WATERBIRDS

JOURNAL OF THE WATERBIRD SOCIETY

VOL. 31, NO. 1 | 2008 | PAGES 1-158

Breeding Abundance and Distribution of Long-billed Curlews (*Numenius americanus*) in North America

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Abstract.—A population survey for Long-billed Curlews (*Numenius americanus*) was completed in the western United States and Canada in 2004 and 2005. This survey was conducted during the early breeding season, using a stratified random sample from habitat strata. The survey design was a 32-km road transect with 40 five-min point counts at 800-m intervals. Detection probabilities were estimated using the removal method in which observations in one-min intervals were removed from further consideration. Model selection based on Akaike's Information Criterion resulted in a model where detection probability varied among observers, but was constant throughout the point count for each observer. Estimated detection probabilities for the point count duration were greater than 0.68 for all observers. Counts were adjusted for detection probability and then used to estimate the mean density within surveyed point count plots. Overall, the range-wide estimate of total population size was 161,181 individuals. The estimates were 183,231 individuals for 2004 and 139,131 for 2005, with corresponding 90% confidence intervals of 113,324 to 422,046 and 97,611 to 198,252, respectively. In addition to estimates for both the United States and Canada, population densities were estimated for geographic sub-regions: Bird Conservation Regions, Shorebird Planning Regions, administrative regions, and for each Canadian province. Issues and assumptions inherent in the study design and their implications are discussed. *Received 13 March 2007, accepted 21 October 2007.*

Key words.—abundance, distribution, grassland, Long-billed Curlew, *Numenius americanus*, point counts, removal method.

Waterbirds 31(1): 1-14, 2008

Long-billed Curlews (*Numenius americanus*) (curlews) are a migratory shorebird that breed in western North America, primarily in the shortgrass and mixed-grass prairies of the Great Plains, desert grasslands of the Great Basin and Columbia River Plateau, and in the intermountain valleys of the Rocky Mountains and British Columbia (Dugger and Dugger 2002). Curlews are a species of special concern with both the United States and Canadian shorebird conservation plans listing them as *Highly Imperiled* throughout their breeding range in North America (Donaldson *et al.* 2000; Brown *et al.* 2001). They are a Bird of Conservation Concern in the United States, in United States Fish and Wildlife Service's Regions 1, 2, 4, and 6, and within several Bird Conservation Regions (BCR) (United States Fish and Wildlife Service 2002). Curlews are listed as Endangered, Threatened, or as a species of concern in several states (NatureServe 2006; Fellows and Jones, in prep.). The Committee on the Status of Endangered Wildlife in Canada designated curlews as a species of Special Concern in 1992 and reconfirmed this designation in 2002 (Committee on the Status of Endangered Wildlife in Canada 2002). In 2004 they were added to Schedule 1 of the Species at Risk Act as a species of Special Concern (Environment Canada 2004). Curlews are Blue Listed in two provinces and extirpated in one (NatureServe 2006; Fellows and Jones, in prep.). The high levels of conservation concern are due to population declines and range contractions, particularly in the shortgrass and mixed-grass prairies of the western Great Plains (Brown *et al.* 2001).

Curlews no longer breed further east than the Missouri River in the Dakotas, in west central Nebraska and in a few counties in southwestern Kansas, although historically they were a locally common breeding bird as far east as southeastern Wisconsin, northeastern Illinois, and throughout southern Manitoba (NatureServe 2006; Fellows and Jones, in prep.). This range contraction has been attributed to intense market hunting in the late 1800s, plowing of the prairies for agriculture, and may have initially begun when Bison (*Bison bison*) were regionally extirpated by early settlers and hunters (R. Russell, pers. comm.). Current threats include habitat loss and fragmentation due to agricultural conversion (cropland and tame pasture), woody vegetation encroachment, loss of a grazing economy, particularly in areas of the Dakotas, Nebraska, and Kansas, severe droughts, wetland drainage, and the spread of exotic invasive plants; to a lesser extent, urban development, and recently wind power development (Dugger and Dugger 2002; Oring 2006).

The reliability of the North American Breeding Bird Survey (BBS) trend estimates for curlews (Sauer *et al.* 2005) has been questioned. Issues of poor precision (J. Bart, pers. comm.), potential observer (Faanes and Bystrak 1981) and road biases (Bart *et al.* 1995; Hanowski and Niemi 1995) have been raised, but the primary concern is the timing of BBS surveys, which are typically conducted in June. This period coincides with the late stage of incubation, where curlews are generally inconspicuous, or the young have already fledged and curlews departed nesting grounds. While the BBS is primarily used for trend monitoring, recent efforts to use BBS data (Thogmartin *et al.* 2006) to make inferences about abundances resulted in a need to validate curlew population estimates.

Concerns over the present status of curlew populations in both the United States and Canada, coupled with inadequacies of the BBS, prompted the development of a study to estimate the breeding population size and distribution of this species rangewide. Also, the first step for the development of management and conservation strategies was the determination of current population numbers, current range, and to identify populations and/or areas of concern. To meet this need, the United States Fish and Wildlife Service (USFWS) and the United States Geological Survey (USGS) designed a survey targeted specifically for curlews (Jones *et al.* 2003) and conducted the survey in 2004 and 2005. The design followed a similar study conducted in Alberta in 2000 (Saunders 2001). Our primary objective was to estimate the population size and provide information on distribution of curlews across the breeding range in North America, as well as by country, geographical region, USFWS administrative boundaries (United States Fish and Wildlife Service 2006), and BCRs (North American Bird Conservation Initiative 2006).

METHODS

Survey Area

Most of the known breeding range of curlews was the area defined for sampling (Fig. 1), including the entire breeding range in the United States and British Columbia. In Alberta and Saskatchewan, the survey area was restricted to the Grassland Natural Region, where most curlews are thought to occur (although some curlews breed in the Parkland Natural Region, though at very low densities).

