Research Article

Estimating the Breeding Population of Long-Billed Curlew in the United States

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ABSTRACT Determining population size and long-term trends in population size for species of high concern is a priority of international, national, and regional conservation plans. Long-billed curlews (*Numenius americanus*) are a species of special concern in North America due to apparent declines in their population. Because long-billed curlews are not adequately monitored by existing programs, we undertook a 2-year study with the goals of 1) determining present long-billed curlew distribution and breeding population size in the United States and 2) providing recommendations for a long-term long-billed curlew monitoring protocol. We selected a stratified random sample of survey routes in 16 western states for sampling in 2004 and 2005, and we analyzed count data from these routes to estimate detection probabilities and abundance. In addition, we evaluated habitat along roadsides to determine how well roadsides represented habitat throughout the sampling units. We estimated there were 164,515 (SE = 42,047) breeding long-billed curlews in 2004, and 109,533 (SE = 31,060) breeding individuals in 2005. These estimates far exceed currently accepted estimates based on expert opinion. We found that habitat along roadsides was representative of long-billed curlew habitat in general. We make recommendations for improving sampling methodology, and we present power curves to provide guidance on minimum sample sizes required to detect trends in abundance. (JOURNAL OF WILDLIFE MANAGEMENT 71(8):2556–2564; 2007)

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Knowledge of how bird populations change through time is of increasing importance to conservation planners, managers, and biologists concerned with widespread degradation of ecosystems, alteration and loss of habitats, and the profound changes to bird and other wildlife populations that result. A strategic framework for monitoring North American bird populations calls for long-term monitoring programs covering extensive geographic regions to provide basic information on distribution, habitat use and availability, abundance, and changes in abundance as fundamental elements of bird conservation programs (North American Bird Conservation Initiative 1998). The Program for Regional and International Shorebird Monitoring has several stated monitoring goals, including estimating the size of breeding populations of 74 shorebird taxa in North America, with priorities for implementing new surveys of species of high conservation concern (Bart et al. 2005).

Long-billed curlews (*Numenius americanus*) are a species of special concern throughout their range in North America, with a status of Highly Imperiled in both the Canadian and United States shorebird conservation plans (Donaldson et al. 2000, Brown et al. 2001). This level of concern is due to apparent population declines in the short- and mixed-grass prairies of the western Great Plains (Brown et al. 2001). Threats to breeding populations include habitat loss and fragmentation due to agricultural conversion of native grasslands and encroachment of woody vegetation due to fire suppression (Pampush and Anthony 1993, Samson and Knopf 1994). Habitat loss in wintering areas results from grassland conversion, wetland drainage, urban development, and changes in coastal habitats (Dahl 1990, Page et al. 1999, Dugger and Dugger 2002). Today, long-billed curlews breed in open grasslands in the Great Plains, Great Basin, and intermountain valleys of the western United States and southwest Canada, although prior to 1900 they extended into the grasslands of midwestern United States and Canada (Dugger and Dugger 2002). During the nonbreeding season, long-billed curlews use shallow wet habitats such as mudflats, estuaries, saline and freshwater lake edges, marshes, and flooded fields along the Pacific, Gulf, and Atlantic coasts (Dugger and Dugger 2002).

Breeding Bird Survey (BBS) data for long-billed curlews include 257 survey routes rangewide, with 202 of those routes in the United States (Sauer et al. 2005). From 1966 to 2004, BBS trends were negative throughout much of the long-billed curlew's range, with significant declines in the United States Fish and Wildlife Service (USFWS) Mountain-Prairie Region (USFWS Region 6, −2.7%/yr, $P = 0.02$; Sauer et al. 2005). We suspect, however, that the BBS may not adequately reflect long-billed curlew distribution and trends because BBS routes are surveyed in June, when long-billed curlews are in late incubation and are largely inconspicuous, or they have left the area (S. L. Jones, USFWS, personal communication). Because of concerns over long-billed curlew distribution, abundance, and trends, we initiated a 2-year study to 1) determine present long-billed curlew distribution and breeding population size in the United States and 2) provide recommendations for a long-term long-billed curlew monitoring protocol.

STUDY AREA

Our sampling frame was composed of townships falling on or within the boundaries of the assumed United States geographic range of breeding long-billed curlews (Fig. 1),

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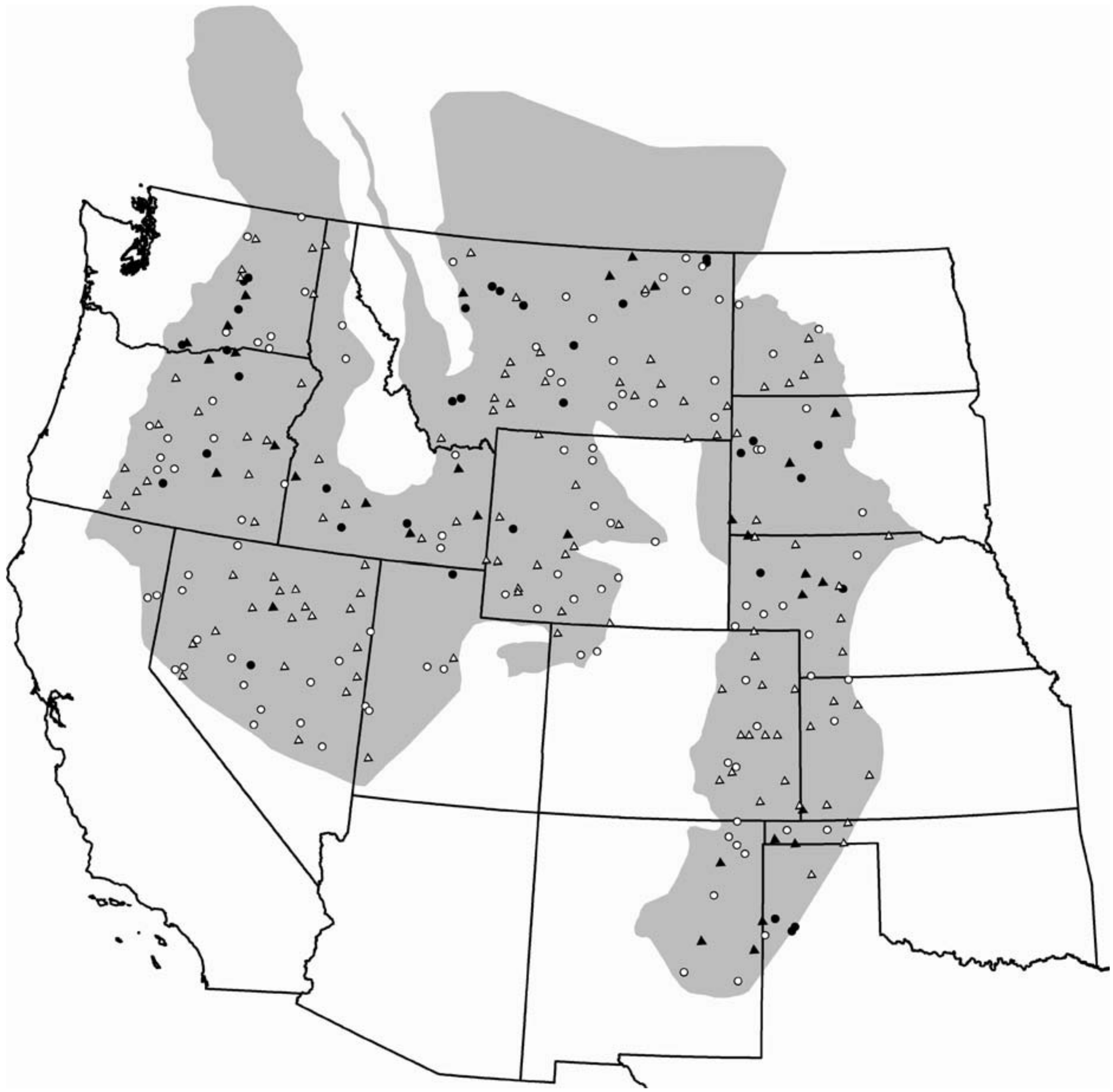

