POPULATION SIZE AND TREND OF YELLOW-BILLED LOONS IN NORTHERN ALASKA

Susan L. Earnst[1,5], Robert A. Stehn[2], Robert M. Platte[2], William W. Larned[3], and Edward J. Mallek[4]

[1]*U. S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 970 Lusk Street, Boise, ID 83706*
[2]*U. S. Fish and Wildlife Service, Migratory Bird Management, 1011 E. Tudor Road, Anchorage, AK 99503*
[3]*U. S. Fish and Wildlife Service, Migratory Bird Management, P.O. Box 1670, Kenai, AK 99611*
[4]*U. S. Fish and Wildlife Service, Migratory Bird Management, 1412 Airport Way, Fairbanks, AK 99701*

Abstract. The Yellow-billed Loon (*Gavia adamsii*) is of conservation concern due to its restricted range, small population size, specific habitat requirements, and perceived threats to its breeding and wintering habitat. Within the U.S., this species breeds almost entirely within the National Petroleum Reserve-Alaska, nearly all of which is open, or proposed to be opened, for oil development. Rigorous estimates of Yellow-billed Loon population size and trend are lacking but essential for informed conservation. We used two annual aerial waterfowl surveys, conducted 1986–2003 and 1992–2003, to estimate population size and trend on northern Alaskan breeding grounds. In estimating population trend, we used mixed-effects regression models to reduce bias and sampling error associated with improvement in observer skill and annual effects of spring phenology. The estimated population trend on Alaskan breeding grounds since 1986 was near 0 with an estimated annual change of −0.9% (95% CI of −3.6% to +1.8%). The estimated population size, averaged over the past 12 years and adjusted by a correction factor based on an intensive, lake-circling, aerial survey method, was 2221 individuals (95% CI of 1206–3235) in early June and 3369 individuals (95% CI of 1910–4828) in late June. Based on estimates from other studies of the proportion of loons nesting in a given year, it is likely that <1000 nesting pairs inhabit northern Alaska in most years. The highest concentration of Yellow-billed Loons occurred between the Meade and Ikpikpuk Rivers; and across all of northern Alaska, 53% of recorded sightings occurred within 12% of the area.

Key words: Alaska, breeding grounds, Gavia adamsii, *population size, population trend, Yellow-billed Loon.*

Tamaño y Tendencia Poblacional de *Gavia adamsii* en el Norte de Alaska

Resumen. Gavia adamsii es una especie cuyo estado de conservación es preocupante debido a su rango de distribución restringido, su pequeño tamaño poblacional, sus requerimientos de hábitat específicos y a la inminente amenaza sobre sus hábitats reproductivos y de invernada. Dentro de los Estados Unidos, esta especie se reproduce casi enteramente dentro de la Reserva Nacional de Petróleo en Alaska, área que está disponible, o estará disponible para ser la explotación de petróleo. Actualmente, existe una carencia de estimadores rigurosos de los tamaños poblacionales y de sus tendencias, a pesar de que estos parámetros son esenciales para la conservación informada de esta especie. Utilizamos dos conteos aéreos anuales de aves acuáticas, uno realizado entre 1986–2003 y el otro entre 1992–2003, para estimar el tamaño poblacional y su tendencia en los territorios reproductivos del norte de Alaska. Para estimar la tendencia poblacional utilizamos modelos de regresión de efectos mixtos, de manera de reducir el sesgo y el error de muestreo asociados a la mejora de las aptitudes del observador y a los efectos anuales de la fenología de primavera. La tendencia poblacional estimada en los territorios reproductivos de Alaska desde 1986 fue cercana a 0, con un cambio anual estimado del −0.9% (95% IC de −3.6% a +1.8%). El tamaño poblacional estimado, promediado a lo largo de los 12 años y ajustado mediante un factor de corrección basado en un método de muestreo aéreo intensivo de vuelos circulares, fue de 2221 individuos (95% IC de 1206–3235 individuos) a inicios de junio y de 3369 individuos (95% IC de 1910–4828 individuos) a fines de junio. Con base en estimaciones de otros estudios sobre las proporciones de *G. adamsii* que se encontraban nidificando en un año determinado, es probable que hayan habitado <1000 parejas nidificantes en el norte de Alaska en la mayoría de los años. La mayor concentración de *G. adamsii* fue observada entre los ríos Meade y Ikpikpuk; y a través de todo el norte de Alaska, el 53% de los avistamientos fue registrado en un 12% del área.

