

**POPULATION ESTIMATES FOR THE LONG-BILLED CURLEW
IN THE UNITED STATES AND CANADA**

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ABSTRACT

A survey for Long-Billed Curlews (*Numenius americanus*) was conducted throughout the current breeding range in the western United States and Canada in 2004 and 2005. A stratified random sample of townships was selected from habitat strata within the study area. A 32 km route along roads was identified within each selected township. Five-minute point counts were conducted at 800 m intervals along the routes during the early breeding season when Long-Billed Curlews were engaged in territorial displays. Detection probabilities were estimated using the removal method in which observations of Long-Billed Curlews in one-minute intervals were removed from further consideration. Model selection based on AIC led to a model in which 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 mean density within surveyed point count plots. Under the assumption that density along roads was unbiased, population estimates were derived by multiplying survey density by total area within each stratum. Sampling variance was estimated via bootstrapping. Range-wide estimate of total population size was 161,181. The estimates were 183,231 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. Population densities were also estimated for geographic sub-regions: Bird Conservation Regions, Shorebird Planning Regions, and USFWS administrative regions, and a combined Canadian Wildlife Service region.

INTRODUCTION

Long-Billed Curlews (*Numenius americanus*) are a migratory shorebird that breeds in western North America primarily in the Great Plains short and mixed-grass prairies, grasslands of the Great Basin and Columbia River Plateau, and intermountain valleys of the Rocky Mountains and British Columbia. Breeding Bird Survey (BBS) data for Long-Billed Curlews (LBCU) are highly variable but suggest contraction of the breeding range (Jones et al., 2003; R. Russell, pers. commun.) and declining population size in recent decades (Sauer et al., 2005). LBCU population density is thought to be relatively low. However, the design of the BBS may not be well-suited to detecting trends in this species.

Concern over the current status and long-term trends of LBCU populations prompted the United States Fish and Wildlife Service (USFWS) and the United States Geological Survey (USGS) to design and conduct a survey targeted specifically at LBCU (Jones et al., 2003). The design followed a similar study conducted in Alberta in 2001 (Saunders, 2001).

The survey area was defined by USFWS delineating the geographic range of LBCUs using a GIS base map (NatureServe, 2006) combined with BBS data and other local data on LBCU occurrence (e.g., Breeding Bird Atlases) (Jones et al., 2003) (Figure 1). Figure 1 also indicates the timing of surveys within geographical areas to coincide with the primary breeding display activity of the LBCU (Jones et al., 2003).

Data from the U.S. portion of the study have been analyzed by Stanley and Skagen (2005). However, the Canadian data have not been analyzed previously. Furthermore, analysis methods used by Stanley and Skagen (2005) considered features of the U.S. sampling design that were not shared by the Canadian surveys. Our report presents a unified analysis of both the U.S. and Canadian data based on common characteristics of the field sampling designs.

The original objective of the survey was to determine the present distribution and population size range-wide, and if available, by Bird Conservation Region (BCR). A general inventory was deemed necessary for the development of management and conservation strategies, which potentially includes the development of monitoring plans, contingent on identifying populations/BCRs of concern. Our objectives for the current comprehensive analysis included: (1) range-wide estimate of population size; and, (2) estimates of population size by BCR, habitat strata, as well as by country.

METHODS

Survey

Surveys were conducted across the western US as well as Alberta, British Columbia, and Saskatchewan in 2004 and 2005. Methods for the Canadian surveys have not been described previously. Here, we provide a brief summary of the U.S. design and describe the features common with the Canadian designs, focusing on issues relevant to our analysis.

In both the U.S. and Canada, surveys were designed to occur when LBCU first arrived on breeding areas, the pre-incubation period when males are most conspicuous in their aerial display flights. This period varies in a manner that correlates, to some degree, with temperature and plant phenology, which, in turn, covaries positively with latitude and elevation. The study area was partitioned so that "windows" of time represented the average breeding period for LBCU in that partition. 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 from the literature (S. Jones, pers. commun.). This information was then used to partition the survey area into large geographic regions according to the sampling windows (Figure 1).

U.S. Surveys

LBCU surveys throughout the western U.S. were designed and coordinated by the USFWS and USGS. A single, unified sampling design was employed for the study area within the U.S. The basic sample unit was the township as created by the Public Land Survey System; a township is typically an approximately square unit of land, 6 miles on a side. 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, 2001) (Stanley and Skagen, 2005). Stratum 4 designated areas judged to be non-LBCU habitat and consisted of townships in which 70% or more of the total township either exceeded an elevation cutoff (which varied among states) or was classified as either *developed*, *forested upland*, or *water*. Townships not within Stratum 4 were then stratified based on percentage of the area classified as *grassland*. Stratum 1 designated potential low quality LBCU habitat and consisted of 0 – 5% grassland, Stratum 2 designated potential medium quality habitat consisting of 5 – 50% grassland, and Stratum 3 designated potential high quality habitat consisting of >50% grassland. U.S. townships falling on or within the boundaries of the delineated geographic range defined the survey area. In 2004, the sampling frame included 21,405 townships, covering a total area of 186,072,700 ha. Modification of the LBCU geographic range by the USFWS in 2005, resulted 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. In both 2004 and 2005, a fixed number of 15 townships were sampled from within Stratum 4 in the U.S. Sample allocation among the remaining three strata 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 U.S. survey.

A single survey route was non-randomly designated within each township generally following methods developed by Saunders (2001). Routes satisfied several criteria including that they follow existing rural roads accessible by automobile, that they not follow primary roads or highways, that they be 32 km in length, and that parallel segments be separated by a distance of at least 1.6 km.