Figure 1. The 2004 and 2005 routes with no long-billed curlews sighted (open circles and open triangles) and the routes with ≥1 breeding long-billed curlew sighted (solid circles and solid triangles) in the western United States. The gray area depicts the assumed geographic range of breeding long-billed curlews.

which we delineated using a Geographic Information Systems (GIS) base map provided by NatureServe (Ridgely et al. 2003), BBS data (Sauer et al. 2005), and other data on the occurrence of long-billed curlews (e.g., Breeding Bird Atlases). A "township" refers to a unit of land defined by the United States Public Land Survey System (Zumberge and Rutford 1983) that is typically square and is nominally approximately 9.6 km to a side. Our sampling frame in 2004 consisted of 21,405 townships covering a total area of 186,072,700 ha, and in 2005 we modified it (based on additional range information provided by W. H. Howe, USFWS, personal communication) to 20,906 townships covering 181,984,268 ha.

METHODS

Sampling Design

We used National Land Cover Data (NLCD; Multi-Resolution Land Characteristics Consortium 2000) and elevation data (Environmental Systems Research Institute 2002) to stratify townships, our sampling units. First, we determined the percentage of each township that could be considered clearly unsuitable for breeding long-billed curlews, such as areas in the Developed, Forested Upland, or Water NLCD cover classes or areas with high elevations (elevation cutoffs were 1,524 m for WA, OR, CA; 2,134 m for ID, NV, UT, MT, CO, NM; 2,347 m for WY; and no cutoff for ND, SD, NE, KS, OK, TX). Next, we assigned townships with <70% unsuitable habitat to 1 of 3 strata using the percent grassland criteria of Saunders (2001). Strata 1–3 consisted of townships with 0–5% grassland (computed as 100%[grassland ha]/[total ha in township]), >5–50% grassland, and >50–100% grassland, respectively, using the NLCD Grassland cover class (code 71). Note that in contrast to the grassland definition of Saunders (2001), which distinguished between native prairie and tame pasture, the NLCD Grassland cover class combines native

Table 1. Number and total area (ha) of townships in the sampling frames for long-billed curlew surveys in the western United States, 2004 and 2005.

Stratum	No. of townships	Area (ha)	% of total area
2004			
1	3,848	33,345,723	17.9
2	7,561	66,444,196	35.7
3	6,820	60,217,221	32.4
4	3,176	26,065,560	14.0
Total	21,405	186,072,700	100.0
2005			
1	3,841	33,292,523	18.3
2	7,382	65,046,472	35.7
3	6,521	57,651,239	31.7
4	3,162	25,994,035	14.3
Total	20,906	181,984,268	100.0

prairie and tame pasture. Stratum 4 consisted of townships with $\geq$70% unsuitable habitat (Table 1).

We selected sample units within each stratum using simple random sampling without replacement. Based on the number of surveyors participating in the study and the expected distances between sample units, we estimated 155 units was the maximum number that could be sampled over the survey period. Because we thought it unlikely stratum 4 would have long-billed curlews, but recognized valid inferences required some sampling of this stratum, we arbitrarily set the number of sample units allocated to this stratum at 15 in both years. In 2004, we allocated the remaining 140 sample units among strata 1–3 using weights computed from the variances reported in Saunders (2001). In 2005, we computed weights using variance estimates from the 2004 field season. Thus, in 2004 we randomly selected 42, 53, and 45 townships from strata 1, 2, and 3, respectively, and in 2005 we randomly selected 26, 64, and 50 townships from strata 1, 2, and 3, respectively. When we could not sample a township because of bad weather, bad roads, lack of access, or other issues, we sampled a nearby randomly selected alternate township in the same stratum, if one was available.

Once we selected townships for sampling, we delineated a 32-km survey route with a random start point along all road types except interstate highways using criteria adapted from Saunders (2001). In townships with insufficient numbers of roads, we truncated routes to a length $\geq$20 km or we extended the route into neighboring townships in the same stratum. For the analysis, routes represent the randomly selected units of replication from which we made inferences to strata, and points along a route represent a systematic subsample from the route.