INTRODUCTION

The Yellow-billed Loon (*Gavia adamsii*) breeds on large, deep, fish-bearing lakes on the tundra of northern Alaska, Canada, and Russia (North 1994, Earnst et al. 2005). Due to its specific habitat requirements, restricted range, rarity, and perceived threats to its breeding and wintering habitat, the Yellow-billed Loon is a species of concern (USFWS 2002) and the subject of a recent petition for listing under the Endangered Species Act (Center for Biological Diversity 2004). Within the U.S., the Yellow-billed Loon breeds primarily within the National Petroleum Reserve-Alaska (NPR-A), 95% of which has been opened, or is proposed to be opened, for oil and gas development (BLM 1998, 2003, 2004). Rigorous estimates of population size and trend are lacking in the peer-reviewed literature, yet essential for informed conservation. Here, we analyze 18 years of aerial survey data to provide a rigorous evaluation of the Yellow-billed Loon population in northern Alaska (i.e., Alaska's North Slope).

Yellow-billed Loons in northern Alaska are monitored during two aerial waterfowl surveys that provide independent annual indices of population size. Regardless of proper design and objective data collection, population trends based on indices are susceptible to criticism if they do not, at a minimum, explicitly address potential bias in the trend estimate (Anderson 2001, Thompson 2002, Bart, Burnham et al. 2004). Bias in a trend estimate can amplify or mask the real trend, and arises when there is a trend in the index ratio (i.e., the ratio of survey result to actual target population), which in turn might arise from a trend in the proportion of individuals present but not detected, or a trend in the proportion of target individuals present at the time of the survey (Bart, Droege et al. 2004).

In this article, we combined the two ongoing aerial surveys to estimate population size, trend, and relative distribution of Yellow-billed Loons. A correction factor, based on an intensive, lake-circling, aerial survey method, was used to reduce bias in the estimated average population size. Mixed-effects regression models were used to assess two potential sources of bias in the estimated population trend: improvement in an observer's ability to detect loons with increasing years of experience, and the effect of spring phenology on proportion of the population present at the time of the survey.

METHODS

EARLY AND LATE JUNE TRANSECT SURVEYS

The Arctic Coastal Plain Breeding Pair Survey (hereafter Late Survey) and the North Slope Eider Survey (hereafter Early Survey) cover all of the range of the Yellow-billed Loon in northern Alaska, and with the exception of <800 individuals in western Alaska (Platte 1999), all of the species' range in the United States. The two surveys differ primarily in area sampled, survey intensity, and timing. The Late Survey, designed to monitor all waterfowl breeding in northern Alaska, encompasses 61 645 km^2 of contiguous wetland habitat north of the Brooks Range in Alaska and from Point Lay to Kaktovik (Fig. 1). The Early Survey, designed to monitor Spectacled Eiders (*Somateria fischeri*), encompasses a 30 755 km^2 subset of the Late Survey study area, and has a sampling intensity twice that of the former with systematic transect lines every 9.6 km rather than 18.5 km apart. The Late Survey, initiated in 1986, had average initiation and completion dates of 26 June and 3 July, respectively. The Early Survey, initiated in 1992 and timed to coincide with presence of male eiders on the breeding grounds, had average initiation and completion dates of 10 June and 18 June, respectively. Initiation of both surveys was adjusted by a few days each year based on snow melt and other weather conditions.

The Late and Early Surveys are ongoing U.S. Fish and Wildlife Service surveys that follow the protocol of the North American Waterfowl Breeding Pair Survey (Smith 1995). Both are flown in a single-engine Cessna aircraft with floats at 145–170 km hr^{-1} and at approximately 30–45 m above ground level. The pilot and an observer in the right-hand passenger seat record all waterfowl and other large waterbirds within 200 m on each side of the plane. Prior to 1997, observations were recorded on audiotapes and later mapped based on time elapsed since transect initiation, producing locations accurate to approximately 1000 m (Butler, Hodges, and Stehn 1995). Since 1997, observations have been recorded directly into laptop computers linked to the aircraft's GPS, producing locations accurate to approximately 200 m. Although aircraft position at time of sighting is recorded, dis-
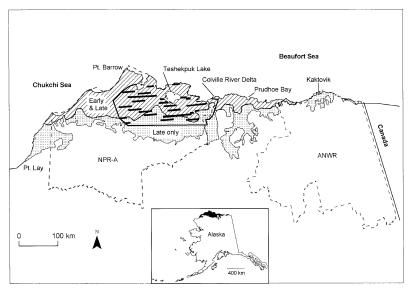
FIGURE 1.   Location of the Early Survey (cross-hatched), Late Survey (cross-hatched and stippled pattern), intensive study area (within bold line), and the 21 intensive plots (black rectangles). Inset map shows the Late Survey study area on the North Slope of Alaska. Dashed lines represent the boundaries of the National Petroleum Reserve—Alaska (NPR-A) and Arctic National Wildlife Refuge (ANWR).

tance and angle from aircraft to the sighting is not.