Routes were traversed by driving a motor vehicle. Point counts were conducted at 800 m intervals so that there were 40 planned stops along each route. To conduct the point count, observers stood nearby the vehicle, recording all LBCU observed (whether seen only, heard only, or both seen and heard) within a 5-minute period. The period was divided into five 1-

minute intervals and the appropriate interval was recorded for each LBCU detected. Distance from the observer to the bird was estimated and recorded in one of three distance zones: 0 – 400 m, 400 – 800 m, and beyond 800 m.

Recording of time intervals during point counts was designed to permit analysis using the removal method as described in Farnsworth et al. (2002). In addition, most point counts were conducted by two observers in the U.S, a strategy designed for analysis using the double-observer method of Nichols et al. (2000).

Canadian Surveys

LBCU surveys in Canada were coordinated with those in the U.S. following protocols similar, but not identical, to those in the U.S. 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.

There were several minor differences between surveys in the U.S. and Canada with respect to sampling frame and stratum definitions. First, a single database comparable to the National Land Cover Database (NLCD, 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 U.S.; in all cases, townships were approximately square, 6 mi on each side. British Columbia had no such existing system; instead a grid was placed over the landscape within a GIS producing “blocks” similar to townships.

Minor differences existed in the definition of strata between the U.S. and each Canadian province; however, these differences do not affect the accuracy of the surveys. For example, none of the Canadian provinces designated a fourth stratum defined by elevation and non-grassland land cover types as was done in the U.S. That is, no samples were reserved exclusively for non-LBCU habitat. On the other hand, as in the U.S., Stratum 1 was defined so that it may have contained townships without any grassland, and such townships had finite probability of entering the sample taken in either year. Alberta and British Columbia defined Strata 1 – 3 as in the U.S. 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 differed from the U.S. strategy. In Alberta, half of the townships (and associated routes) that had been randomly selected during Saunders’ (2001) study were retained for the purpose of monitoring trend. Each year, approximately 20 were run by the same observer assigned to the same route. Additional routes were randomly selected in 2004 and again in 2005 from the remaining pool for the purpose of this survey. In Saskatchewan some townships/routes in the sample were those retained from surveys that had been conducted in 1988, 1989, and 1991 (U.

Banasch, pers. commun.). The design of those surveys was similar to the Alberta study (Saunders, 2001); in particular, townships had been randomly selected. In the 2004 and 2005 surveys in Saskatchewan, however, an effort was made to obtain equal sample sizes among the three strata. Stratum areas within British Columbia were relatively small, with few blocks in Strata 1 and 3 particularly. In both regions of British Columbia, they sought to maintain target sample sizes within each stratum. Consequently, some blocks/routes were randomly selected in both years of the study for all three provinces.

LBCU surveys in all three Canadian provinces differed from those in the U.S. in that all point counts in Canada were conducted by a single observer rather than two.

Data Processing

During field observations, birds were classified into three distance zones: 0 – 400 m, 400 – 800 m, and beyond 800 m. Because centers of point count plots along each route were separated by 800 m, only the 0 – 400 m zones of adjacent points were non-overlapping. Furthermore, we considered observations of birds beyond 400 m to be less reliable. Therefore, our analysis addressed only those observations within the 0 – 400 meter zone.

LBCUs that flew into the plot during the 5-minute period (denoted “fly-ins”), birds that flew over the plot but did not land (“fly-overs”), and flocks of non-breeding birds either observed feeding within the plot or flying over were so noted in the database. To provide conservative estimates, our analysis excluded all these birds; that is, it included only those birds judged to be on the ground within the plot at the onset of the count. The analysis included all such birds, whether detected aurally or visually or both.

Because no sampling was conducted within a fourth stratum (non-LBCU habitat) in Canada and, furthermore, because no LBCU were observed in Stratum 4 in the U.S. in either year, our analysis considered only data from Strata 1, 2, and 3.

Analysis

Detection Probability Modeling

As noted above, point counts in Canada were generally conducted by a single observer while those in the U.S. were generally conducted by paired observers. Clearly, this difference in protocol made it impossible to analyze the Canadian data using the double-observer method (Nichols et al., 2000). To ensure that estimates were comparable between the U.S. and Canada, we conducted a unified analysis of detection probability using the removal method (White et al., 1982).

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-minute intervals. In effect, detected birds were ‘removed’ from the population within the plot. The fundamental data were the lengths of each interval (one minute for this study), and the counts of birds within each interval. Observations within one-minute intervals were summed across the two observers

in the U.S. In effect the two observers were treated as a team in the analyses. Consequently, we expected higher probability of detection on routes in the U.S. than in Canada.

To illustrate the model, let q be the probability that a bird is not detected in one minute and assume that q is constant over the 5-minute 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-minute 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

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

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

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

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

Model Selection

We considered models in which the parameter q was assumed constant over the 5-minute period but allowed to vary with one or more of several factors including year, country, stratum, state or province, and observer identity (whether an individual or a unique pair of individuals) (Table 1). As described in Results below, the data were too sparse and the numbers of observers and states were too large to permit a complete examination of all observers and states/provinces. We 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. Repeated model fitting indicated that consistent convergence occurred with 10 or more LBCUs counted in the first minute in all factor levels. Observers or states with fewer than 10 LBCUs counted in the first minute were included in “Other” level. Each of the remaining factors had either two or three levels only, such that sparse data presented a less severe problem for estimation.

In addition to main effects models, we fit selected interaction models 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, we did not consider interactions or additive models involving either observer identity or state/province.

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.