Survey Period

We targeted a narrow time window corresponding to the arrival and pre-incubation period for surveys because males are most conspicuous in their aerial display flights during this time (Redmond et al. 1981). We partitioned the survey area into windows of time representing the average pre-incubation period for long-billed curlews in each region within the survey area. We accomplished this by correlating First Lilac Leaf Date data (Cayan et al. 2001) with breeding records gleaned from the literature and personal communications, then combining this information with expert opinion to partition the survey area into sampling windows (S. L. Jones, personal communication). The sampling dates for windows 1–4 in 2004 were 21 March–10 April, 28 March–17 April, 11 April–1 May, and 21 April–15 May, respectively, and in 2005 were 28 March–20 April, 3 April–27 April, 8 April–3 May, and 21 April–15 May, respectively (survey timing map available at <http://mountain-prairie.fws.gov/species/birds/longbilled_curlew/curlew_040505.pdf>).

Data Collection on Survey Routes

Teams of 2 observers surveyed the route using a vehicle and stopped at points spaced 0.8 km apart to record all long-billed curlews seen or heard within 5 minutes. Surveys started no earlier than 30 minutes after sunrise and continued for 4 to 9 hours ($\bar{x} = 6.2$ hr for 32-km routes). On several days observers ran >1 route; later surveys ceased at least one-half hour before sunset. At each survey point, a primary observer detected long-billed curlews by sight or sound and determined by laser rangefinder or ocular estimation the radial distance band (0–400 m, >400–800 m, >800 m) in which the curlews occurred. The secondary observer recorded these data and the 1-minute time interval in which each long-billed curlew was detected, and also recorded all curlews (and the radial distance band) detected that the primary observer did not detect. During the 2005 field season, the secondary observer also recorded the percentage of the circle created by the 0-m to 400-m radial distance band that was visible, or had no obvious topographic or other factors that prevented visual or auditory detection of long-billed curlews. Observers alternated roles as the primary and secondary observer between stops.

When recording curlews detected at points, observers noted age (ad, juv, downy young) and sex when possible, the behavior of the bird (e.g., feeding, flying overhead, or engaging in territorial displays), and other relevant information (e.g., paired birds). For purposes of analysis, we omitted observations of nonbreeders (e.g., juv or downy young birds, flying overhead and passing through the area), birds that moved to the survey point from a previously surveyed point (as noted by the observer), or birds arriving during the 5-minute count (such birds violate the closure assumption and were noted by the observers). We considered all other birds to be members of the breeding population.

Detection probabilities

We estimated detection probability, $\hat{p}^*$, using the double-observer method of Nichols et al. (2000) and the removal model of Farnsworth et al. (2002). As originally developed, the double-observer method allows detection probabilities to be separately estimated for each of the 2 observers. If we denote the probabilities for observers 1 and 2 by p_1 and p_2, then $\hat{p}^* = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2)$. In this study, curlew detections for distinct teams of observers were too sparse to estimate detection probabilities separately for each observer, so we pooled data for primary and secondary observers across all teams of observers and imposed the constraint $p_1 = p_2 = p$. Thus, for our data, $\hat{p}^* = 1 - (1 - \hat{p})^2$, and the conditional log-likelihood from Nichols et al. (2000) becomes

$$c_p \ln\left[\frac{p}{p + (1-p)p}\right] + c_s \ln\left[\frac{(1-p)p}{p + (1-p)p}\right],$$

where c_p = the number of long-billed curlews counted by primary observers and c_s = the number of curlews counted by secondary observers that were not counted by the primary observers. Using standard maximum likelihood methods, we get $\hat{p} = 1 - c_s/c_p$ and the estimated variance of $\hat{p}$, which we denote as $\hat{V}(\hat{p})$, is $\hat{V}(\hat{p}) = c_s(c_p + c_s)/c_p{}^3$. Using the delta method (Seber 1982), we find $\hat{V}(\hat{p}^*) = 4(1-\hat{p})^2\hat{V}(\hat{p})$.

When analyzing the detection data under the removal model of Farnsworth et al. (2002), we kept data from time intervals 1–5 separate. Thus, the conditional likelihood for our model (omitting the multinomial constant) was

$$\left[\frac{1-cq}{1-cq^5}\right]^{x_1} \prod_{t=2}^{5} \left[\frac{cq^{t-1}(1-q)}{1-cq^5}\right]^{x_t},$$

where c = the probability a bird belongs to the portion of the population that is difficult to detect (i.e., group 2 birds as defined by Farnsworth et al. 2002), q = the probability of failing to detect a group 2 bird, and x_t = the number of curlews counted by the primary observer in time interval t ($t = 1, 2, \ldots, 5$). Note, a model with $0 < c < 1$ allows for heterogeneity in detection probabilities by assuming there are 2 groups of birds: easy to detect (group 1) and difficult to detect (group 2). Under the constraint $c = 1$, it is assumed all birds belong to group 2 and that detection probabilities are homogeneous. Under the Farnsworth et al. (2002) model, the value of p^* is estimated as $\hat{p}^* = 1 - \hat{c}\hat{q}^5$ and $\hat{V}(\hat{p}^*) = \hat{q}^{10}\hat{V}(\hat{c}) + 25\hat{c}^2\hat{q}^8\hat{V}(\hat{q})$.

Population Estimation

We combined density estimates for routes to obtain point and error estimates of abundance for strata in the United States portion of the geographic range using the standard formulae of sampling theory (Cochran 1977). If we let N denote the number of breeding long-billed curlews in the United States, then our estimate of N is $\hat{N} = \sum_{h=1}^{4} A_h \overline{d}_h$, where A_h is the area in hectares of stratum h ($h = 1, 2, 3, 4$), and $\overline{d}_h$ is the average density of breeding curlews in stratum h. We estimate average density as $\overline{d}_h = \frac{1}{n_h}\sum_i \hat{d}_{hi}$, where n_h = the number of routes sampled in stratum h, and $\hat{d}_{hi}$ = the estimated density of long-billed curlews along the ith route of stratum h. This latter quantity is estimated as $\hat{d}_{hi} = \frac{1}{A_{hi}}\frac{c_{hi}}{\hat{p}_{hi}}$, where A_{hi} = the area in hectares sampled along the ith route of stratum h, c_{hi} = the total number of breeding curlews counted along the ith route of stratum h, and $\hat{p}_{hi}$ = the estimated detection probability of curlews along the ith route of stratum h. Because curlew detections in this study were sparse (i.e., counts were low), we were unable to estimate the $\{\hat{p}_{hi}\}$ and constrained those parameters to be equal across both routes and strata (i.e., $\hat{p}_{hi} = \hat{p}^*$). The estimated variance of $\hat{N}$, which we denote $\hat{V}(\hat{N})$, is $\hat{V}(\hat{N}) = \sum_{h=1}^{4} A_h^2 \hat{V}(\overline{d}_h)$. (Note, because $\sum_i A_{hi} \ll A_h$ for all h, we omit the finite-population correction factor from our calculations.) The estimated standard error of $(\hat{N})$ is $\sqrt{\hat{V}(\hat{N})}$. The quantity $\hat{V}(\overline{d}_h)$ can be derived by rewriting $\hat{d}_{hi}$ as $\hat{d}_{hi} = b_{hi}/\hat{p}^*$, where $b_{hi} = c_{hi}/A_{hi}$ and the constraint $\hat{p}_{hi} = \hat{p}^*$ is imposed, then expressing $\overline{d}_h$ as $\overline{d}_h = \frac{1}{n_h}\sum_i \frac{b_{hi}}{\hat{p}*} = \frac{\overline{b}_h}{\hat{p}*}$ and applying the delta method (Seber 1982). Doing this yields the expression