The sampling plan for each survey was stratified, systematic sampling with unequal-sized clusters (i.e., transects of unequal length), with the caveat that strata were superimposed onto systematic transects rather than transects being drawn independently in each. Strata were delineated using visual inspection of a land-cover map (USDI 1995) and based on large-scale patterns in habitat features, such as predominant cover types and wetland abundance. The area encompassed by both surveys included nine strata, and the larger Late Survey study area included an additional three. Within Early and Late Surveys, spacing of transects was equal among strata, except Early Survey transects were 4.8 km rather than 9.6 km apart in one stratum around Teshekpuk Lake in 1998 and 1999.

The north-south placement of the east-west oriented transects varied between surveys and among years. The location of each survey's initial transect was chosen at random and others spaced systematically from it in 1986 (Late Survey only), 1992, and 1998. In other years, transect location was either the same as, or systematically offset from, the previous year's. In both surveys, beginning in 1992 and again in 1998,

lines were offset from the previous year's lines such that a set of lines was repeated every fifth year. In total, 8 different sets of lines were used in the Early Survey and 10 in the Late Survey. The sequence in which transects were flown varied among years, depending on logistic constraints, including weather. Two different pilot-observers and seven different passenger-observers flew Late Surveys. One pilot-observer and four different passenger-observers flew Early Surveys.

INTENSIVE SURVEYS AND THE CORRECTION FACTOR

We delineated 21 rectangular plots, each approximately 102 km² (3.2 × 32 km), between the Colville and Meade Rivers and north of latitude 70 degrees (Fig. 1). Each plot was surveyed once using a Cessna 206 fixed-wing aircraft during late June through August of 1998–2000 (average date = 23 July) by a pilot and observer who did not participate in the Early and Late transect surveys. Plots surveyed in 1998 were placed along Early or Late Survey lines in the approximate center of each third of the study area; plots in subsequent years were placed systematically along survey lines. During intensive surveys, each lake >10 ha whose centroid was within a plot was searched thoroughly by slowly

circling the shoreline (Earnst et al. 2005). Lake centers and segments of rivers within plots were also searched. Yellow-billed Loons are restricted to waterbodies and the smallest brood-rearing lake documented on the Colville River Delta is 13.4 ha (North and Ryan 1989). Lake circling provides high detection probabilities because considerable time is available per unit area of loon habitat (Caughley 1974) and lakes can easily be recircled to identify diving loons and resolve questionable sightings. All observed loons were plotted on topographic maps.

The correction factor was calculated as mean density on plots during the intensive, lake-circling survey divided by mean density on plots during pooled Early and Late transect surveys during 1992–2003. A cumulative total of 1585 km² within plots also fell within transects of Early and Late Surveys during 1992–2003 (each transect was 400 m wide). Plots were approximately the same size and surveyed in entirety during intensive surveys, so we calculated the mean density from intensive surveys as a simple, not weighted, average (sum of area in all plots was 2283 km²). During the transect surveys, only portions of the plots were covered and the covered areas varied substantially in size, so we calculated the mean density from transect surveys as a weighted average using transect area observed in each plot as the weight. The variance of the correction factor was estimated using the standard formula for ratios (Cochran 1977).

The correction factor (which is the inverse of the index ratio in Bart and Earnst 2002) is best thought of as a ratio that, when multiplied by the index from the transect surveys, yields an unbiased estimate of the average number of birds present in the whole study area during the time-frame of the intensive surveys (defined as the period of interest). The two relevant assumptions of double sampling are that an intensive survey measures number present at the time of the survey with negligible error and intensive surveys randomly sample the target population. The estimates are unbiased despite random movements across plot borders between the time of intensive and transect surveys, because such movements do not change the expected value of number detected across all plots and therefore do not change the expected value of the correction factor. The correction factor is not strictly a visibility correction for proportion of loons

"missed" on Early and Late Surveys, because it also adjusts transect survey estimates to the time-frame of the intensive surveys, thus incorporating any birds that might arrive or excluding those that might leave the North Slope between the time of transect and intensive surveys.

During all surveys, most loons (95%) were recorded as pairs or singles; flocks were rare. Throughout the Results we present the total number of loons observed in all types of sightings.

POPULATION SIZE

Annual population indices and their variances were estimated using formulas for stratified sampling with unequal-sized clusters (i.e., unequal transect lengths) within strata (Cochran 1977). We treated transects as independent among years because most transect locations were repeated in only 1 or 2 years, and even if repeated, actual flight paths were different each year due to minor inconsistencies in navigation.

