGIS Desktop 8.3 (Johnston et al. 2001) via the local polynomial interpolation option provided with the extension (Pearse 2007). After predicting distributions, we developed 4 categories of duck density to illustrate spatial variation (i.e., no birds observed, low, medium, and high densities). We used the mean density in the high-density stratum over all surveys to separate the high- and medium-density categories (0.223 mallards/ha; 0.410 total ducks/ha) and the mean density of the northwest, southeast, and southwest strata (Fig. 1) over all surveys to separate the medium- and low-density categories (0.037 mallards/ha; 0.111 total ducks/ha). We used a subjective value of 0.004 birds/ha to separate the categories of low density and no birds observed.

RESULTS

Bias correction increased estimates of mallard abundance by an average 48% (SE = 2%), other dabbling ducks by 40% (SE = 2%), diving ducks by 40% (SE = 3%), and total ducks by 43% (SE = 2%). Variance due to bias correction accounted for 61% (SE = 3%) of the estimated variances of mallard abundance, 50% (SE = 2%) for other dabbling ducks, 48% (SE = 3%) for diving ducks, and 58% (SE = 2%) for total ducks. Bias correction decreased MSEs by 75% (SE = 5%) for mallards, 69% (SE = 3%) for other dabbling ducks, 51% (SE = 5%) for diving ducks, and 80% (SE = 3%) for total ducks. Thus, estimates of duck abundance corrected for visibility bias had increased variances, yet they were more accurate than population indices for mallards and other species groups in all surveys. Additionally, despite variation in factors influencing the magnitude of bias corrections, correlations between population indices and bias-corrected abundance estimates among surveys were strong for mallards ($r = 0.998$), other dabbling ducks ($r = 0.990$), diving ducks ($r = 0.940$), and total ducks ($r = 0.991$).

We achieved our a priori objective for precision of bias-corrected abundance estimates (CV $\leq$ 15%) in 50% of survey estimates for mallards, 36% for other dabbling ducks, 0% for diving ducks, and 71% for total ducks (Table 1). Among estimates not meeting the objective, only one for mallards and one for total ducks had coefficients of variation >20%. Furthermore, the maximum coefficient of variation for other dabbling ducks was 23%. Generally, we met our objective for precision of estimates in surveys conducted from late December to mid-February but not during early winter (Table 1).

We completed 6 surveys that provided data for comparing precision of estimates from 3 and 5 days of sampling effort. We sampled 4% of the study area with 3 days of flying and 6% with 5 days. We found that 2 additional days of sampling decreased coefficients of variation an average 2% for mallards and total ducks and 3% for other dabbling and diving ducks (Table 2).

Estimated mallard abundances peaked in January for 2 of 3 winters, abundances of other dabbling duck followed a similar seasonal trend as mallards, and diving duck abundances varied less than other species or species groups within winters and averaged 86,325 across surveys (Table 1). Among years, estimated duck abundance increased from early winter to mid- and late winter by 89,630 for mallards ($z = 5.80$, $P \leq 0.001$), 15,416 for other dabbling ducks ($z = 4.13$, $P \leq 0.001$), and 157,764 for total ducks ($z = 5.24$, $P \leq 0.001$). In contrast, we did not detect a difference in diving duck abundance between early and mid- and late winter periods (5,006 ducks, $z = 0.46$, $P = 0.648$). We also failed to detect a difference in abundance of mallards and other species groups between midwinter and late winter ($P \geq 0.060$). Comparing mean indices of mallard populations from December and January surveys in our study ($n = 11$; Pearse 2007) with comparable values from December 1988–January 1990 ($n = 5$; Reinecke et al. 1992), we found estimates from the late 1980s averaged 217,370 more mallards (2.9 times) those from our surveys ($z = 6.20$, $P \leq 0.001$).