United States. A single, unified sampling design was employed for the study area within the United States. The sample unit was the township, as created by the Public Land Survey System. A township is approximately a 9.7 km per side square unit of land. Each township was assigned to one of four strata based on elevation and land cover classification as defined by the National Land Cover Database (NLCD) (National Land Cover Database 2001; Stanley and Skagen 2005). Townships were stratified based on percentage of the area classified as grassland cover. Stratum 1 designated potential low quality curlew habitat (0-5% grassland cover), Stratum 2 designated potential medium quality habitat (5-50% grassland cover), and Stratum 3 designated potential high quality habitat (>50% grassland cover). Finally, Stratum 4 designated areas thought to be unsuitable curlew habitat and consisted of townships in which 70% or more of the total township either exceeded an elevation cutoff (Jones *et al.* 2003) or was classified as either *developed*, *forested upland*, or *water*. Townships falling on or within the boundaries of the delineated geographic range defined the survey area. In 2004, the United States sampling frame included 21,405 townships, covering a total area of 186,072,700 ha. In 2005, the geographic

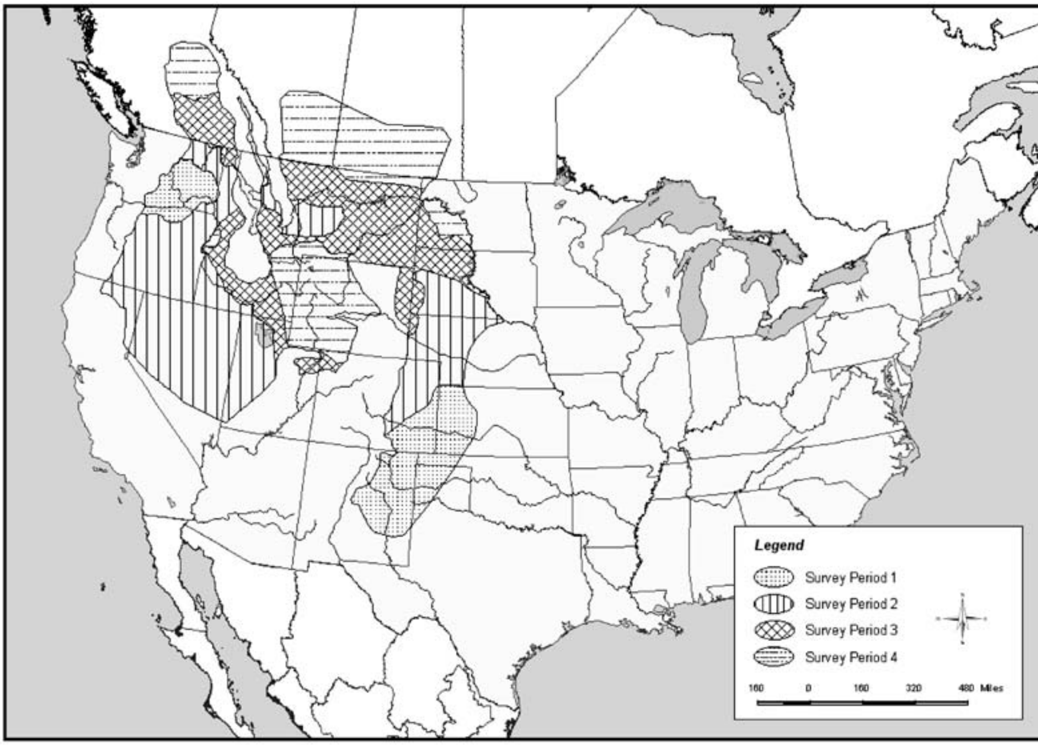

Figure 1. Long-billed Curlew rangewide survey area and timing. Four survey periods were defined geographically and surveyed during periods of the first arrival of Long-billed Curlews on breeding grounds. In 2004: survey period 1 = 21 March-10 April; survey period 2 = 28 March-17 April; survey period 3 = 11 April-1 May; and survey period 4 = 21 April-15 May. In 2005: survey period 1 = 28 March-20 April; survey period 2 = 3 April-27 April; survey period 3 = 8 April-3 May; and survey period 4 = 21 April-15 May.

range was modified, decreasing areas in Oklahoma, Texas and New Mexico that were outside the current curlew known range, resulting in an altered sampling frame that included 20,906 townships, covering an area of 181,984,268 ha (Stanley and Skagen 2005).

Townships were selected by simple random sampling within each stratum and each year. Sample allocation among Strata 1-3 was proportional to estimated variances; allocation in 2004 was based on variance estimates from Saunders' (2001) results from Alberta, while allocation in 2005 was based on variance estimated from the 2004 United States survey.

Canada. Curlew surveys in Canada were coordinated following protocols similar, but not identical, to those in the United States. Differences included habitat stratification, survey design and field protocols. Furthermore, surveys in each of the three provinces (Alberta, British Columbia, and Saskatchewan) were conducted independently of each other. Within British Columbia, further administrative division led to largely independent surveys in two separate regions of the province.

A single database comparable to the NLCD (National Land Cover Database 2001) was not available in Canada to determine land cover. Alberta relied on its Native Prairie Inventory (Saunders 2001), which is based on satellite imagery. Saskatchewan has a similar prairie inventory, but British Columbia classified land cover based on non-satellite data from Nature Conservancy Canada.

Alberta and Saskatchewan had existing township systems similar to that developed in the United States with townships approximately square, 9.7 km per side. British Columbia had no such existing system; rather, a grid was placed over the landscape within a geographic information system producing "blocks" similar to townships.

Minor differences existed in the definition of strata between the United States and each Canadian province; however, these differences do not affect the accuracy of the surveys (Nations *et al.* 2007). Alberta and British Columbia defined Strata 1-3 as in the United States, while Saskatchewan designated the cutoff between Strata 1 and 2 as 10% rather than 5% grassland.