We calculated the current 12-year average population size for both the Early Survey and Late Survey. The Early Survey covered a smaller area, produced more precise annual indices because of higher sampling intensity, and was flown about two weeks earlier than the Late Survey. We estimated the average population size inside the Early study area ($\hat{Y}_I$) as the average Early population index (y_{IE}) times the correction factor (C), thus $\hat{Y}_I = y_{IE}C$. In this and subsequent formulas, "average" refers to the 12-year average, subscripts I and O indicate "inside" and "outside" the Early study area, and subscripts E and L indicate estimates from the Early and Late Surveys. To estimate the total birds that would have been obtained by the Early Survey if it had covered the whole Late Survey study area, we used the Late Survey to estimate the ratio of loons observed outside to inside the Early study area ($y_{OL}y_{IL}^{-1}$), then multiplied this ratio by the average Early Survey estimate. Thus, the estimate for outside the Early study area was $\hat{Y}_O = y_{IE}C(y_{OL}y_{IL}^{-1})$. The average population size for the Early Survey, extrapolated to the whole North Slope, was then the sum of the estimates for inside and outside the Early study area, which simplified to the following:

$$\hat{Y}_I = y_{IE}C(1 + y_{OL}y_{IL}^{-1}) \qquad (1)$$

The average population size estimate for the Late Survey ($\hat{Y}_L$) was simply the 12-year aver-

age population index from the entire Late study area (y_L) times the correction factor, thus $\hat{Y}_L = y_L C$.

Variance formulas. We defined the statistical population of interest as bounded in space and time (years 1992–2003), and thus treated both geographic areas and years as strata, and estimated the variances of y_{IE}, y_{OL}, y_{IL}, and y_L using formulas for stratified sampling (Cochran 1977). $V(y_{OL}y_{IL}^{-1})$ was estimated using the standard formula for variance of a ratio (Cochran 1977). We considered indices from the Early and Late survey independent from the correction factor, so $V(y_{IE}C)$ and $V(y_L C)$ were calculated from the standard formula for variance of a product (Goodman 1960). For example,

$$V(\hat{Y}_{IE}C) = y_{IE}^2 V(C) + C^2 V(y_{IE}) - V(y_{IE})\, V(C)$$
(2)

and we used an analogous formula for the variance of the Late Survey estimate, $V(y_L C)$. The three multiplicative terms in Equation 1 are independent so the variance of $\hat{Y}$ can also be expressed as the variance of a product as in Equation 2, where the first term is $y_{IE}C$ and the second term is $(1 + y_{OL}y_{IL}^{-1})$.

Estimates of population size are reported as 12-year means ± SE with 95% confidence intervals (CI). Independent, two-tailed *t*-tests were used for comparisons except where noted otherwise.

POPULATION TREND

The 1986–2003 population trend was estimated using log-linear regression on the annual population indices. Annual indices were available for 18 years from the Late Survey and for 12 years from the Early Survey. Separate indices were calculated for the pilot-observer and passenger-observer in each survey-year. Thus the models described below were based on 60 observations (36 and 24 from the Late and Early Surveys, respectively), however, we used the effective sample size of 18 years in confidence intervals.

We used mixed-effects models to estimate trends (PROC MIXED with maximum likelihood estimation, SAS 2000). We incorporated independent variables that were potential sources of bias in the trend, such as observer experience and spring weather, and variables that might reduce the variance in the trend, such as survey type (Early or Late Survey) and observer

type (pilot or passenger). Observer identity was included in all models as a random effect, thus accounting for the lack of independence between population indices from a single observer in successive years (Littell et al. 1996). Our primary interest was in obtaining an unbiased and precise coefficient for year, thus our interest in model selection and in other variables in the models focused on their effect on the year coefficient and its standard error. We included survey type in all models because it accounted for difference in size of the two study areas. All models with year and survey type, including those with first-order interactions, were candidates for the best subset of models.

We divided observer experience into three categories: 1 year, 2–3 years, and 4+ years of experience. These categories were chosen because they resulted in the most even distribution of observers across categories and thus reasonable sample sizes (14, 10, and 7 observers, respectively), and because we expected skill to plateau after a few years rather than continuing to increase indefinitely. We considered using a continuous function with an asymptote to model the effect of experience, however, most observers (10 of 14) had ≤5 years of experience, thus we were concerned about over-fitting (≥3 parameters required to fit an asymptote) and that values in the tail of the skewed distribution (i.e., 3 observers with ≥9 years of experience) would unduly affect the shape of the trend.