$$\hat{V}(\overline{d}_h) = \left(\frac{-\overline{b}_h}{(\hat{p}^*)^2}\right)^2 \hat{V}(\hat{p}^*) + \left(\frac{1}{\hat{p}^*}\right)^2 \hat{V}(\overline{b}_h),$$

where $\hat{V}(\hat{p}^*)$ is obtained from the relevant likelihood function (given above) and $\hat{V}(\overline{b}_h) = \frac{\sum_i (b_{hi} - \overline{b}_h)^2}{n_h(n_h - 1)}$.

For estimates of population size and detection probabilities, we used only observations (audio and visual) of breeding long-billed curlews in the 0-m to 400-m distance band counted during the 5-minute sampling interval. The visibility-corrected area calculations for the 2005 data used the following formula: (%VIS/100)(400 m)$^2\pi$/(10,000 m^2/ha), where %VIS was the percentage of the circle created by the 0-m to 400-m radial distance band that was visible (as defined above).

Stratification and Power Analyses

To evaluate whether our stratification scheme improved the precision of our overall abundance estimate, we performed 2 separate analyses. First, we estimated mean long-billed curlew density and SE over the entire survey area for both years, under the assumption that the routes we sampled represented a simple random sample (SRS) from the survey area. We then compared the SRS standard error (SE_{srs}) with that obtained from the stratified random sample (SE_{str}). In the second analysis, we used bootstrap methods (Efron 1979) to estimate mean densities of curlews and SE_{srs} and SE_{str}, where bootstrap samples (10,000 total) were drawn from each stratum in proportion to the total area represented by that stratum, and sample sizes equaled actual sample sizes.

We performed power analyses using the model of Urquhart and Kincaid (1999) under the assumption data would be obtained from a simple random sample with trend analyzed using linear regression. The model of Urquhart and Kincaid (1999) is of the form $Y_{ij} = \mu + S_i + T_j + E_{ij}$, where μ is the expected value of Y_{ij} (i.e., density), site effect $S_i \sim (0, \sigma^2_{Route})$, time effect $T_j \sim (0, \sigma^2_{Year})$, and the residual effect $E_{ij} \sim (0, \sigma^2_{Residual})$; ($\sigma^2_x$ denotes variance due to source x). We estimated σ^2_{Route} using the 2004 and 2005 route data, and estimated σ^2_{Year} using the 2004 and 2005 density estimates. We were unable to estimate $\sigma^2_{Residual}$ because none of the 2004 routes were resampled in 2005, so this value was set to zero. We used Monte Carlo simulations to generate curlew density data where μ was a linearly decreasing function of time, the site effect was $S_i \sim Normal(0, \sigma^2_{Route})$, and the time effect was $T_j \sim Normal$(0,

σ^2_{Year}). We generated 10,000 data sets with a 20% decline in long-billed curlew density occurring over 5 years, 10 years, 15 years, and 20 years, and then we analyzed them under a linear regression model to determine the number of times the slope parameter was significantly different from zero at $\alpha = 0.05$ and $\alpha = 0.20$.

Evaluation of Roadside Habitat

For each township we sampled in 2004 and 2005, we used GIS overlays of the NLCD and the Bureau of Transportation Statistics Roads (<http://seamless.usgs.gov/website/seamless/products/bts.asp>) databases to estimate the proportion of the township that was within 400 m of a road (p_b), the proportion of the habitat within 400 m of a road that was grassland (p_{bg}; NLCD code 71) or developed (p_{bd}; NLCD codes 21, 22, 23, which collectively represent residential, commercial, industrial, and transportation), and the proportion of the township as a whole that was grassland (p_{tg}) or developed (p_{td}). For grassland, we computed the weighted average (k_g) of the ratio p_{tg}/p_{bg}, where p_{tg} was the weighting variable, for each year-by-stratum combination. k_g is a measure of how representative roadsides are of the proportion of grassland in the township as a whole and, under the assumption that long-billed curlew occur only in grassland, k_g represents a bias correction factor where $k_g = 1$ indicates there is zero bias. For developed areas, we computed the weighted average (k_d) of the ratio $(1 - p_{td})/(1 - p_{bd})$, where p_{td} was the weighting variable, for each year-by-stratum combination. k_d is a measure of how representative roadsides are of the proportion of the nondeveloped land in the township as a whole and, under the assumption that long-billed curlew never occur in developed areas, k_d represents a bias correction factor where $k_d = 1$ indicates there is zero bias.

RESULTS

During the 2004 and 2005 field seasons, we surveyed 139 and 145 routes, and we detected $\geq$1 long-billed curlew on 34 and 32 of these routes, respectively (Fig. 1). In both years we detected curlews in all radial distance bands, with the majority of birds detected in the 0-m to 400-m distance band. In 2004 and 2005, we detected 192 and 170 birds in the 0-m to 400-m distance band; however, we omitted 20 and 17 of these birds, respectively, from the analysis because they were flying overhead and passing through the area, or they arrived during the 5-minute count (hence violating the closure assumption; Table 2).