Strategies for selecting townships within strata varied among the Canadian provinces and the United States. In Alberta, half of the townships (and associated routes) randomly selected during Saunders' (2001) study were retained to monitor changes in abundance and distribution. Approximately 20 routes, randomly sub-sampled from those in the previous study, were surveyed again using the same observers in both years of this study. Additional routes were randomly selected in 2004 and again in 2005 from the remaining pool for the purpose of this range-wide survey. In Saskatchewan, some townships/routes in the sample were those retained from surveys that had been conducted in 1988, 1989, and 1991, using townships that had been randomly selected (U. Banasch, pers. comm.). In both regions of British Columbia and in Saskatchewan, survey organizers sought to maintain target sample sizes within each stratum. Consequently, blocks were randomly selected in both years of the study for all three provinces.

Survey Timeframe

Curlew surveys were completed in 2004 and 2005 during the pre-incubation stage, when birds are most conspicuous (Redmond *et al.* 1981; Jones *et al.* 2003). Time-of-year for this stage correlates with ambient air temperature and plant phenology, which in turn, varies with latitude and elevation (Redmond *et al.* 1981). To develop this index, the study area was partitioned so that date intervals represented the average breeding period for curlews for that specific location. This was accomplished by correlating "First Lilac Leaf Date" data (Redmond *et al.* 1981; Cayan *et al.* 2001) with extensive first arrival date and breeding records acquired from the literature (SLJ, unpubl. data). This information was then used to partition the entire survey area into large geographic regions to conduct surveys (Fig. 1). In general, southern latitudes were surveyed earlier than more northern latitudes in both years. Four survey periods were defined geographically (Fig. 1) and surveyed during the following dates in 2004: (1) 21 March-10 April; (2) 28 March-17 April; (3) 11 April-1 May; and (4) 21 April-15 May. Surveys were adjusted, based on observations from 2004, to take place a week later in 2005 to avoid counting late migrants in the southern portion of the range and to increase the sampling time. The dates in 2005 were: (1) 28 March-20 April; (2) 3 April-27 April; (3) 8 April-3 May; and (4) 21 April-15 May (Fig. 1).

Survey Protocol

A single road transect was non-randomly designated within each township, following the methods developed by Saunders (2001). Selection criteria included that routes follow existing secondary or tertiary roads, were 32-km long, and parallel segments had to be separated by a distance ≥1.6 km. Routes were traversed by motor vehicle. Five minute point counts were conducted at 800-m intervals so that there were 40 planned stops along each route. Surveys started ≥0.5 h after sunrise and typically took four to six h to complete and were terminated at least 0.5 h before sunset. More than one route was occasionally conducted per day. Surveys were not conducted during periods of inclement weather, i.e. during moderate rain and snow, or in high winds >25 km/h.

During each point count, all curlews seen or heard within a five-min period were recorded. Each count period was divided into five one-min intervals and the appropriate interval was recorded for each detected curlew. Distance from the observer to the bird was estimated using either a laser rangefinder or by ocular estimation, and recorded in one of three distance bands: <400 m, 400-800 m, and >800 m. Additional information for each detected curlew included behavior, sex (if possible), and flocking status (e.g., single, pair, flock). In Canada, single observers were used for each transect. In the United States, transects were generally (92.1% in 2004 and 86.2% in 2005) surveyed by teams of two observers using the double observer method (Nichols *et al.* 2000).

Analysis

Curlews that flew into the plot during the five-min period (fly-ins), birds that flew over the plot but did not land (flyovers), and flocks of non-breeding birds either observed feeding within the plot or flying over were so noted during data collection. To provide conservative estimates, the analysis excluded all these data. In addition, the analysis addressed only those observations within the 0-400 m zone.

In 2004 and 2005, 15 townships were sampled from within Stratum 4 in the United States only. Because no sampling was conducted within Stratum 4 in Canada and no curlews were observed in Stratum 4 in the United States in either year, the analysis considered only data from Strata 1, 2, and 3.

Detection Probability Modeling

A unified analysis of detection probability was conducted using the removal method (White *et al.* 1982; Farnsworth *et al.* 2002). Field protocols were consistent with the removal model in that birds newly observed within each successive interval were recorded and not counted again in the remaining one-min intervals. The fundamental data were the lengths of all one-min intervals, totaling five-min and the counts of birds within each interval. Observations within one-min intervals were summed across the two observers in the United States and the two observers were treated as a team.

To summarize the model, let q be the probability that a bird is not detected in one minute and assume that q is constant over the five-min period. For a bird observed during the first minute, the unconditional probability of being detected is $1 - q$. A bird newly observed during the second minute must have been unobserved during the first minute; thus, its unconditional probability of detection is $q(1 - q)$. Similarly, the probability of detection during the third minute is $q^2(1 - q)$, and so on. Finally, probability of detection at any time during the five-min period equals $1 - q^5$.

The full multinomial model depends on the total number of birds present, which is unknown. Conditioning on the total number of birds observed removes that dependency, and the resulting probability density function is

$$f(x_1, \ldots, x_5 | x_\bullet) = \frac{x_\bullet!}{\prod_{i=1}^{5} x_i!}\left[\frac{1-q}{1-q^5}\right]^{x_1}\left[\frac{q(1-q)}{1-q^5}\right]^{x_2}\left[\frac{q^2(1-q)}{1-q^5}\right]^{x_3}\left[\frac{q^3(1-q)}{1-q^5}\right]^{x_4}\left[\frac{q^4(1-q)}{1-q^5}\right]^{x_5} \tag{1}$$

where x_i is the number of birds observed in the i^{th} minute and $x_\bullet$ is the total number observed. The likelihood for this model is

$$L(q | x_1, \ldots, x_5) \propto \left[\frac{1-q}{1-q^5}\right]^{x_1}\left[\frac{q(1-q)}{1-q^5}\right]^{x_2}\left[\frac{q^2(1-q)}{1-q^5}\right]^{x_3}\left[\frac{q^3(1-q)}{1-q^5}\right]^{x_4}\left[\frac{q^4(1-q)}{1-q^5}\right]^{x_5} \tag{2}$$

The parameter estimate $\hat{q}$ is obtained by maximizing the log likelihood. Then, the probability that a bird is detected during the five-min period is calculated as $\hat{p} = 1 - \hat{q}^5$.