Thaw-degree days from 1 May through 10 June were used as a measure of the timing of spring. For each day, thaw-degrees were calculated as the average daily Fahrenheit temperature, (maximum + minimum) 2^{-1}, minus the freezing point (i.e., 32°F). Thaw-degree days were the cumulative sum of thaw-degrees from the beginning of the period. Annual thaw-degree days for 1986–2003 were calculated from daily temperatures at each of the four NOAA sites within the loon's range on the North Slope (Point Barrow, Colville Village, Kuparak, and Umiat, Alaska). Annual thaw-degree days were then averaged across sites. We log-transformed mean annual thaw-degree days to reduce the right-hand skew in the untransformed data.

We used Akaike's Information Criterion corrected for small samples (AIC_c) to choose the best subset of models (Burnham and Anderson 2002). Under this approach, the model with the lowest AIC_c score is considered the most parsi-

monious model, and models within two AIC_c units of it are also considered to have substantial empirical support. A model's weight (w) reflects its probability of being the best-fitting model of those under consideration. We used model averaging across the best subset of models (Burnham and Anderson 2002) to calculate the unconditional regression coefficient ($\pm$SE) for year (i.e., the population trend across time). These parameters incorporate uncertainty in model selection, and thus are not conditional on selection of a particular single model. Inferences based on model averaging are considered more stable than inferences based on a single 'best' model (Burnham and Anderson 2002). Before proceeding with model selection, we used the deviance of the most parameterized model to assess goodness-of-fit and found no evidence of lack of fit ($\chi^2_{51} = 46.2$, $P = 0.66$).

Estimates of population trend are expressed as percent annual change $\pm$ SE, where percent annual change = (EXP[year coefficient from loglinear regression]$-$ 1) * 100%. The standard error, based on a Taylor's series approximation, was calculated as SE = (percent annual change) * (SE of year coefficient). Regression coefficients for other terms are also expressed as percent change in the population index ($\pm$ SE) and calculated by substituting the coefficient of interest into the preceding equations. In addition, 95% CI are given for trend estimates and most other regression coefficients. Trends or coefficients are significantly different from 0, at $P <$ 0.05, if the CI does not include 0. For some estimates of population trend, we give the more intuitive total percent change that would accumulate from a given percent annual change expressed over a period of interest, such as the 18-year survey period. The total percent change is $[(1 + r)^{period\_length} - 1] \times 100\%$ where r is percent annual change expressed as a proportion.

Predicting number present in average and warm springs. To better interpret the average population size estimate for the Late Survey, we also calculated predicted number of loons present in the warmest year relative to the average year on the Late Survey. We used Model 5 (see Results) because it included an interaction term that allowed the effect of thaw-degree days to be appropriately calculated for the Late Survey. The predicted number present during Late Surveys was calculated using both the highest and average value of thaw-degree days recorded dur-

ing our 18-year period, keeping observer experience and year constant. The difference in predicted values was expressed as a percent of the highest value.

POWER TO DETECT A TREND

We estimated power of the current surveys to detect a 2.5%, 3.4%, or 6.7% annual decline as statistically significant. A 3.4% annual decline, which is equivalent to a 20-year decline of 50%, is often used as a compromise between smaller annual declines that would be of interest, but difficult to detect with reasonable expenditure of effort and money, and higher annual declines that would be easier to detect logistically but would result in a population size from which it may be difficult for a long-lived bird with low annual productivity to recover (Bart, Burnham et al. 2004).

Power is generally expressed as

$$Power = P\left[Z > Z_{\alpha/2} - \frac{R_1 - R_0}{SE(r)}\right], \quad (3)$$

where Z is a standard normal variate; $\alpha = 0.05$; $Z_{\alpha/2}$ is the value of Z exceeded with probability $\alpha/2$; R_1 is the hypothesized parameter, in this case, the annual change of interest (i.e., -0.025, -0.034, or -0.067); R_0 is the parameter value under the null hypothesis (i.e., 0); and SE(r) is the standard error of the observed change, r, estimated from the existing data (Steel and Torrie 1980).

RELATIVE DENSITY

A relative density map was created by pooling all data from Early and Late Surveys during 1992–2003. The term relative density is used to emphasize that observations were not corrected for visibility bias. Yellow-billed Loon observations were converted to relative densities by overlaying a grid of 10 × 10 km cells on flightlines and loon locations. Relative density for each grid cell was calculated by dividing the number of observations by the area encompassed by transect strips within each cell (Butler, Stehn, and Balough 1995). The resulting density was assigned to the center of the cell, and a triangulated irregular network (TIN) was created from the density points (Burrough and McDonnell 1998) using ArcInfo® version 8.3 (ESRI®, Environmental Systems Research Institute, Redlands, CA). Contours, or isopleths, of relative density were then generated using TIN-