Double-Observer Method

We estimated detection probability, $\hat{p}^*$, using the double-observer method of Nichols et al. (2000) with data from routes with 2 observers present (128 of 139 routes in 2004 and 125 of 145 routes in 2005). In 2004, $c_p = 141$ and $c_s = 12$; thus, $\hat{p} = 0.915$ (SE = 0.026) and $\hat{p}^* = 0.993$ (SE = 0.004). Substituting this estimate into the formulae above for estimating long-billed curlew abundance, and assuming the area sampled per survey point was $(400 \text{ m})^2\pi/(10{,}000 \text{ m}^2/\text{ha}) = 50.3$ ha, we got a non–visibility-corrected abundance estimate of 130,175 (Table 3). In 2005, $c_p = 109$ and $c_s = 10$; thus, $\hat{p} = 0.908$ (SE = 0.030) and $\hat{p}^* = 0.992$ (SE = 0.006). Calculating the population estimate using the visibility correction gave an estimate of 105,457 (Table 3).

Table 2. The number of breeding long-billed curlews (LBCU) counted in the western United States during the 2004 and 2005 field seasons.

Stratum	Total no. of routes	No. of routes with LBCU	Distance band (m) 0–400	>400–800	>800	Total LBCU
2004						
1	37	7	45	27	34	106
2	52	15	70	44	6	120
3	45	12	57	15	1	73
4	5	0	0	0	0	0
Total	139	34	172	86	41	299
2005						
1	23	2	15	2	1	18
2	63	16	58	71	36	165
3	48	14	80	72	23	175
4	11	0	0	0	0	0
Total	145	32	153	145	60	358

Removal Method

In 2004 and 2005, the primary observer recorded 156 and 122 long-billed curlews with detection time-interval data. In 2004, the numbers detected during time intervals 1–5, where 1 refers to the first minute, 2 refers to the second minute, etc., were 53, 37, 28, 20, and 18, respectively, and in 2005, the numbers were 82, 18, 10, 9, and 3, respectively (Fig. 2). In 2004, the general model (i.e., $0 < c < 1$) yielded an Akaike's Information Criterion (AIC) value (Burnham and Anderson 2002) of 481.2, whereas the constrained model (i.e., $c = 1$) yielded an AIC value of 479.5. Though the AIC values under these 2 models were close, we chose to estimate q under the constrained model to get $\hat{q} = 0.749$ (SE = 0.045), which gave $\hat{p}^* = 0.764$ (SE = 0.070). Substituting this value into the formulae above for estimating curlew abundance, and again assuming the area sampled per survey point was 50.3 ha, we got the non–visibility-corrected abundance estimate of 157,128 (Table 3).

In 2005, AIC under the general model was 258.4 and under the constrained model was 265.2. Under the general model, $\hat{c} = 0.591$ (SE = 0.091) and $\hat{q} = 0.612$ (SE = 0.095), yielding $\hat{p}^* = 0.949$ (SE = 0.040). By substituting this value into the formulae above for estimating curlew abundance and using the visibility correction, we got an abundance estimate of 109,533 (Table 3).

Estimated Breeding Population

We believe the most defensible estimate of breeding long-billed curlews in the United States for 2004 is 164,515 (SE = 42,047), which is the 2004 double-observer estimate adjusted using the 2005 visibility correction factor of 1.2638 (Table 3). We favor the double-observer method over the removal method for 2004 because the estimate of p^* under the removal method seems anomalously low when compared to the double-observer method in 2004 (i.e., 0.993) and both methods in 2005 (i.e., $\geq$0.949). Furthermore, the 2004

Table 3. Estimated abundance of breeding long-billed curlews in the United States for 2004 and 2005 using the double-observer and removal methods.

Stratum	Double-observer method Abundance	SE	Removal method Abundance	SE
	2004—no visibility correction			
Total United States	130,175	33,270	157,128	39,987
1	15,034	6,730	29,809	15,594
2	66,168	27,055	67,421	28,641
3	48,972	18,154	59,898	23,141
4	0	0	0	0
	2004—visibility correction[a]			
Total United States	164,515	42,047	196,001	49,880
1	19,000	8,505	37,184	19,452
2	83,623	34,192	84,101	35,727
3	61,891	22,943	74,717	28,866
4	0	0	0	0
	2005—no visibility correction			
Total United States	83,440	26,615	87,812	24,396
1	11,133	11,133	11,378	10,623
2	20,980	8,883	30,342	11,464
3	51,327	22,484	46,092	18,732
4	0	0	0	0
	2005—visibility correction			
Total United States	105,457	33,765	109,533	31,060
1	18,029	18,029	18,203	17,198
2	26,415	11,058	37,392	13,945
3	61,013	26,321	53,938	21,782
4	0	0	0	0

[a] The 2004 visibility corrections used coeff. computed from the 2005 data (i.e., 1.2638 for double observer and 1.2474 for removal).

depletion curve under the removal method had an unusually heavy tail (Fig. 2), indicating that relatively more birds were detected later in the 5-minute sampling period in 2004, whereas this was not the case in 2005.

In 2005, estimates for the 2 analytical methods were consistent, and we applied visibility corrections. Because coefficients of variation for total abundance for the double-observer and removal methods were 32.0% and 28.4%, respectively, we favor the removal method population estimate of 109,533 ($\pm$ 31,060) breeding long-billed curlews in the United States for 2005 (Table 3).

Stratification and Power Analyses

There were no statistical differences among strata 1, 2, or 3 in curlew densities in 2004 (0.45 $\pm$ 0.20 SE, 1.00 $\pm$ 0.41, and 0.81 $\pm$ 0.30 curlews/1,000 ha, respectively) or in 2005 (0.55 $\pm$ 0.52, 0.57 $\pm$ 0.21, and 0.94 $\pm$ 0.38 curlews/1,000 ha, respectively). We evaluated whether our stratification scheme improved the precision of our overall abundance estimate by comparing it to the precision obtained when we assumed our routes were from a simple random sample. In 2004 and 2005, the ratio SE_{srs}/SE_{str} was 0.99 and 1.00, indicating that SE_{srs} was about 1% lower than SE_{str} in 2004, but that there was no difference in 2005. Likewise, using bootstrap methods, in both 2004 and 2005 the ratio SE_{srs}/SE_{str} was 1.01, indicating that SE_{srs} was about 1% higher than SE_{str} in both years. Both analyses indicate that