Model Selection

Consideration was given to models in which the parameter q was assumed constant over the five-min period, but was allowed to vary with one or more factors, which included year, country, stratum, state or province, and observer identity (whether an individual or a unique pair of individuals). It was found that the large number of factor levels (observers or states) tended to produce models whose parameters could not be estimated (i.e., not all parameters were identifiable). Therefore, observers or states with few counts were collapsed into an "Other" category. In addition to main effects models, selected interaction models were fitted including *year* × *country*, *year* × *stratum*, *country* × *stratum*, and *year* × *country* × *stratum*. For instance, *year* × *country* denoted a two-way interaction model in which the parameter q varied freely at each of the four combined levels of year and country. Finally, linear constraints were imposed on interactions so that effects were additive rather than multiplicative. For instance, *year + country* denoted parallelism such that any difference between the Canada and the United States was the same in 2004 and 2005. Because of sparse data, interactions or additive models involving either observer identity or state/province were not considered.

To construct the dataset appropriate for each of the candidate models, counts were aggregated across routes. Using the observer model, for instance, counts made by each observer (or observer team) within each minute were totaled across both space and year.

The final list of candidate models was evaluated within an information-theoretic framework (Burnham and Anderson 2002). Akaike's Information Criterion (AIC) was calculated for each model, models were ranked from smallest to largest AIC, and differences in AIC were calculated. For model i, the difference $\Delta_i = \mathrm{AIC}_i - \min_i(\mathrm{AIC})$ was calculated, where $\min_i(\mathrm{AIC})$ was the minimum AIC (Burnham and Anderson 2002). The model with the lowest AIC was selected. Differences in AIC between the top-ranked model and each of the remaining models were so large that model averaging was unnecessary. Goodness-of-fit for the top-ranked model was assessed using chi-squared procedures (White *et al.* 1982). The expected count at each interval was calculated as

$$\hat{E}(x_i) = \hat{N}(1 - \hat{q})\hat{q}^{i-1}, i = 1,\ldots,5$$

where was the total count adjusted for detection probability. Then, the chi-squared statistic was calculated in the usual way as

$$X^2 = \sum_{i=1}^{5} \frac{[x_i - \hat{E}(x_i)]^2}{x_i} \qquad (3)$$

Population Size Estimation

Detection probability was estimated using only those observations for which the time interval was recorded. However, population estimation relied on all observations including those that lacked any record of the one-min interval. For each point count, probabilities were estimated using the selected model. Dividing the observed count by the estimated probability of detection yielded the adjusted count (adjusted to account for the assumption that not all curlews were counted at a given point).

Estimates of population size were obtained for each stratum within each political entity in each year. First, adjusted bird counts were summed across all points within each combination of stratum, political entity, and year. The corresponding survey area (for each combination of stratum, political entity, and year) was obtained by multiplying the number of points by plot area (the area of the 400-m radius circle surrounding each point). Then, density was calculated by dividing the total adjusted count by the total area (for each combination). In effect, each completed stop received equal weight, or equivalently, each route received weight proportional to the number of completed stops. Multiplying density by stratum area (within each political entity and year) yielded population size within each stratum. A population total was obtained for each political entity and year by summing across strata, and a grand total was obtained for each year by summing estimates across both strata and political entities.

Variance estimates were obtained using a bootstrapping procedure (Manly 2007) that followed the sample design. At each bootstrap iteration, a random sample of routes was drawn with replacement from each of the 24 combinations of political entity (4), stratum (3), and year (2). Detection probabilities were re-estimated from the re-sampled data using the models fit to the original data. Population estimates were calculated as described above and then stored. This process was repeated 1,000 times to generate a bootstrap distribution of population estimates. If the nonlinear optimization routines used to maximize the likelihood failed to converge on a solution, then additional bootstrap samples were generated to form a total of 1,000 bootstrapped estimates. Means, medians, and standard deviations were calculated from each set of 1,000 bootstrapped estimates. In addition, 90% confidence intervals were estimated using the percentile method (Manly 2007).

All analyses were performed using the numerical analysis software package Matlab 6.5 (Mathworks 2002).

RESULTS

Survey Summary

In the United States, 41% of the routes were <32 km in length, and consequently had <40 stops. In 2004, 62% of the routes were <32 km in length, with a mean of 32 stops per route. In 2005, 22% of the routes were <32 km in length, with a mean of 38 stops per route. Where recorded, the causes for shortened routes included poor weather, impassable roads, time constraints, or no access to private property.

In 2004, shortened routes in British Columbia and Saskatchewan were primarily an unintended consequence of logistical constraints (e.g., difficulty in identifying routes of adequate length and insufficient time for surveys). In 2005, shortened routes were created by design in both provinces, though in Saskatchewan additional townships/routes were selected randomly to compensate for the shorter lengths. Transects in British Columbia averaged 32.3 stops/route in 2004 and 23.7 stops/route in 2005. Saskatchewan surveys averaged 28.7 and 24.8 stops per route, respectively, in 2004 and 2005. In Alberta, over both years combined, five routes were shortened because of impassable road conditions.

More curlew habitat was contained within the United States (ca. 150 million ha) than Canada (ca. 24 million ha) (Table 1). Furthermore, curlew habitat within the United States was characterized by greater proportion of grassland cover. Roughly 42% of the study area in the United States was classified as Stratum 3 while about 25% of the study area in Canada was similarly classified. Both in terms of number of routes and total area actually surveyed, absolute survey effort was greater in the United States than in Canada. However, relative to amount of curlew habitat, survey intensity was greater in Canada.

Table 1. Stratum area in hectares and percentage area, by political entity for Long-billed Curlew rangewide survey, 2004-2005.