TABLE 1.   Annual population indices from the Early and Late June Surveys used in estimating the current 12-year average population size for Yellow-billed Loons on Alaskan breeding grounds. The Late Survey corrected population-size estimate is thus $2893.6 \times 1.1644 = 3369$ individuals, where 1.1644 is the correction factor (see Results). The Early Survey corrected estimate, from Eq. 1 in Methods, is $(1092.8 \times 1.1644) \times [1 + (1235.5 \times 1658.1^{-1})] = 2221$ individuals.

| | Early Survey | | Late Survey | | | |
| | Early study area | | Inside Early study area | | Outside Early study area | |
Year	Population index[a]	SE	Population index[a,b]	SE	Population index[a,b]	SE
1992	1006	193	1485	188	1754	603
1993	1201	281	989	215	1386	341
1994	827	198	1738	370	1368	525
1995	1246	295	2831	598	1308	382
1996	1044	188	2915	483	1941	653
1997	1280	559	1581	341	1011	330
1998	907	166	2325	648	1072	470
1999	972	192	1675	354	1272	751
2000	660	177	810	234	703	307
2001	1109	167	474	137	868	237
2002	1544	297	715	260	1232	304
2003	1317	228	2359	381	911	264
Mean ± SE[c]	1092.8 ± 77		1658.1 ± 110		1235.5 ± 133	

[a] Number of individuals observed per km^2 extrapolated to the study area in question; index not corrected for visibility.

[b] Annual indices differ slightly from those in earlier USFWS reports because our stratification differed and we included data from a first-year observer in 2000.

[c] We defined the statistical population of interest as being bounded in space and time (1992–2003), and thus treated both geographic areas and years as strata. SE were calculated using formulas for stratified sampling (Cochran 1977).

LATTICE and LATTICEPOLY commands. Relative densities >1 individual per 100 km^2 were pooled into four equal-sized classes (see Fig. 6). The TIN method does not provide a measure of statistical precision of the location of the density polygons, however, the exact borders are not relevant to our discussion. To provide a general description of the degree of patchiness, we calculate the proportion of Late Survey sightings (1992–2003) that fall within various relative density polygons. We use Late Survey rather than Early Survey sightings for this purpose because the former provides complete coverage of the study area.

RESULTS

POPULATION SIZE

The estimated 12-year average Yellow-billed Loon population size on Alaska's North Slope during early June was 2221 ± 460 individuals (95% CI: 1209–3233). The estimated correction factor (density during intensive surveys divided by density during Early and Late Surveys) was 1.16 ± 0.22, indicating that 16% more loons were sighted during intensive surveys (9.55 ± 1.85 loons per 100 km^2, 213 loons total) than during Early and Late transect surveys on intensive plots (8.20 ± 1.72 loons per 100 km^2, 130 loons, cumulative 12-year total). Correction factors calculated separately for Early and Late Surveys did not differ (1.18 ± 0.28 and 1.14 ± 0.27, respectively, $n = 21$ plots each, $t_{40} = 0.1$, $P = 0.92$) and had high standard errors because of the smaller area surveyed in each subset; therefore, the pooled estimate was used. The corrected 12-year average population size for the Early Survey was 1272 loons inside and 948 loons outside the Early study area (Table 1). The estimates for inside and outside the Early study area were then added to provide the 12-year corrected population-size estimate expanded to the entire North Slope for the Early Survey of 2221 individuals (Eq. 1 in Methods, Table 1) with a 95% CI of 1209 to 3233 individuals.

The 12-year average corrected population estimate for the Late Survey was 3369 (±663) individuals (95% CI: 1910–4828). This estimate was not significantly different from the estimate
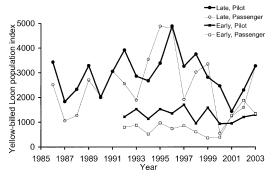
FIGURE 2.   Annual population indices from the Early and Late June aerial surveys for pilot- and passenger-observers. Late and Early study areas were 61 645 km² and 30 755 km², respectively.
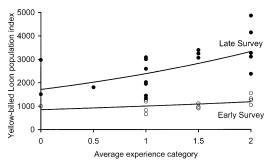

FIGURE 3.   Relationship between Yellow-billed Loon population index and observer experience on the Late June and Early June aerial surveys. The natural logarithm of population index was used in regressions but the y-axis is shown on the original scale for ease of interpretation.

of 2221 ($\pm$ 460) individuals obtained in the Early Survey ($t_{22} = 1.4$, $P = 0.17$).

ASSESSING POTENTIAL BIAS IN THE POPULATION TREND

Visual inspection of the uncorrected annual indices suggested no long-term trend over the 18-year Late Survey or the 12-year Early Survey (Fig. 2), but we suspected that trends in observer experience and timing of spring might obscure the true relationship with year.