We generated maps of predicted distributions for mallards

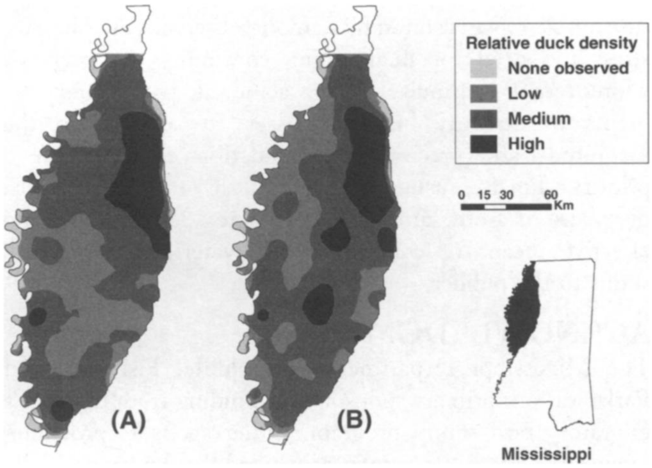

Figure 2. Interpolated distribution of mallards (A) and total ducks (B) derived from an aerial survey conducted 8–13 January 2003 in western Mississippi, USA. Relative density categories were none observed (<0.004 birds/ha), low (<0.037 mallards/ha; <0.111 total ducks/ha), medium (0.037–0.223 mallards/ha; 0.111–0.410 total ducks/ha), and high (>0.223 mallards/ha; >0.410 total ducks/ha).

and all ducks for the 14 surveys (Pearse 2007). Maps resulting from analysis of data collected during the 8–13 January 2003 survey are representative of spatial distributions of wintering ducks in the region (Fig. 2). With few exceptions (e.g., 9–13 Feb 2004), mallard densities were highest in the northeastern portion of the study area and relatively low elsewhere. For total ducks, the pattern was similar except increased densities in certain parts of the central and southern portions of the study area due to consistently high numbers of diving ducks associated with aquaculture ponds.

DISCUSSION

Bias Correction

Visibility bias is a pervasive source of error in aerial surveys and should be acknowledged and assessed when possible (Pollock and Kendall 1987). We applied a model-based bias correction method and found it increased variances of abundance estimates by an average 48% for diving ducks to 61% for mallards. Despite increased variances, bias-corrected estimates were more accurate than population indices for all surveys. Thus, the benefit of removing bias offset the reduction in precision of abundance estimates.

The magnitude of bias correction varied temporally and among duck species groups as a function of the percentage of ducks observed in forested wetlands and group size (Pearse et al. 2008). However, the strong correlations between estimates of indices and abundances for mallards and other species groups suggested these sources of variation had minimal effect on observed bias, and population indices provided reliable measures of relative abundance in our surveys. Reinecke et al. (1992) simulated hypothetical effects of bias and also concluded that population indices of mallards in the MAV were robust to habitat-specific visibility bias.

Precision

We achieved our goal for precision of estimates (CV $\leq$ 15%) most consistently when we estimated total duck abundance. Among species or species groups, we estimated abundance of mallards more precisely than other groups and attained adequate precision in half the surveys. We expected this result because expected distributions of mallards influenced choice of stratum boundaries and other aspects of survey design. The level of precision we attained in estimating mallard abundance in Mississippi improved over previous winter surveys (Reinecke et al. 1992), yet further research is needed to obtain precise species-specific estimates of other dabbling and diving ducks. If precise estimates of individual species were attainable from aerial transect or other sample surveys, current procedures for midwinter inventories could be modified to provide reliable estimates of waterfowl populations (Eggeman and Johnson 1989, Heusmann 1999).

Generally, we achieved more precise estimates with surveys conducted in mid- and late winter (Jan–Feb) rather than early winter (Nov–Dec). We attributed this improved precision to greater dispersion of individuals across the region, likely influenced by increased wetland availability, depletion of foraging resources, and behavioral separation due to pair formation (Reinecke et al. 1992). Reinecke et al. (1992) also reported increased precision of estimates in late compared with early winter during 1988–1990 in Mississippi, but differences they observed were greater. Thus, we infer that creating a high-density stratum and optimally allocating sample effort in our surveys decreased disparity in precision between early and late winter surveys.