We calculated Akaike's Information Criterion (AIC) for each model, ranked models from smallest to largest AIC, and calculated differences in AIC. For model *i*, the difference $\Delta_i = \text{AIC}_i - \min_i(\text{AIC})$ was calculated, where $\min_i(\text{AIC})$ was the minimum AIC (Burnham and Anderson, 2002). We selected the model with the lowest AIC. (As reported below, differences in AIC between the top-ranked model and each of the remaining models were so large that model averaging was considered unnecessary.)

Goodness-of-fit for the top-ranked model was assessed using the chi-squared procedure described by White et al. (1982). The expected count at each interval was calculated as

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

where $\hat{N} = x_{\bullet} / \hat{p}$ was the total count adjusted for detection probability. Then, the chi-squared statistic was calculated in the usual way as

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

Population Estimation

Detection probability was necessarily 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 time 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 LBCU are counted at a given point).

Following the sampling design, estimates of population size were obtained for each stratum within each political entity (the United States and each of the three Canadian provinces) 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). That is, density was estimated as a ratio of totals. 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. Furthermore, population density was estimated for each combination of geographic region and year. Three regional classification schemes were used: Bird Conservation Regions (NABCI, 2006), Shorebird Planning Regions (USFWS, 2006a), and USFWS administrative regions (USFWS, 2006b) together with a single Canadian Wildlife Service region.

Variance estimates were obtained via a bootstrapping procedure (Manly, 2007) that, again, followed the sampling design. That is, 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 1000 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 1000 bootstrapped estimates. Means, medians and standard deviations were calculated from each set of 1000 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 U.S., a total of 41% of the routes were less than 32 km (40 stops). In 2004, 62% of the routes were less than the prescribed 40 stops per route; the average route had 32.4 stops. In 2005, 22% of the routes were shorter than prescribed; the average route length was 37.6 stops. Where stated, reasons for the shortened routes included weather, bad roads, no access to private property, and attempting to cover more than 1 route/day.

In 2004, shorter 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, shorter routes comprised of fewer stops were created by design in both provinces, though in Saskatchewan additional townships/routes were selected randomly to compensate for the shorter lengths. British Columbia surveys averaged 32.3 stops per route in 2004 but only 23.7 stops per 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, 5 routes were shortened because of impassable road conditions.

As defined by this study, most LBCU habitat was within the United States (~150 million ha) relative to the three Canadian provinces (~24 million ha) (Table 2). Furthermore, LBCU habitat within the U.S. was characterized by greater proportion of grassland – roughly 42% of the study area in the U.S. 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 U.S. than in Canada (Table 3). However, relative to amount of LBCU habitat, survey intensity was greater in Canada.

Observations of LBCU were rare throughout the study area (Table 4). Across all three strata, fewer than 200 birds were observed in the U.S. in each year of the study. Counts were relatively high in Canada, particularly in Alberta in 2005. The high counts in Canada may have been due in part to the relatively high survey intensity. However, given the relatively small amount of LBCU habitat in Canada (Table 2), the expected contribution to total population size is modest.

Model Selection and Estimation

Model selection results are summarized in Table 5. The top model contains only the main effect of observer identity (individual or team). A data summary for the selected model is shown in Table 6. There were 9 observer “teams” (either individuals or unique pairs of observers) with sufficient data for estimation. The remaining 45 teams were collapsed together into the “Other” category. Estimated detection probabilities are high (close to 1) for most observers (Table 7). Only two observer teams had estimated detection probabilities less than 0.9.

The chi-squared goodness-of-fit test required pooling counts in the last 3 minutes because numerous expected counts were less than 5. Tests for each observer team (Table 8) indicate that the model fits adequately for all of the teams except Team 8 and “Other”. Closer examination of results for team 8 indicates that very low expected counts (even after pooling) in the last 3 minutes reduced the reliability of the test. For the “Other” observer team, the removal depletion curve shows that counts increased after the second minute (Figure 2), though in terms of fit, the data departs from model structure in the first 2 minutes (Table 8). We discuss the implication of this lack of fit below.

Population Size and Density

Population estimates and bootstrapping results for each political entity, stratum, and year are shown in Table 9. Estimates with 90% confidence intervals for each country and for both countries combined are shown in Figure 3. In general, sampling variance is high; confidence intervals are wide and overlap substantially (e.g., in comparing total population sizes between 2004 and 2005, for any political entity). In Table 9, cells in which bootstrap means and standard deviations represented with a dash (–) indicate cases where one or more of the estimated probabilities of detection were nearly zero and the estimated values are extremely large ($> 10^{14}$ for population size; $> 10^9$ for density). The cause of these extreme values and their effect on estimated confidence intervals are addressed in the Discussion section.

Population density estimates for Bird Conservation Regions (Table 10), Shorebird Planning Regions (Table 11), and Administrative Regions (Table 12) show substantial variation both among regions and the two years of the study. For example, among Bird Conservation Regions (Table 10), estimated density ranges from 0.0249 LBCU/km² in the Short-Grass Prairie Region (BCR18) to 0.4218 LBCU/km² in the Central Mixed Grass Prairie Region (BCR19) (both estimates for 2005). Nearly all other density estimates are within this range. As with the population estimates summarized in Table 9, sampling variance is substantial for all regional density estimates.

DISCUSSION

Population Estimates

The range-wide estimate of total population size for LBCU was 161,181 averaged across both years. In 2004, the range-wide estimate was 183,231 with 90% confidence interval (113,324 to 422,046); in 2005, the corresponding estimates were 139,131 and (97,611 to 198,252). We note that there is substantial overlap (Figure 3) of the two confidence intervals leading to the conclusion that there is little statistical support for a decrease in population size between 2004 and 2005. Methods included random selection of new townships and routes each year (in the U.S.) to increase information concerning distribution of LBCU; in Canada there was a mixture of reselection of routes and using the same routes in both years.