Observer experience. The potential for observer experience to affect the trend in the index ratio is indicated by the increase in average observer experience category over the survey period ($r^2 = 0.26$, $t_{17} = 2.4$, $P = 0.03$). If more experienced observers detect more loons, it would produce a positive trend in the index ratio and thus a positive bias in the trend in loon numbers across years. First we provide independent evidence that experienced observers detect more loons and then we examine the effect of observer experience on estimates of population trend.

An independent means of assessing observer skill is to compare passenger-side detections to detections made by the pilot, who was typically more skilled and experienced, in the same survey-year. Pilots observed 25% more Yellow-billed Loons per 1000 km² than passengers (paired, two-tailed t-test, $\bar{x}$ difference = 8.8 $\pm$ 3.6 loons per 1000 km², $t_{30} = 2.5$, $P = 0.03$) in the Early and Late Surveys combined. Pilots recorded more loons per 1000 km² than passengers in 22 of the 30 survey-years, and in 19 of 21 survey-years when one highly experienced passenger was excluded. Consistent with these findings, the natural logarithm of population index (hereafter, population index) increased with average experience category on the Late Survey ($r^2 = 0.35$, $t_{17} = 2.9$. $P = 0.009$) and showed a similar tendency on the Early Survey ($r^2 = 0.18$, $t_{11} = 1.5$, $P = 0.16$, Fig. 3).

Observers also appeared to improve in skill after their first survey-year. For 5 of 7 passengers contributing >1 year of data, the pilot-passenger difference in loons recorded per 1000 km² decreased from the passenger's first to last survey. When averaged within experience categories, the pilot-passenger difference for these 7 passengers decreased from 18.0 $\pm$ 3.9 birds per 1000 km² in their first year, to 11.2 $\pm$ 4.3 in their second and third years, and to 4.7 $\pm$ 7.4 in later years.

Observer experience had a noticeable effect on the year coefficient and entered each of the models in the best subset (Table 2). The year coefficient was positive in all models without experience (Model A–D) and negative in all models with experience (Models 1–5, Table 2). For example, when experience was added to the model with only year and survey type, the year coefficient changed from +1.83 to −0.85 (Model C vs. Model 1, Table 2), indicating that entering experience in the model removed a strong positive bias.

Timing of spring. Springs became increasingly warm through 1996 (Fig. 4), but were variable thereafter, thus, thaw-degree days was a potential source of positive bias in the loon population trend during the first decade of the survey and a source of noise thereafter. The natural logarithm of thaw-degree days (hereafter, thaw-de-

TABLE 2.   Summary of models used to estimate percent annual change in the Yellow-billed Loon population index. Change in AIC_c is the difference in AIC_c relative to the model with the lowest AIC_c score. A model's weight (w) reflects its probability of being the best-fitting model of those under consideration. Models 1–5 comprise the best model subset ($\Delta AIC_c < 2$); Models A–D shown only to illustrate change in the year coefficient (% annual change) when experience is added to the model. Model averaging of Models 1–5 produced an unconditional estimate of percent annual change = $-0.9\% \pm 1.2\%$ (95% CI: -3.6% to $+1.8\%$).

Model	Fixed parameters[a]	k[b]	AIC_c	ΔAIC_c	w	Percent annual change ($\pm$SE)[c]
Best model subset						
1	YR + SURV + OBSEXP	7	66.6	0	0.23	–0.85 ± 1.21
2	YR + SURV + OBSEXP + LNTHDG	8	66.7	0.1	0.22	–0.78 ± 1.21
3	YR + SURV + OBSEXP + LNTHDG + OBSTYPE	9	67.3	0.7	0.16	–0.85 ± 1.07
4	YR + SURV + OBSEXP + OBSTYPE	8	67.5	0.9	0.15	–0.86 ± 1.11
5	YR + SURV + OBSEXP + LNTHDG + SURV * LNTHDG	9	67.8	1.2	0.13	–1.24 ± 1.22
Models without observer experience						
A	YR + SURV + LNTHDG	6	69.5	2.9	0.05	1.34 ± 1.30
B	YR + SURV + LNTHDG + OBSTYPE	7	69.8	3.2	0.05	0.93 ± 1.23
C	YR + SURV	5	72.7	6.1	0.01	1.83 ± 1.36
D	YR + SURV + OBSTYPE	6	73.2	6.6	0.008	1.46 ± 1.31

The column header structure: "Model summary" spans k, AIC_c, ΔAIC_c, w; "Population trend" spans "Percent annual change ($\pm$SE)".