Political entity	Stratum	Area (ha)	% Total area
Alberta	1	1,732,600	17.2
	2	5,326,800	52.9
	3	3,004,400	29.9
British Columbia	1	807,621	30.9
	2	1,560,685	59.6
	3	249,348	9.5
Saskatchewan 2004	1	2,927,664	27.8
	2	5,073,581	48.3
	3	2,511,130	23.9
Saskatchewan 2005	1	3,283,027	26.9
	2	6,316,963	51.8
	3	2,585,779	21.2
United States 2004	1	33,345,723	20.8
	2	66,444,196	41.5
	3	60,217,221	37.6
United States 2005	1	33,292,523	21.3
	2	65,046,472	41.7
	3	57,651,239	37.0

Model Selection and Estimation

The top model (Table 2) contained only the main effect of observer identity (individual or team). Estimated detection probabilities approached 1.0 for most observers; only two observer teams had estimated detection probabilities less than 0.9 (Table 3).

The chi-squared goodness-of-fit test required pooling counts in the last three-min because numerous expected counts were less than five min. Tests for each observer team indicated that the model fitted adequately for all of the teams except Team 8 and the pooled "Other" category (Table 4). Note that relatively large *p*-values ($P > 0.05$) in Table 4 indicate that the model fits the data well, while large chi-squared components and consequent small P-values indicate departure from removal model assumptions. Closer examination of results for Team 8 indicated that very low expected counts (even after pooling) in the last three-min reduced the reliability of the test. For the "Other" observer team, the removal depletion curve shows that counts increased after the second minute, though in terms of fit, the data depart from model structure in the first two min interval (Table 4). The implication of this lack of fit are discussed below.

Population Size and Density

Total curlew population size, averaged across the two years was 161,181 individuals with bootstrapped 90% confidence interval of 120,882 to 549,351 individuals (Table 5). Point estimates for the United States were 166,244 for 2004 and 96,276 for 2005, with corresponding 90% confidence intervals of 97,636 to 404,424 and 55,809 to 141,385, respectively (Table 5). Estimated totals and 90% confidence intervals for the three Canadian provinces combined were 16,988 (90% confidence interval: 11,999 to 23,897) for 2004, and 42,856 (90% confidence interval: 31,597 to 72,152) for 2005.

Population density estimates for BCRs, Shorebird Planning Regions, and administrative regions (Table 6) showed substantial variation both among regions and the two

Table 2. Detection probability models with Akaike's Information Criterion (AIC) and change in AIC, for Long-billed Curlew rangewide survey 2004-2005; np = number of parameters.

Model	np	Rank	AIC	ΔAIC
Observer	10	1	1710.3	0.0
State/province	7	2	1727.9	17.6
Year × Country × Stratum	12	3	1764.1	53.8
Year × Country	4	4	1773.7	63.4
Country × Stratum	6	7	1784.4	74.1
Year + Country	3	9	1789.3	79.0
Year	2	12	1793.5	83.2
Year + Stratum	4	13	1793.8	83.5
Country	2	14	1793.9	83.6
Country + Stratum	4	15	1795.6	85.3
Year × Stratum	6	16	1795.9	85.6
Null	1	17	1805.0	94.7
Stratum	3	18	1805.8	95.5

years of the survey. For example, among BCRs, estimated density ranged from 0.0249 Long-billed Curlew/km^2 in the Short-Grass Prairie Region BCR to 0.4218 Long-billed Curlew/km^2 in the Central Mixed Grass Prairie Region BCR (both estimates for 2005). Nearly all other density estimates were within this range.

DISCUSSION

Population Estimates

Estimates averaged over time are meaningful only under the assumption of stable population size and we urge caution in their interpretation. Population size can depend on temporally varying environmental factors such as weather, food supply, and other ecological conditions, including migration and wintering conditions.

Patterns in population density are difficult to discern among BCRs, Shorebird Planning Regions, or administrative regions. Bootstrap 90% confidence intervals for regional density tend to be wide. Given the considerable overlap among intervals, we cannot reasonably reject the possibility that differences in point estimates were due to sampling error. The data do suggest a roughly even distribution across the entire range, although densities appear to be especially low in the shortgrass prairie, as well as in the North American Great Plains, and lower for USFWS Region 1.

The United States estimate was larger for 2004 than 2005, while the reverse was true for Canada. The variability within BCRs and

Table 3. Estimated detection probability (P) by observer team for Long-billed Curlew rangewide survey 2004-2005.

			P, bootstrap distribution	
Observer team	Team size	P, original data	Mean	SD
1	2	0.9952	0.9927	0.0087
2	2	0.9906	0.9827	0.0196
3	1	0.9218	0.9103	0.0519
4	1	0.9997	0.9901	0.0410
5	2	0.9124	0.8325	0.2255
6	2	0.9998	0.9876	0.0186
7	2	0.6864	0.6629	0.2110
8	1	1.0000	1.0000	0.0001
9	1	0.9820	0.9807	0.0088
Other	mixed	0.8006	0.7859	0.0945

Table 4. Chi-squared goodness-of-fit for the observer detection probability model, Long-billed Curlew rangewide survey 2004-2005. Observed and expected counts were pooled over the last three time intervals. Chi-squared components were calculated using Equation 3. For each team, the P-value was determined by referencing the sum of the components to the χ^2 distribution with 1 DF. Tests for each observer team indicated that the model fitted adequately for all of the teams except Team 8 and the pooled "Other" category.

	Chi-squared components			
Observer team	1 min	2 min	3-5 min	P-value
1	0.088	0.382	0.025	0.48
2	0.071	0.104	0.018	0.66
3	0.375	1.541	0.173	0.15
4	0.207	1.928	0.559	0.10
5	1.572	1.026	0.281	0.09
6	0.020	0.531	0.727	0.26
7	0.007	0.063	0.061	0.72
8	0.086	2.596	3.332	0.01
9	0.016	0.264	0.666	0.33
Other	9.446	21.246	0.612	<0.01

the administrative regions also sometimes varied in opposite directions between the two years. The causes of this pattern is unknown, but could be due to birds stopping before reaching Canada and nomadic behavior, drought/wet local conditions in breeding habitats, and non-breeding in some years by some individuals.