Most of the population is estimated to reside in the U.S.; point estimates for the U.S. are 166,244 for 2004 and 96,276 and for 2005 with corresponding 90% confidence intervals of (97,636 to 404,424) and (55,809 to 141,385). Interestingly, the U.S. estimate is larger for 2004 than 2005, while the reverse is true for Canada – estimated totals and 90% confidence intervals for the three Canadian provinces combined are 16,988 and (11,999 to 23,897) for 2004, and 42,856 and (31,597 to 72,152) for 2005. The same pattern holds within each of the three provinces. Among the provinces, Alberta has the largest estimated population while British Columbia has the smallest.

The total LBCU population averaged across the two years is 161,181 with bootstrapped 90% confidence interval of (120,882 to 549,351). We caution against relying too heavily on estimates averaged over time, as they are only meaningful with the assumption of stable population size. Population size may depend on temporally varying environmental factors such as weather and food supply. Furthermore, the average obscures any effect of possible long term trend.

Patterns in population density are difficult to discern whether among Bird Conservation Regions, Shorebird Planning Regions, or Administrative Regions. While density appears to vary widely across regions and years, most of these differences are likely due to sampling variability. Bootstrap 90% confidence intervals for regional density tend to be wide. The considerable overlap among intervals suggests that there is very little statistical evidence for real difference among corresponding point estimates.

This survey was conducted to verify earlier estimates and to obtain a statistically defensible estimate of the Long-billed Curlew population in North America. This survey suggests that there are considerably more Long-billed Curlews than previous estimates of 20,000 individuals (Morrison et al., 2001) and 55,000 individuals (54,873, range 32,700 – 62,500) (S. Jones, unpubl. data.). These estimates were based mostly on expert opinion and were considered to be unreliable (S. Jones, unpubl. data.). Morrison (*In Prep.*) re-estimated a minimum of 123,500 Long-billed Curlew individuals. For Canada, an earlier population estimate was derived by summing minimum estimates from the three provinces in which the species occurs (Saskatchewan 4,000 birds, Alberta \geq 19,000 birds (Saunders 2001), and British Columbia 500 birds) to produce a minimum total of 23,500 mature birds (COSEWIC, 2002; Morrison, *In Prep.*). *Partner's In Flight* (PIF) used BBS data to estimate avian numbers (Thogmartin et al., 2006) and arrived at an estimated 1.2 million individuals for Long-billed Curlews in North America (K. Rosenberg, pers. commun.). The PIF approach has not been verified for shorebirds and the population estimate based on the BBS is not supported in this survey. Our point estimates for Alberta are within the confidence limits previously estimated by Saunders (2001).

Adjustment for Detection Probability

A number of recent papers in the ornithological literature have argued strongly that bird counts unadjusted for detection probability are unreliable indices of population size (e.g., Thompson, 2002). We agree with that position, particularly when counts are made over large spans of time and space, under widely varying conditions. In such circumstances, detection probability is almost certain to vary, and thus without correction, its effects are likely to be confounded with actual variation in population size.

We used the removal model (White et al., 1982) to estimate detection probabilities. Model selection using AIC indicated that the model for observer identity was superior to all other models considered. There was little evidence that detection probability depended on the isolated effects of year, country, or stratum; Δ AIC values for these models were much greater than 10. Based on the top model, estimated detection probabilities for the point count duration for most observer teams were high, generally greater than 0.9.

Goodness-of-fit testing showed the model for observer identity fit the data reasonably well for 8 of the 9 teams and the test was not reliable for the 9th, Team 8. The ad hoc grouping into the “Other” category produced a data set with an indication of lack of fit to the model assuming constant probability of detection. The estimated probability of detection for this group was 0.8, resulting in an inflation factor of 1.25 (= 1/0.8) for LBCU counts in areas surveyed by this group. If no such inflation factor were applied in areas surveyed by this group, the conservatively estimated total population sizes in 2004 and 2005, respectively, would be 165,908 and 127,079 rather than 183,231 and 139,131 as reported in Table 9.

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).

In addition to the reported adjusted population estimates, we computed “naive” unadjusted estimates for general interest, because these serve as reference points, allowing one to assess the magnitude of detection probability correction. Total unadjusted population estimates for 2004 and 2005 are 138,302 and 125,497, respectively; that is, naive estimates are less than adjusted estimates by 24% and 10%, respectively.

Comparison of results with those in Stanley and Skagen (2005).

Methods for data summary and data analysis differed from those used by Stanley and Skagen (2005). For example, for their removal method analysis, Stanley and Skagen (2005) restricted data to observations made by the primary observer only. In contrast, we included observations made by the secondary observer, when one was present, by considering unique pairings of primary and secondary observers to be teams (i.e., each pair was treated the same as each individual). While we expected such pairs to have higher detection probabilities than individual observers working alone, our results (Table 7) showed that estimated detection probabilities for some individuals was as great or greater than probabilities for paired observers.

The U.S. data were analyzed by Stanley and Skagen (2005) using the double-observer method (Nichols et al., 2000) and a newly developed double-observer-removal hybrid method as well as the classic removal method employed here. We did not use any double-observer method because it would have excluded all of the Canadian data in addition to those counts in the U.S. that were conducted by single observers (a small proportion of all U.S. counts). In any case, 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).

Stanley and Skagen (2005) reported estimates both with and without correction for the proportion of the plot visible from the central observation point. We did not correct for this “visibility bias” for two reasons. First, field crews only estimated the proportion of plot area visible in the U.S. in 2005; such procedures were not followed in the U.S. in 2004, nor in Canada in either year. Second, LBCU 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 is probably inappropriate for detections based on auditory cues.