Based on our survey parameters and costs, each extra survey day cost approximately $1,000 (Pearse 2007), providing impetus for an objective manner to determine when extra sampling is necessary. We found 2 additional days of sampling effort decreased coefficients of variation by 2% for mallards and total ducks and 3% for other dabbling and diving ducks. Increasing sample effort from 3 days to 5 days increased the number of estimates of duck abundance that satisfied precision goals from 10 to 14. Thus, increased survey effort often provided tangible benefits, and we propose implementing future surveys with a 2-phase adaptive strategy (Brown 1999). Specifically, we recommend conducting an initial 3-day survey and, after determining precision of estimates from that survey, deciding whether and where additional sample effort is warranted based on stratum-specific and overall variances. Generally, the initial survey would include sampling 4% of a study area such as ours with an additional sample of $\leq$2% if precision goals were not met initially.

Survey Applications

Combining estimates across winters, mallards and other dabbling ducks were more abundant in mid- and late than early winter, although we did not detect differences in abundances of mallards or other species groups between midwinter and late winter. Thus, mallards and other dabbling ducks were most abundant after the first of the

year on average when waterfowl inventories are traditionally conducted (i.e., first week in Jan), yet we found that peak abundances of ducks occurred during midwinter in only 2 of 3 winters. Alternatively, abundance of diving ducks was relatively stable during winter. This type of information can provide guidance to agencies responsible for monitoring populations of wintering waterfowl or scheduling waterfowl hunting seasons. Understanding patterns of waterfowl abundance also has implications for habitat conservation if temporal objectives for habitat management are warranted (e.g., Wilson and Esslinger 2002). For example, if waterfowl are most abundant in Mississippi during January to early February, managers should ensure adequate food and wetland availability during this period by not flooding all managed areas in early winter.

Our study also provided evidence of long-term changes in duck abundance in Mississippi. Using population indices for comparison, we found evidence that numbers of mallards in western Mississippi have decreased between the late 1980s and winters 2002–2004. This trend toward decreasing mallard numbers apparently has occurred in most of the MAV except southeastern Missouri, USA, and the overall decrease in the southern MAV suggests a northward shift in distribution within and beyond the MAV (K. J. Reinecke, United States Geological Survey, Patuxent Wildlife Research Center, unpublished data). Factors influencing these patterns are speculative but may include changes in habitat availability and quality, short- or long-term climate, and hunting-related disturbance. The rigorous survey design we developed will help evaluate goals of regional conservation strategies to maintain historical distributions of ducks and document population responses to management programs (Reinecke and Loesch 1996).

Finally, the random sampling protocol of the survey and spatial coordinates collected for observed groups of ducks enabled us to predict and depict duck distributions in the study area from sample data. We were able to prepare maps soon after completing surveys for use by agencies in communicating the status of duck populations to the public. Other potential applications include investigating factors influencing duck distribution (e.g., Pebesma et al. 2005), identifying wetland or other areas for land acquisition, development, or conservation easement, and prioritizing areas for wildlife enforcement effort (e.g., Gray and Kaminski 1994).

MANAGEMENT IMPLICATIONS

The aerial survey we designed met expectations and should serve as the primary method of monitoring mallard and total duck populations in western Mississippi. We recommend conducting 3–5 surveys per winter to assess the dynamics of duck abundance within and among winters. Our general survey method likely would be successful in other portions of the MAV and potentially elsewhere and for additional species (e.g., Pearse et al. 2007). Although we found strong correlations between population indices and bias-corrected abundances for one observer, surveys such as ours are susceptible to variation in bias among observers. As such, we stress the need for maintaining continuity of observers. Moreover, if continuity can be achieved, periodic experiments to quantify bias and assess its effects on the magnitude and precision of population estimates are a priority. Finally, using spatial analysis to predict duck distributions from sample transects provided a timely and effective means of communicating waterfowl population status to the public.

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