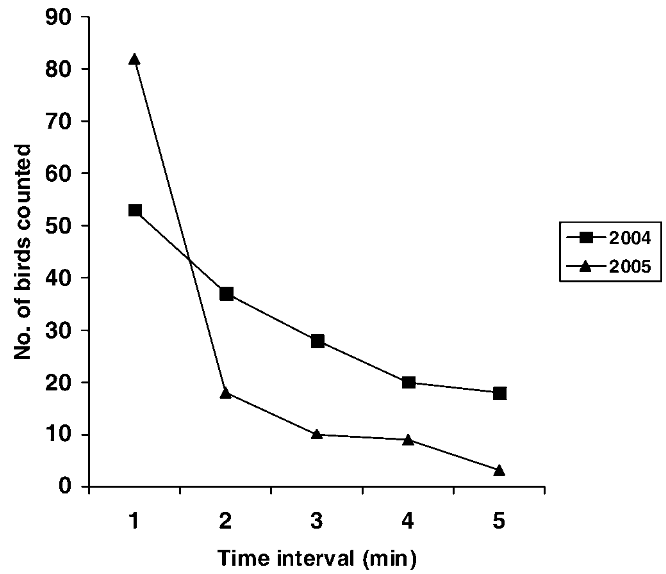

Figure 2. Removal method depletion curve showing the number of long-billed curlews counted during time intervals 1–5 by the primary observer in 2004 and 2005 in the western United States.

the stratification scheme we used did not improve precision relative to simple random sampling.

In 2004, we sampled 139 total routes with a resulting coefficient of variation of 25.6% under the double-observer method, and in 2005 we sampled 145 total routes for a coefficient of variation of 28.4% under the removal method. A biologically and operationally important question related to the attained level of precision is how many routes need to be sampled to detect a change in long-billed curlew abundance over a defined period of time with a desired level of certainty. Power analyses reveal that sample sizes as much as 13 times those in this study are required to detect a 20% population decline over 5 years, 10 years, 15 years, and 20 years (Fig. 3).

Roadside Habitat

Estimates of the average proportion of a township within 400 m of a road (p_b) ranged from 0.48 to 0.64 in 2004, and from 0.48 to 0.56 in 2005 (Table 4). Our estimates of the bias-correction factors for grassland (k_g) and developed areas (k_d) showed, overwhelmingly, that the bias in abundance estimates incurred from sampling roadsides was small and slightly negative. One exception was k_g for stratum 1 in 2005, which suggested grasslands were overrepresented by about 8.7% along roadsides when compared to the township as a whole. However, because the number of long-billed curlew in stratum 1 was proportionately small relative to that in strata 2 and 3, the net effect of the bias corrections for this stratum and the other strata was to increase our estimates of abundance. To compute the bias-corrected abundance estimate (N_a), we used the formula $N_a = \sum_{i=1}^{4} k_i N_i$, where k_i is the estimated correction factor for the ith stratum (Table 4), and N_i is the abundance estimate for the ith stratum (Table 3). For grassland in 2004 and 2005, the adjusted abundance estimates were 169,934 and 110,493, and for developed areas in 2004 and 2005 the

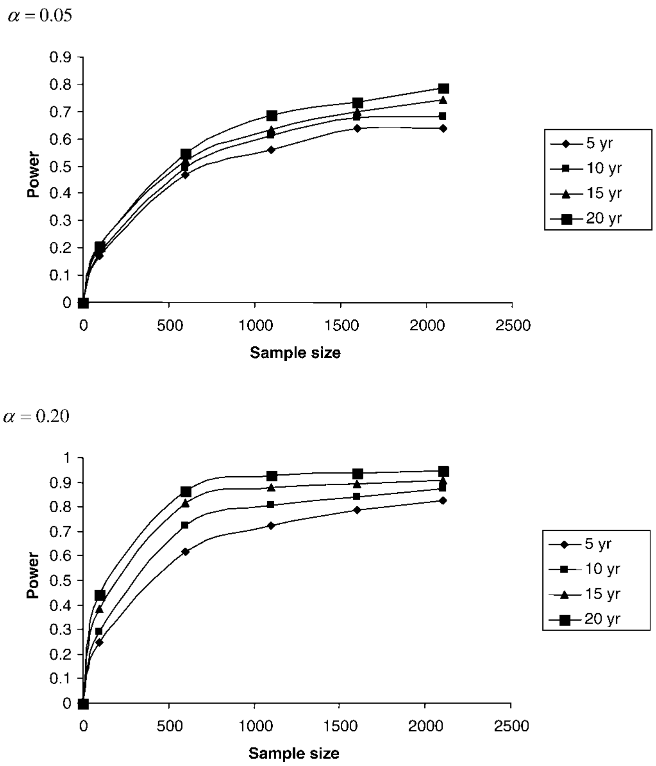

Figure 3. Power curves showing sample sizes needed to detect a 20% decline in long-billed curlew abundance occurring over 5 years, 10 years, 15 years, or 20 years in the western United States.

Table 4. Results of the 2004 and 2005 roadside habitat analysis for long-billed curlew surveys in the western United States, where n is the number of townships, p_b is the proportion of the township within 400 m of a road, k_g is the grassland bias correction factor ($k_g = 1$ indicates bias is zero), and k_d is the bias correction factor for developed land ($k_d = 1$ indicates bias is zero).

		p_b		k_g		k_d	
Stratum	n	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**
2004							
1	37	0.48	0.024	1.02	0.052	1.02	0.002
2	52	0.60	0.024	1.05	0.028	1.01	0.001
3	45	0.55	0.017	1.02	0.012	1.01	0.001
4	5	0.64	0.073	1.00	0.132	1.00	0.000
2005							
1	23	0.48	0.043	0.92	0.056	1.01	0.001
2	63	0.56	0.024	1.04	0.024	1.00	0.000
3	48	0.56	0.016	1.02	0.008	1.00	0.000
4	11	0.53	0.061	1.01	0.052	1.00	0.000

adjusted abundance estimates were 166,573 and 110,137. These estimates are slightly larger but very close to the unadjusted estimates (Table 3). Thus, there is little reason to believe surveying roadsides seriously biased our abundance estimates.