Our point estimates for the United States (Table 9) are similar to the Stanley and Skagen (2005) point estimates uncorrected for “visibility bias” (Stanley and Skagen, 2005). The greatest differences occur in Stratum 3. Their Stratum 3 estimates for 2004 and 2005 are 59,898 and 46,092, respectively, while our corresponding estimates are 67,509 and 57,247, roughly 13% and

24% greater (Table 9). However, our estimates for total U.S. 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 (reported in both tables), the actual estimated differences are very small.

Potential Biases & Errors Due to Route Selection

Conducting surveys along roads satisfies a logistical constraint, namely the need to survey low-density populations across large areas in a relatively short period of time with limited number of field crews. However, population estimates based on these surveys carries the assumption that LBCU density estimated along the route is unbiased for density throughout the township. Bias might arise because LBCU are either attracted to or repelled by roads. Furthermore, habitat adjacent to roads might vary systematically from habitat throughout the township if, for instance, roads were more likely to be built through open grassland than forest.

Sparse Data

LBCUs are uncommon and were rarely recorded in this survey. In each year of the study, approximately 435,000 ha were directly surveyed (within 400 m plots) across the U.S. and Canada. Yet, only 305 LBCUs were counted in 2004, and 460 in 2005. Such sparse data present a challenge for any abundance estimation method. For our analysis, data were aggregated (i.e., counts are summed) across many routes. Numbers of LBCU counted were low, particularly toward the end of the 5-minute period (e.g., Table 6) due to the high estimated probability of detection by each team.

Closure Assumption: Fly-ins, Fly-overs, 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. That is, there are no increases due to birth or immigration, and no decreases due to death or emigration during the five-minute 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 maximum likelihood estimation of the removal model. If there are many such 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.

Fly-overs and flocks of non-breeding birds (collectively designated “fly-overs” in Methods and Results) present similar problems. Assuming that fly-overs are indeed non-resident and that non-breeding flocks can be easily identified by observers, then their exclusion from analysis appears legitimate. On the other hand, it is not difficult to imagine that a small flock (of, say, five or fewer transient birds) feeding on the ground within a plot might not be recognized as a group of transient birds. Counting these small flocks will result in an over-estimate of the size of the breeding population, but is likely difficult to control. Finally, counting birds flying over the plot,

particularly in later intervals, may present difficulty for estimation similar to that caused by fly-ins.

To obtain conservative estimates, we followed a relatively strict interpretation of the closure assumption by excluding all fly-ins, fly-overs and non-breeding flocks for the analysis presented above. However, we also examined the consequences of progressively relaxing those assumptions by (1) including fly-ins but excluding fly-overs and flocks, and (2) including all three categories of birds. In the first case, population estimates were similar to the reported results. For instance, when fly-ins were included total population size was estimated to be approximately 2% – 3% larger than results when excluding fly-ins (Table 9). Including fly-overs and flocks as well as fly-ins led to somewhat larger estimates; total population size was estimated to be roughly 31% – 42% larger than reported estimates. We note that these larger population estimates were due both to higher unadjusted counts (including more observations) and to lower estimated detection probabilities (different fitted models).

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 U.S. and the Canadian provinces. Our procedure incorporated both sampling variation in detection probability and LBCU 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 resampling 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 under-represented 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. Rather than report these unrealistic estimates in Tables 9-12, we have substituted dashes (–). In Table 10, these occur exclusively for British Columbia in 2005 and the U.S. in 2004. Note, however, that when it is available, i.e., when division by approximately 0.0 is avoided, the mean of the bootstrap distribution is generally very similar to the original point estimate. Furthermore, the bootstrap median is always available (because it is relatively unaffected by the occasional large values) and is similar to the point estimate (Tables 9-12). 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.

Confounded Effects

We modeled detection probability as a function of several alternative effects including year, country, state or province, stratum, and observer identity (Table 1). We selected the best models using AIC. While the modeled effects appear very different superficially, we acknowledge that there is likely to be confounding among 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. In short, the two models for observer effects and state/province effects may not be substantially different from each other in terms of the (confounded) effects they actually represent.

Conclusion

Using probability sampling methods (stratified-random sampling), as was done here and in Alberta (Saunders 2001), good estimates can be obtained by making inferences about population characteristics from relatively small samples. Our results suggest that there are many more LBCU than previously thought. However, this result should not be surprising. This and the earlier study in Alberta (Saunders, 2001) are likely the most rigorously conducted surveys for LBCU. As we frequently discover in wildlife work, systematic surveys tend to reveal larger populations than were previously thought to exist. While this study leaves room for improvement, our attempt to survey the entire range of a species in a coordinated fashion represents a massive effort and one that we feel was justified. Much work is still to be done for the conservation of Long-billed Curlews, and we hope that this study is a worthy continuation of ongoing work.

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Table 1. Factors (main effects) and factor levels considered in detection probability modeling. Levels of the State/Province and Observer factors were collapsed due to sparse data. Observer identities (whether an individual or a unique pair) are represented by numerals.

Factor	Levels
Year	2004, 2005
Country	Canada, U.S.
Stratum	1, 2, 3
State / Province	AB, BC, MT, NE, OR, SK, Other
Observer	1, 2, ..., 9, Other

Table 2. Stratum area in hectares and percentage area, by political entity.

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

Table 3. Survey characteristics. Area indicates total area within 400 m plots on all routes in a given stratum.