This survey was conducted to verify earlier estimates and to obtain new estimates of curlew populations in North America using statistically defensible methods; although the overall CI is wide, our survey results strongly suggest that there are considerably more curlews then previously thought. The previous estimates were of 20,000 individuals (Morrison *et al.* 2001) or 55,000 individuals (54,873, range 32,700-62,500) (SLJ, unpubl. data). These estimates were based mostly on expert opinion and were considered to be unreliable (SLJ, unpubl. data). In 2006, Morrison (2007) re-estimated the population at a minimum of 123,500 individuals, which is within the range of this analysis. For Canada, an earlier population estimate was derived by summing minimum estimates from the three provinces in which the species occurs (Saskatchewan 4,000 individuals, Alberta ≥19,000 individuals (Saunders 2001), and British Columbia 500 individuals) to produce a minimum total of 23,500 mature birds (Morrison 2007). Our point estimates for Alberta are within the confidence limits previously estimated by Saunders (2001). In their publication on the U.S. portion of the study, Stanley and Skagen (2007), estimated there were 164,515 (SE = 42,047) breeding curlews in 2004, and 109,533 (SE = 31,060) breeding curlews in 2005 (Stanley and Skagen, 2007).

The United States data were analyzed using the double-observer method (Nichols *et al.* 2000) and a newly developed double-observer-removal hybrid method (Stanley and Skagen 2005), as well as the classic removal method employed here. In this study, the authors did not use the double-observer method to estimate the total population numbers, since it excluded the Canadian data, in addition to those counts in the United States that were conducted by single observers. Stanley and Skagen (2005) found that estimated population sizes were least for the double-observer method, intermediate for the removal method, and greatest for the double-observer-removal hybrid method. Estimated standard errors either followed a similar pattern (in 2004) or were roughly constant across methods (in 2005). Furthermore, estimated standard errors were very similar to estimates obtained in this study.

Beginning in 2005, the percent of each 400-m radius count circle that could be observed from the survey-point center was estimated (i.e., visibility limitations due to topographical obstructions). Stanley and Skagen (2005) reported estimates both with and

Table 5. Long-billed Curlew population estimates (N) adjusted for detection probability. Bootstrap distribution based on 1,000 samples. Confidence intervals estimated from percentiles of bootstrap distribution. SD = standard deviation, L90 = lower 90% confidence limit, U90 = upper 90% confidence limit. Table cells with a dash (—) indicate values where one or more of the 1,000 detection probabilities are nearly zero and the corresponding estimates of population size are extremely large (>10^{14}).

Political entity	Year	Stratum	No. of routes	N, original data	N, bootstrap distribution				
					Mean	Median	SD	L90	U90
Alberta	2004	1	9	484	494	484	247	97	893
		2	10	2404	2405	2384	1036	795	4278
		3	19	4666	4713	4695	1042	3017	6481
		Total	38	7554	7612	7581	1476	5303	10157
	2005	1	8	4495	4310	4391	3673	219	12346
		2	9	4900	4943	4871	1477	2607	7424
		3	18	10319	10414	10309	1828	7563	13646
		Total	35	19714	19666	19365	4275	13506	27015
British Columbia	2004	1	5	1432	1690	1475	1319	0	4101
		2	11	1161	1217	1128	930	113	2963
		3	8	340	357	344	267	23	889
		Total	24	2934	3263	2994	1620	1039	6061
	2005	1	4	4731	—	4792	—	0	12446
		2	14	2066	—	2094	—	697	8006
		3	6	638	—	632	—	166	1422
		Total	24	7436	—	7747	—	2405	18470
Saskatchewan	2004	1	8	963	1011	942	944	0	2693
		2	15	3841	4040	3836	2130	787	7997
		3	16	1696	1667	1551	1070	281	3573
		Total	39	6500	6718	6441	2686	2915	11354
	2005	1	20	1469	1521	1388	989	148	3251
		2	20	10885	10924	10803	4411	3798	17967
		3	25	3351	3422	3365	1118	1679	5414
		Total	65	15706	15867	15717	4693	8188	23594
United States	2004	1	37	28932	—	28497	—	9829	57341
		2	52	70201	—	72265	—	31233	159906
		3	45	67111	—	65169	—	26771	244288
		Total	134	166244	—	170966	—	97636	404424
	2005	1	23	12440	12222	11951	11044	0	34458
		2	63	27637	27907	27437	9783	12495	44374
		3	49	56198	56920	55408	21400	25022	94260
		Total	135	96276	97049	95986	26305	56809	141385
Grand total	2004		235	183231	—	188100	—	113324	422046
	2005		259	139131	—	141700	—	97611	198252

without adjustment for the proportion of the plot visible from the central observation point. Adjusted estimates for the entire United States were approximately 25% greater than unadjusted estimates. We did not adjust for this "visibility bias" for two reasons. First, field crews only estimated the proportion of plot area visible in the United States in 2005; such procedures were not followed in the United States in 2004, or in Canada in either year. Second, the data included observations based on auditory cues and both auditory and visual cues (an unknown proportion of the latter likely would have been seen only because they were heard first). Visibility correction seems inappropriate for detections based on auditory cues.

Our point estimates for the United States are similar to the Stanley and Skagen (2005) point estimates uncorrected for "visibility bias" (Stanley and Skagen 2005). The greatest differences occurred in Stratum 3. Their

Table 6. Long-billed Curlew density estimates (*D*, LBCU/km^2) adjusted for detection probability, by Bird Conservation Region, Shorebird Planning Region, Administrative Region and year. Bootstrap distribution based on 1,000 samples. Confidence intervals estimated from percentiles of bootstrap distribution. SD = standard deviation, L90 = lower 90% confidence limit, U90 = upper 90% confidence limit. Table cells with a dash (—) indicate values where one or more of the 1,000 detection probabilities are nearly zero and the corresponding density estimates are extremely large (>10^9).