DISCUSSION

Prior to this survey, shorebird experts estimated the North American long-billed curlew population to be 20,000 (Brown et al. 2001, Morrison et al. 2001). This estimate was based primarily on expert opinion and local surveys during winter and migration (i.e., nonbreeding periods) and was proposed with moderate confidence (thought to be within 50% of true no.). Recently, this estimate was revised upwards to 40,000 (R. I. G. Morrison, Environment Canada, personal communication). Extrapolations from counts recorded on BBS surveys using Partners in Flight physiographic strata resulted in a much higher estimate of 168,000, which was considered unrealistic because of the coarse nature of the land cover data (Morrison et al. 2001). Our 2004 population estimate, however, is very close to this number. The population estimates from our study, 164,515 in 2004 and 109,533 in 2005, far exceed the currently accepted estimate of 40,000 birds, suggesting that even given the obvious nature of large flocks during migration and winter, a substantial portion of the population is unrepresented in counts during the nonbreeding period.

In southern Alberta, Canada, Saunders (2001) estimated 23,884 ± 4,762 long-billed curlews. Saunders (2001) and this study similarly found that curlews were present and apparently breeding in areas with little native grassland, as demonstrated by the lack of strong differences in curlew densities between stratum 1 and stratum 2 (2004 difference [curlews/1,000 ha] was 0.55 ± 0.46 SE, 2005 difference was 0.02 ± 0.56 SE). Saunders (2001), however, found significantly more curlews in stratum 3 than in strata 1 and 2, whereas we did not (largest difference [curlews/ha] was 0.39 ± 0.64 SE for stratum 1 vs. 3 in 2005). This contrast in findings could be due either to the large variances in our strata estimates, or it could be due to differences in the land-use databases used to classify the landscape into strata. For example, Saunders (2001) was able to distinguish tame pasture from native prairie using Alberta's Native Prairie Inventory (Alberta Environmental Protection 1999), whereas we were not able to do so using NLCD. Our grassland was therefore analogous to native prairie + tame pasture found in Saunders (2001); thus, each Canadian stratum probably averaged more grassland than did the comparable United States stratum because of the added tame pasture component in the United States.

Survey Design Considerations

The stratification scheme we used had virtually no effect on precision of population estimates. Most grassland habitats in stratum 1 (township contains 1–5% grassland or 93–466 ha of grassland) were likely larger than the minimum size of grasslands used by long-billed curlews (<100 ha; derived from information in Dugger and Dugger 2002); therefore, even grasslands in stratum 1 may have been above a minimum size threshold for breeding. Because the rationale for using stratification is to minimize the variance in the sample and increase precision of the estimate, and our stratification scheme did not do so, we recommend use of simple random sampling in future applications of this survey design. Alternatively, stratification schemes based on other criteria could be formally investigated. Grassland type, vegetation structure, and grazing history (as it affects vegetation structure) appear to play a role in habitat selection

(Pampush and Anthony 1993, Dugger and Dugger 2002) and may be useful for stratification.

The single-observer detection probabilities of curlews under the double-observer method (0.915 in 2004 and 0.908 in 2005) and under the removal method (0.764 in 2004 and 0.949 in 2005) suggest that simple single-observer counts of curlews uncorrected for detectability would be negatively biased. Thus, in future surveys some means of estimating detectability will be crucial. As was concluded by Moore et al. (2004), we favor use of the removal method over the double-observer method on the basis of both precision and cost-effectiveness. The relative precision of the methods based on coefficients of variation alone showed the removal method was more precise than the double-observer method, and the removal method is more cost-effective because it requires only one observer whereas the double-observer method requires 2 observers. There is a need, however, to ensure the homogeneity of detection probability and closure assumptions of the removal method are met. In 2004, our depletion curve under the removal method had an unusually heavy tail (Fig. 2), indicating that we detected relatively more birds later in the 5-minute sampling period. Thus, in future surveys we recommend observers put more effort into 1) quickly scanning a full 360° at a point before searching the area more intensively, 2) streamlining the data recording process so that more time can be spent searching earlier in the sampling interval (this is especially important when many curlews are present), and 3) clearly distinguishing on the data sheet which birds were seen arriving during the sampling interval. Such measures should help produce depletion curves that do not flatten out at a value above zero.

Potential Sources of Bias

Various potential sources of bias that might degrade abundance estimates are a concern in studies such as ours. One potential source of bias stems from the fact that roadside habitat may not be representative of habitat in the township as a whole. It is well known that long-billed curlews breed in grasslands (Dugger and Dugger 2002). If grassland habitat is more common along roads than in the township as a whole, we would expect our abundance estimates to be positively biased. Likewise, if curlews avoid developed habitats that occur more frequently along roads than in the township as a whole, our abundance estimates might be negatively biased. Our results suggested that differences in grassland and developed areas between roadsides and the township as a whole were minimal and had negligible effects on our abundance estimates (Table 4). They suggest that, if anything, our estimates are slightly negatively biased and could be adjusted upwards (the adjustment is $<3.3\%$).

A second potential source of bias occurs if the effective area sampled is larger than the nominal area sampled, which would tend to positively bias abundance estimates. This effect can occur in 2 ways: the first if the closure assumption was violated and there was a net movement of birds into the 400-m band during the 5-minute count, and the second if observers made errors when estimating the location of the 400-m distance band. As discussed earlier, we omitted birds from our analysis that arrived during the 5-minute count and have multiple reasons to believe it is unlikely that arriving birds would go unnoticed. Thus, we do not think there was bias due to failure of the closure assumption. We cannot, however, dismiss the possibility that observers incorrectly estimated the location of the outside edge of the 400-m distance band. To explore this potential problem we estimated the percent bias in area sampled as a function of the error of the distance estimate. We found that for an error of 10 m, the percent positive bias in our abundance would be approximately 0.125%, which is arguably trivial. Even with an error of 50 m, the percent bias in our abundance estimates would only be 3.125%. Because observers had laser rangefinders to aid in distance estimation, the halfway point between consecutive stops was 400 m and could be used as a visual guide, and observers were also counting birds in the 400-m to 800-m band (hence, there should not have been a temptation to lump into the 400-m band birds detected just outside the 400-m band), we are confident that errors were small and the effective area sampled was close to the nominal area sampled.