Political Entity	Year	Stratum	# Routes	Area (ha)
Alberta	2004	1	9	18,096
		2	10	20,106
		3	19	37,046
	2005	1	8	16,085
		2	9	18,096
		3	18	34,633
British Columbia	2004	1	5	8,294
		2	11	16,789
		3	8	13,873
	2005	1	4	4,373
		2	14	16,537
		3	6	7,138
Saskatchewan	2004	1	8	13,270
		2	15	24,429
		3	16	18,498
	2005	1	20	26,088
		2	20	26,138
		3	25	28,702
United States	2004	1	37	62,379
		2	52	85,703
		3	45	70,221
	2005	1	23	40,816
		2	63	120,888
		3	49	93,544

Table 4. Observed numbers of Long-Billed Curlews by political entity, year, & stratum.

Political Entity	Year	Stratum	Number of LBCUs
Alberta	2004	1	5
		2	9
		3	57
	2005	1	41
		2	16
		3	112
British Columbia	2004	1	13
		2	10
		3	17
	2005	1	21
		2	19
		3	15
Saskatchewan	2004	1	3
		2	15
		3	10
	2005	1	9
		2	51
		3	35
United States	2004	1	42
		2	69
		3	55
	2005	1	15
		2	44
		3	82

Table 5. Detection probability models, ranked by Akaike's Information Criterion (AIC). np = number of parameters.

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

Table 6. Long-Billed Curlew counts by observer team. x_i represents the count in time interval i .

Observer Team	x_1	x_2	x_3	x_4	x_5
1	17	4	1	2	0
2	10	3	0	2	0
3	29	25	9	10	2
4	11	0	0	1	0
5	24	8	1	5	6
6	12	1	1	0	0
7	23	19	13	9	11
8	39	0	0	1	0
9	91	38	28	4	3
Other	96	18	33	30	27

Table 7. Estimated detection probability (p) by observer team.

Observer Team	Team Size	p , Original Data	p , Bootstrap Distribution 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 8. Chi-squared goodness-of-fit for the observer detection probability model. Observed and expected counts were pooled over the last 3 intervals.

Observer Team	Chi-squared components			p -value
	1	2	3-5	
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

Table 9. Long-Billed Curlew population estimates (N) adjusted for detection probability. Bootstrap distribution based on 1000 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 1000 detection probabilities are nearly zero and the corresponding estimates of population size are extremely large ($> 10^{14}$).

Political Entity	Year	Stratum	N , Original		N , Bootstrap Distribution			
			Data	Mean	Median	SD	L90	U90
Alberta	2004	1	484	494	484	247	97	893
		2	2404	2405	2384	1036	795	4278
		3	4666	4713	4695	1042	3017	6481
		Total	7554	7612	7581	1476	5303	10157
	2005	1	4495	4310	4391	3673	219	12346
		2	4900	4943	4871	1477	2607	7424
		3	10319	10414	10309	1828	7563	13646
		Total	19714	19666	19365	4275	13506	27015
British Columbia	2004	1	1432	1690	1475	1319	0	4101
		2	1161	1217	1128	930	113	2963
		3	340	357	344	267	23	889
		Total	2934	3263	2994	1620	1039	6061
	2005	1	4731	–	4792	–	0	12446
		2	2066	–	2094	–	697	8006
		3	638	–	632	–	166	1422
		Total	7436	–	7747	–	2405	18470
Saskatchewan	2004	1	963	1011	942	944	0	2693
		2	3841	4040	3836	2130	787	7997
		3	1696	1667	1551	1070	281	3573
		Total	6500	6718	6441	2686	2915	11354
	2005	1	1469	1521	1388	989	148	3251
		2	10885	10924	10803	4411	3798	17967
		3	3351	3422	3365	1118	1679	5414
		Total	15706	15867	15717	4693	8188	23594
United States	2004	1	28932	–	28497	–	9829	57341
		2	70201	–	72265	–	31233	159906
		3	67111	–	65169	–	26771	244288
		Total	166244	–	170966	–	97636	404424
	2005	1	12440	12222	11951	11044	0	34458
		2	27637	27907	27437	9783	12495	44374
		3	56198	56920	55408	21400	25022	94260
		Total	96276	97049	95986	26305	56809	141385
Grand Total	2004		183231	–	188100	–	113324	422046
	2005		139131	–	141700	–	97611	198252

Table 10. Long-Billed Curlew density estimates (D , LBCU/km²) adjusted for detection probability, by Bird Conservation Region and year. Bootstrap distribution based on 1000 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 1000 detection probabilities are nearly zero and the corresponding density estimates are extremely large ($> 10^9$).

Bird Conservation Region	Year	D , Original	D , Bootstrap Distribution				
		Data	Mean	Median	SD	L90	U90
Great Basin (9)	2004	0.0683	0.0716	0.0666	0.0328	0.0257	0.1326
	2005	0.0797	0.0802	0.0786	0.0270	0.0388	0.1244
Northern Rockies (10)	2004	0.1712	–	0.1806	–	0.0946	0.3411
	2005	0.0904	–	0.0962	–	0.0424	0.2351
Prairie Potholes (11)	2004	0.0954	–	0.0969	–	0.0694	0.1374
	2005	0.1798	0.1811	0.1786	0.0324	0.1318	0.2415
Southern Rockies/ Colorado Plateau (16)	2004	0.0492	0.0459	0.0439	0.0459	0.0000	0.1286
	2005	0.2923	0.3018	0.2907	0.0520	0.2563	0.3780
Badlands and Prairies (17)	2004	0.0936	–	0.0863	–	0.0225	0.4416
	2005	0.0532	0.0556	0.0500	0.0405	0.0048	0.1289
Short Grass Prairie (18)	2004	0.0300	–	0.0287	–	0.0000	0.0809
	2005	0.0249	0.0254	0.0244	0.0106	0.0095	0.0438
Central Mixed Grass Prairie (19)	2004	0.0935	–	0.0861	–	0.0000	0.2862
	2005	0.4218	0.4111	0.4070	0.2146	0.0812	0.7805

Table 11. Long-Billed Curlew density estimates (D , LBCU/km²) adjusted for detection probability, by Shorebird Planning Region and year. Bootstrap distribution based on 1000 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 1000 detection probabilities are nearly zero and the corresponding density estimates are extremely large ($> 10^9$).