				D, bootstrap distribution				
Unit	Year	No. of routes	D, original data	Mean	Median	SD	L90	U90
Bird Conservation Region								
Great Basin (9)	2004	48	0.0683	0.0716	0.0666	0.0328	0.0257	0.1326
	2005	54	0.0797	0.0802	0.0786	0.0270	0.0388	0.1244
Northern Rockies (10)	2004	44	0.1712	—	0.1806	—	0.0946	0.3411
	2005	41	0.0904	—	0.0962	—	0.0424	0.2351
Prairie Potholes (11)	2004	87	0.0954	—	0.0969	—	0.0694	0.1374
	2005	104	0.1798	0.1811	0.1786	0.0324	0.1318	0.2415
Southern Rockies/Colorado Plateau (16)	2004	3	0.0492	0.0459	0.0439	0.0459	0.0000	0.1286
	2005	1	0.2923	0.3018	0.2907	0.0520	0.2563	0.3780
Badlands and Prairies (17)	2004	26	0.0936	—	0.0863	—	0.0225	0.4416
	2005	21	0.0532	0.0556	0.0500	0.0405	0.0048	0.1289
Short Grass Prairie (18)	2004	25	0.0300	—	0.0287	—	0.0000	0.0809
	2005	32	0.0249	0.0254	0.0244	0.0106	0.0095	0.0438
Central Mixed Grass Prairie (19)	2004	2	0.0935	—	0.0861	—	0.0000	0.2862
	2005	6	0.4218	0.4111	0.4070	0.2146	0.0812	0.7805
Shorebird Planning Regions								
Canadian Intermountain West	2004	24	0.1184	0.1264	0.1246	0.0513	0.0477	0.2161
	2005	24	0.2346	—	0.2478	—	0.1091	0.5863
Canadian Prairies	2004	77	0.0811	0.0825	0.0823	0.0148	0.0587	0.1067
	2005	100	0.1894	0.1908	0.1892	0.0333	0.1381	0.2527
Central Plains/Playa Lakes	2004	27	0.0344	—	0.0339	—	0.0041	0.0944
	2005	38	0.0859	0.0857	0.0798	0.0399	0.0295	0.1552
Intermountain West	2004	70	0.1184	—	0.1240	—	0.0627	0.2364
	2005	71	0.0563	0.0567	0.0558	0.0187	0.0286	0.0899
Northern Plains/Prairie Potholes	2004	37	0.1217	—	0.1174	—	0.0511	0.4062
	2005	26	0.0430	0.0448	0.0393	0.0331	0.0038	0.1029
Administrative Region								
Fish and Wildlife Service, Region 1	2004	46	0.0876	0.0919	0.0881	0.0373	0.0388	0.1595
	2005	49	0.0673	0.0674	0.0650	0.0245	0.0304	0.1092
Fish and Wildlife Service, Region 2	2004	13	0.0185	0.0196	0.0173	0.0209	0.0000	0.0541
	2005	10	0.1089	0.1135	0.1097	0.0343	0.0649	0.1727
Fish and Wildlife Service, Region 6	2004	75	0.1240	—	0.1269	—	0.0649	0.3482
	2005	76	0.0526	0.0532	0.0505	0.0234	0.0192	0.0943
Canada (Canadian Wildlife Service)	2004	101	0.0897	0.0925	0.0918	0.0169	0.0656	0.1225
	2005	124	0.1966	—	0.1999	—	0.1520	0.2928

Stratum 3 estimates for 2004 and 2005 were 59,898 and 46,092, respectively, while our corresponding estimates were 67,509 and 57,247, roughly 13% and 24% greater. However, our estimates for total United States population size across all three strata exceed the Stanley and Skagen (2005) estimates by only 4% and 12% in 2004 and 2005, respectively. Considering the large sampling variation in these estimates the actual estimated differences are quite small.

Adjustment for Detection Probability

In part, lack of fit could be due to heterogeneity in detection probabilities. In addition to the constant probability model, we examined two other classes of model that permit heterogeneity: the Farnsworth *et al.* (2002) model, which accounts for different detection probabilities among two groups of birds; and the generalized removal model (White *et al.* 1982), which allows different probabilities across time (e.g., one probability for the first minute and another probability for each of the remaining four minutes). We encountered problems in fitting both of these more general classes of model. In both cases, maximum likelihood estimation frequently failed to converge. Otherwise, when convergence was successful, parameter estimates were frequently unrealistic (e.g., extremely low detection probabilities that were inconsistent with patterns in observed counts).

Road Bias

Conducting surveys along roads is valuable for logistical reasons—to adequately survey populations across large areas in a relatively short period, with limited number of field crews. However, population estimates based on road surveys carries the required assumption that densities of curlews estimated along the route are unbiased for density throughout the township. Bias might arise because curlews are either attracted to or repelled by roads. Only secondary and tertiary roads were used in this study, and road placement in the United States was apparently representative of the habitat in general (Stanley and Skagen, 2007). Therefore, while the amount and direction of this potential bias for curlews is still unknown, it is thought to be small, since we have no evidence curlews were behaviorally attracted or repelled by roads.

Closure Assumption: Fly-ins, Flyovers, and Non-breeding Flocks

A standard assumption of the removal method for estimation of detection probability is that the population of interest is closed during the sampling period, i.e., there are no increases due to birth or immigration, and no decreases due to death or emigration during the five-min point count. However, birds that fly into the plot during the count might be strictly regarded as "immigrants". Alternatively, at least some of these birds may well be residents of the "population" within the plot and it is even possible that some were present at the onset of the count, left the 400-m plot, and then were detected when they flew back to the ground. Irrespective of the interpretation, such detections may present problems for the maximum likelihood estimation of the removal model (Farnsworth *et al.* 2002). If there are many of these detections in later intervals, then counts may increase rather than decrease through the period. Thus, estimation may not converge on a solution because the data do not fit the model structure.