A third potential source of bias would occur if a route is sampled before the arrival of breeding birds to an area or after the courtship period when birds are less conspicuous (i.e., detectability falls to near zero). In either case, counts would be negatively biased and estimates of the breeding population size would be conservative. Although Saunders (2001), following recommendations of Redmond et al. (1981), targeted the courtship-to-hatching period for surveys, we attempted to further narrow the survey window to exclude the incubation period. The implementation of a narrower time window for surveys, however, is problematic, especially over such a broad geographic area, because when the number of surveyors is limited it is often not physically possible to sample every route during the optimal time. Thus, in our study some routes may have been sampled before the arrival of breeders or after incubation had begun, and our estimates of the breeding population size are probably conservative.

MANAGEMENT IMPLICATIONS

Our study demonstrates that statistically rigorous, large-scale surveys to determine the distribution and abundance of an uncommon species like the long-billed curlew are possible. One implication of our research is that the Highly Imperiled status for long-billed curlew in the Canadian and United States shorebird conservation plans (Donaldson et al. 2000, Brown et al. 2001) should, perhaps, be revisited. A second implication of our study is that any effort to implement a monitoring program to assess trends in long-billed curlew abundance will require a long-term commitment and vast resources. Sample sizes as much as 13 times larger than ours would be required to detect a 20% decline in the population over a 20-year period ($\alpha = 0.05$, power $=$ 0.80; Fig. 3). Finally, an unexpected finding was that long-billed curlews were present and presumably breeding in areas with relatively little native grassland (e.g., stratum 1, 93–466 ha grassland), suggesting that managing for the current estimated minimum size threshold for breeding (i.e., 100 ha) is reasonable.

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LITERATURE CITED

Alberta Environmental Protection. 1999. Baseline inventory of native vegetation in the grassland native region. Prairie Resource Information Unit, Alberta Environmental Protection, Lethbridge, Canada.

Bart, J., B. Andres, S. Brown, G. Donaldson, B. Harrington, V. Johnston, S. Jones, R. I. G. Morrison, and S. K. Skagen. 2005. The program for regional and international shorebird monitoring (PRISM). Pages 893–901 *in* C. J. Ralph and T. D. Rich, editors. Bird conservation implementation and integration in the Americas. Volume 2. United States Department of Agriculture Forest Service General Technical Report PSW-GTR-191, Pacific Southwest Research Station, Albany, California, USA.

Brown, S., C. Hickey, B. Harrington, and R. Gill, editors. 2001. United States shorebird conservation plan. Second edition. Manomet Center for Conservation Sciences, Manomet, Massachusetts, USA. <http://www.fws.gov/shorebirdplan/USShorebird/downloads/USShorebirdPlan2Ed.pdf>. Accessed 4 Jan 2007.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82:399–415.

Cochran, W.G. 1977. Sampling theory. John Wiley and Sons, New York, New York, USA.

Dahl, T. E. 1990. Wetland losses in the United States 1780's to 1980's. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C., USA.

Donaldson, G. M., C. Hyslop, R. I. G. Morrison, H. L. Dickson, and I. Davidson. 2000. Canadian shorebird conservation plan. Canadian Wildlife Service Special Publication CW69-15/5-2000E, Ottawa, Ontario, Canada.

Dugger, B. D., and K. M. Dugger. 2002. Long-billed curlew (*Numenius americanus*). Account 628 *in* A. Poole and F. Gill, editors. The birds of North America. Birds of North America, Philadelphia, Pennsylvania, USA.

Efron, B. 1979. Bootstrap methods: another look at the jackknife. Annals of Statistics 7:1–26.

Environmental Systems Research Institute (ESRI). 2002. ESRI data and maps 2002. Environmental Systems Research Institute, Redlands, California, USA. <http://www.esri.com>. Accessed 4 Jan 2007.

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. Auk 119:414–425.

Moore, J. E., D. M. Scheiman, and R. K. Swihart. 2004. Field comparison of removal and modified double-observer modeling for estimating detectability and abundance of birds. Auk 121:865–876.

Morrison, R. I. G., R. E. Gill, B. A. Harrington, S. Skagen, G. W. Page, C. L. Gratto-Trevor, and S. M. Haig. 2001. Estimates of shorebird populations in North America. Environment Canada Canadian Wildlife Service Occasional Paper 104, Ottawa, Ontario, Canada.

Multi-Resolution Land Characteristics Consortium. 2000. National land cover characterization. <http://landcover.usgs.gov/uslandcover.php>. Accessed 4 Jan 2007.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393–408.

North American Bird Conservation Initiative. 1998. Strategic framework for monitoring North American bird populations. <http://www.nabci-us.org/aboutnabci/monstratframe.pdf>. Accessed 4 Jan 2007.

Page, G. W., L. E. Stenzel, and J. E. Kjelmyr. 1999. Overview of shorebird abundance and distribution in wetlands of the Pacific Coast of the contiguous United States. Condor 101:461–471.

Pampush, G. J., and R. G. Anthony. 1993. Nest success, habitat utilization, and nest-site selection of long-billed curlews in the Columbia Basin, Oregon. Condor 95:957–967.

Redmond, R. L., T. K. Bicak, and D. A. Jenni. 1981. An evaluation of breeding season census techniques for long-billed curlews (*Numenius americanus*). Studies in Avian Biology 6:197–201.

Ridgely, R. S., T. F. Allnutt, T. Brooks, D. K. McNicol, D. W. Mehlman, B. E. Young, and J. R. Zook. 2003. Digital distribution maps of the birds of the western hemisphere. Version 1.0. NatureServe, Arlington, Virginia, USA. <http://www.natureserve.org>. Accessed 4 Jan 2007.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44:418–421.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, results and analysis 1966–2005. Version 6.2.2006. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. <http://www.mbr-pwrc.usgs.gov/bbs/>. Accessed 12 Jan 2007.

Saunders, E. J. 2001. Population estimate and habitat associations of the long-billed curlew (*Numenius americanus*) in Alberta. Alberta Species at Risk Report 5, Edmonton, Canada. <http://mountain-prairie.fws.gov/species/birds/longbilled_curlew/LBCU-Alberta.pdf>. Accessed 4 Jan 2007.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Second edition. Macmillan, New York, New York, USA.

Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics 4:404–414.

Zumberge, J. H., and R. H. Rutford. 1983. Laboratory manual for physical geology. Sixth edition. W. H. Brown, Dubuque, Iowa, USA.

Associate Editor: Ransom.