Shorebird Planning Region	Year	D , Original		D , Bootstrap Distribution			
		Data	Mean	Median	SD	L90	U90
Canadian Intermountain West	2004	0.1184	0.1264	0.1246	0.0513	0.0477	0.2161
	2005	0.2346	–	0.2478	–	0.1091	0.5863
Canadian Prairies	2004	0.0811	0.0825	0.0823	0.0148	0.0587	0.1067
	2005	0.1894	0.1908	0.1892	0.0333	0.1381	0.2527
Central Plains/ Playa Lakes	2004	0.0344	–	0.0339	–	0.0041	0.0944
	2005	0.0859	0.0857	0.0798	0.0399	0.0295	0.1552
Intermountain West	2004	0.1184	–	0.1240	–	0.0627	0.2364
	2005	0.0563	0.0567	0.0558	0.0187	0.0286	0.0899
Northern Plains/ Prairie Potholes	2004	0.1217	–	0.1174	–	0.0511	0.4062
	2005	0.0430	0.0448	0.0393	0.0331	0.0038	0.1029

Table 12. Long-Billed Curlew density estimates (D , LBCU/km²) adjusted for detection probability, by Administrative Region and year. CWS = Canadian Wildlife Service.

Administrative Region	Year	D , Original		D , Bootstrap Distribution			
		Data	Mean	Median	SD	L90	U90
CWS	2004	0.0897	0.0925	0.0918	0.0169	0.0656	0.1225
	2005	0.1966	–	0.1999	–	0.1520	0.2928
FWS 1	2004	0.0876	0.0919	0.0881	0.0373	0.0388	0.1595
	2005	0.0673	0.0674	0.0650	0.0245	0.0304	0.1092
FWS 2	2004	0.0185	0.0196	0.0173	0.0209	0.0000	0.0541
	2005	0.1089	0.1135	0.1097	0.0343	0.0649	0.1727
FWS 6	2004	0.1240	–	0.1269	–	0.0649	0.3482
	2005	0.0526	0.0532	0.0505	0.0234	0.0192	0.0943

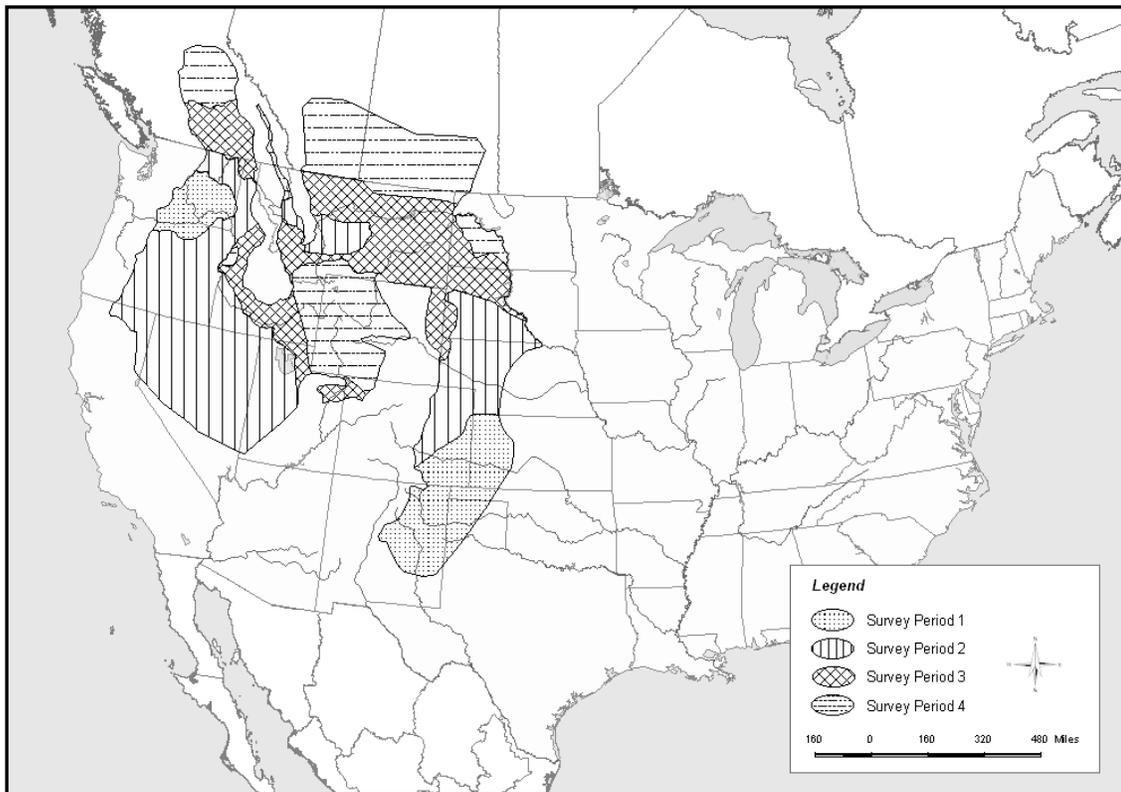


Fig. 1. Long-Billed Curlews Rangewide Survey 2004 area and timing. Four survey periods were defined geographically and surveyed during early arrival dates. In 2004: Survey Period 1 = 21 March - 10 April, Survey Period 2 = 28 March - 17 April, Survey Period 3 = 11 April - 1 May, and Survey Period 4 = 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. (Sean Fields and Mike Artmann, USFWS).