We followed a strict interpretation of the closure assumption by excluding all fly-ins, flyovers and non-breeding flocks for the analysis. However, we also examined the consequences of progressively relaxing those assumptions by (1) including fly-ins but excluding flyovers and flocks, and (2) including all three categories of birds. In the first case, population estimates were similar to the reported results (Nations *et al.* 2007). When fly-ins were included, then the total population size was estimated to be approximately 2%-3% larger than when the calculation excluded fly-ins. Including flyovers, flocks, and fly-ins, then the total population size was estimated to be roughly 31%-42% larger than reported estimates. These larger population estimates were due both to higher unadjusted counts (including more observations) and to lower estimated detection probabilities (different fitted models) (Nations *et al.* 2007).

Bootstrapping

We chose to estimate the distribution of population size via bootstrapping because we felt that asymptotic variance estimates were likely to be unreliable given the sparse data and various sampling designs employed in the United States and the Canadian provinces. Our procedure incorporated both sampling variation in detection probability and curlew counts; with each bootstrap sample of routes, we re-estimated detection probabilities using the models fit to the original data. However, we did not consider uncertainty in model selection. Doing so would have entailed re-fitting all candidate models to each bootstrap sample, a highly impractical procedure for automation given the degree of oversight required in the initial model selection.

Bootstrapping was not without problems. In particular, data re-sampling occasionally produced data configurations that resulted in very small estimates of detection probability for some observers (or, states or provinces), essentially division by 0.0, and, thus, very large estimates of population size. We conjecture that such situations arose when one or more observers (or, states or provinces) were underrepresented in the bootstrap sample. If such a sample were to arise in an actual survey, it is likely that another model or a similar model with an alternative collapsing of factor levels would be fit to the data. If this conjecture is correct, then re-fitting models to each bootstrap sample might have produced less variable population estimates than we obtained with smaller values for the upper confidence limits (while, at the same time, more appropriately accounting for model uncertainty).

In any case, the very small detection probabilities and extremely large population estimates in some of the bootstrapped samples led to correspondingly large values for the mean and standard deviation of the bootstrap distribution (Table 5). The bootstrap median is always available (because it is relatively unaffected by the occasional large values) and is similar to the point estimate (Table 5). In most cases, 90% confidence limits indicate right-skewed distributions of population size since the lower limit is closer than the upper limit to the mean, or median. Not surprisingly, the skewedness is most pronounced when the mean and standard deviation are unrealistically large.

Confounding Effects

We modeled detection probability as a function of several alternative effects including year, country, state or province, stratum, and observer identity (Table 5). While the modeled effects appear very different superficially, we acknowledge that there are likely to be confounding effects. For instance, observer identity is associated with country since only one observer worked in both countries. Furthermore, observers (whether individuals or pairs) tended to work at the local-to-regional level, often with a single state or province though sometimes in several adjacent states. Within Canada, observers did not participate in surveys in more than one province. Therefore, the two models for observer effects and state/province effects may not be substantially different from each other in terms of the (confounding) effects they actually represent.

CONCLUSION

Using probability sampling methods (e.g., stratified-random sampling), as was done here and in Alberta (Saunders 2001), reliable estimates can be obtained by making inferences about population characteristics from relatively small samples. Our results suggest that there were considerably more curlews than previously thought (Morrison 2001, 2007). However, this result should not be surprising. This study and the earlier study in Alberta (Saunders 2001) are the only rigorously conducted surveys for curlews. As we frequently discover in wildlife inventories, systematic surveys tend to reveal larger populations than were previously thought to exist. While this study has many areas that could be improved, our attempt to survey the entire range of a species in a coordinated survey represented a massive effort and one that we feel was justified. The benefit of this survey is that it gave an estimate of the real breeding population size throughout the entire range, rather than just an index, which is provided by the BBS.

This survey could be improved by increasing sample size (including not using the double observer method), exploring road bias, and dropping stratification. In addition, modifying the survey to include other grassland shorebirds, such as Willet (*Tringa semipalmata*), Upland Sandpiper (*Bartramia longicauda*), and Marbled Godwit (*Limosa fedoa*) would improve the overall benefits of this effort. The breeding population of curlews was discovered in this study to be larger then thought, and there may be no need to conduct an intensive monitoring program specifically for this species rangewide. However, some curlew populations will require more work to supplement this study. Indeed, the threats and range contractions of curlews, along with these data, suggest that USFWS Region 1, the areas of range contraction in the eastern portion of the range, the shortgrass, and mixed-grass prairie regions should be considered a priority for increased conservation measures.

ACKNOWLEDGMENTS

We particularly want to thank the over 100 surveyors who assisted on this project. Their participation was the only reason the survey was possible and we greatly appreciate their efforts. Regional survey coordinators included Sue Thomas and Bill Howe (USFWS), Tom Stanley and Susan Skagen (USGS), Garry Donaldson (CWS), John Surgenor and Julie Steciw (British Columbia), Richard Quinlan (Alberta), and Ursula Banasch (Saskatchewan). They coordinated surveyors and data collection, which were vital to the success of this project. Roland L. Redmond, J. Scott Dieni, Cheri Gratto-Trevor, Jon Bart, Brad Andres, and Jeff Marks, assisted in the early stages of development of this study and shared their knowledge on the biology of curlews. Brad Andres, Ursula Banasch, Mark Colwell, J. Scott Dieni, Cheri Gratto-Trevor, Richard Lanctot, Jim Lyons, David R. C. Prescott, Mark Seamans, Rex Sallabanks, and John R. Sauer provided helpful reviews of previous versions of this manuscript. Thanks to Sean Fields and Mike Artmann (USFWS) for the map used as Figure 1.

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