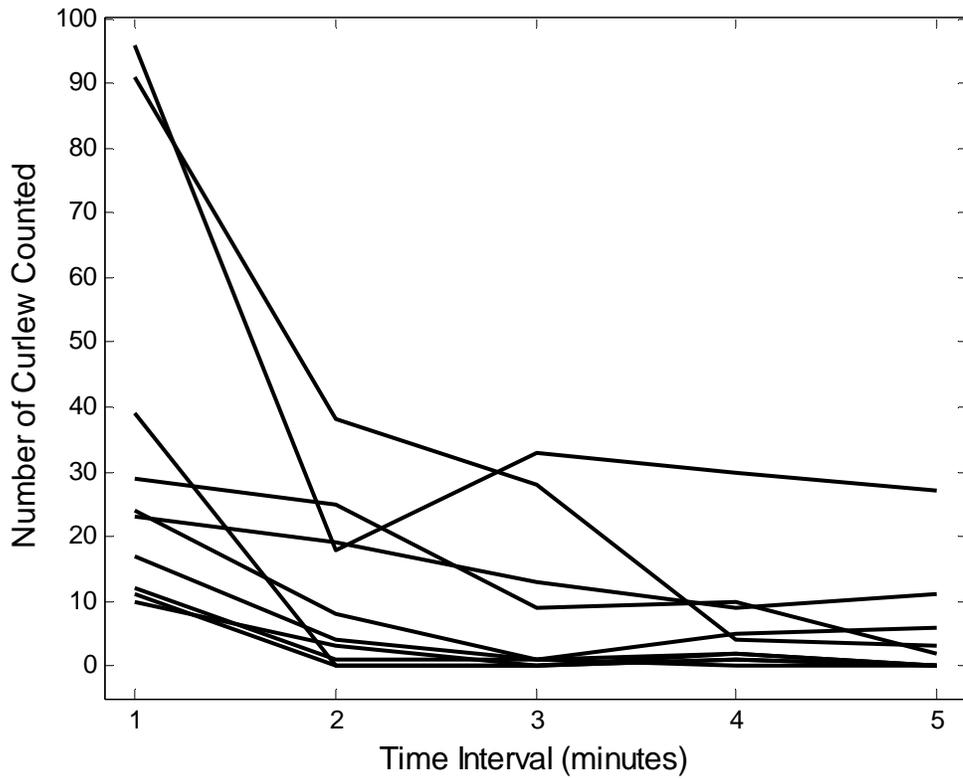


Figure 2. Depletion curves for the 10 observers (including ‘Other’). Curves for other detection probability models were qualitatively similar in terms of slow rate of depletion and occasional count increases in later time intervals.

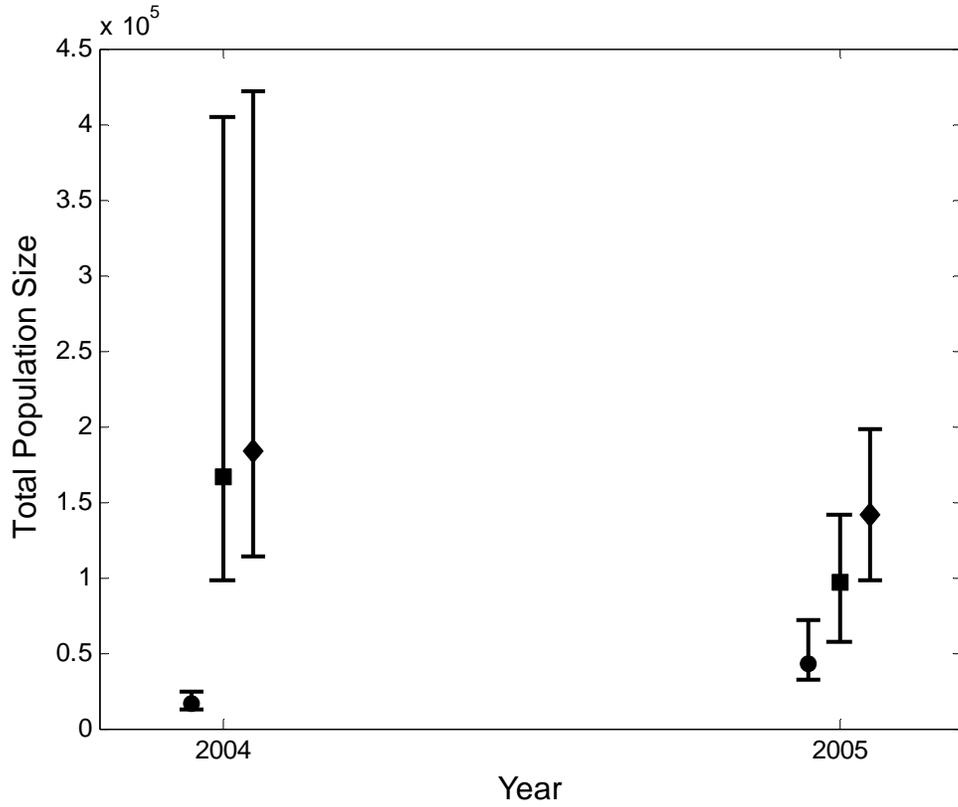


Figure 3. Estimated total population size of Long-Billed Curlews in Canada (circles), the U.S. (squares), and both countries combined (diamonds) in 2004 and 2005, with 90% confidence intervals estimated from 1000 bootstrap samples.