[a] Abbreviations used for year (YR), survey (SURV), observer experience category (OBSEXP), natural logarithm of thaw degree days (LNTHDG), and observer type (OBSTYPE).
[b] k = number of parameters, which includes fixed parameters + 1 random parameter + intercept + residual.
[c] Percent annual change = (EXP[year coefficient] − 1) × 100%.

gree days) had a significant, positive relationship with the observed population index for the Late Survey ($r^2 = 0.35$, $t_{17} = 3.0$, $P < 0.01$) but not the Early Survey ($r^2 < 0.01$, $t_{11} = 0.2$, $P = 0.82$; Fig. 5). This disparity between surveys was investigated further by restricting the Late Survey to the area and years covered by both surveys (Early study area, 1992–2003), and confirming a similar positive relationship between thaw-degree days and population index therein ($r^2 = 0.31$, $t_{11} = 2.2$, $P = 0.06$). Similarly, the difference between Late and Early population indices

was positively related to thaw-degree days in the area and years covered by both surveys ($r^2 = 0.26$, $t_{11} = 1.9$, $P = 0.09$) and not related to any difference between surveys in average observer experience ($r^2 = 0.06$, $t_{11} = 0.8$, $P = 0.45$), suggesting that more loons arrive between Early
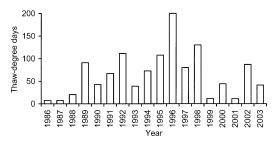

FIGURE 4.   Annual variation in timing of spring, as measured in thaw-degree days from 1 May to 10 June, during years of the Late (1986–2003) and Early (1992–2003) Surveys.
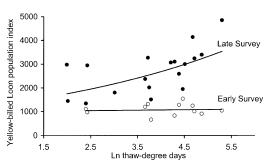

FIGURE 5.   Relationship between Yellow-billed Loon population index and timing of spring, measured as the natural logarithm of thaw-degree days (Ln thaw-degree days) from 1 May to 10 June, on Late June Surveys and Early June Surveys. The natural logarithm of population index was used in regressions but the y-axis is shown on the original scale for ease of interpretation.

TABLE 3. Model-averaged regression coefficients for 5 predictors on the annual Yellow-billed Loon population index in log-linear regression (i.e., response variable is natural logarithm of population index). Model averaging conducted using the 5 models in the best subset; those with $\Delta AIC_c < 2$, in Table 2. The average regression coefficient is also expressed as percent change in the population index, where percent change = (EXP[coefficient] − 1) × 100%. The interaction between survey and thaw-degree days entered one of the best model subset, so thaw-degree days is interpreted separately for the two surveys (where thaw-degree days is the natural logarithm of thaw-degree days). Abbreviations follow those in Table 2.

Parameter	Average coefficient	Percent change (±SE) in population index	95% CI[a]	
			Lower	Upper
YR[b]	−0.009	−0.9 ± 1.2	−3.6	1.8
SURV[c]	−0.874	−58.3 ± 9.1	−78.9	−37.7
OBSEXP, first year[d]	−0.409	−33.6 ± 9.4	−54.8	−12.4
OBSEXP, intermediate[d]	−0.394	−32.6 ± 8.4	−51.5	−13.6
LNTHDG for Late Survey	0.099	10.4 ± 7.8	−7.2	28.0
LNTHDG for Early Survey	0.065	6.7 ± 8.3	−12.2	25.5
OBSTYPE[e]	−0.177	−16.2 ± 13.5	−46.7	14.3

[a] Based on 9 df, where df = 18 years − k, and k = 9 parameters in most parameterized model.
[b] Change in population index with year.
[c] Early Survey relative to Late Survey.
[d] First-year and intermediate observers (2–3 years) relative to experienced observers (4+ years).
[e] Passenger-observer relative to pilot-observer.

and Late Surveys during warm springs than cold springs.

The positive bias induced by the effect of spring phenology on number of loons that we observed can be seen in the decrease in the year coefficient when thaw-degree days was added to a model (e.g., Model C vs. A, Model D vs. B) but the effect was less apparent in models containing observer experience (Model 1 vs. 2, Model 4 vs. 3; Table 2).

POPULATION TREND

There was no indication of a substantial population trend since 1986, but the estimated uncertainty about the mean trend was large. The unconditional mean population trend for 1986–2003 was −0.9% ± 1.2% annual change (95% CI: −3.6% to +1.8%, Table 3), thus, the trend was not statistically distinguishable from 0. Likewise, the year coefficients in the best subset of models ranged from −0.8% to −1.2% (Table 2) and none differed significantly from 0 (all P > 0.32).

The most parsimonious model contained only year, survey type, and observer experience (Model 1, Table 2). Observer experience was clearly the most important predictor variable in the models we investigated. It entered each of the best models, and had a large effect on the number of birds that were recorded. Based on the model-averaged coefficient, first-year ob-

servers saw 33.6% ± 9.4% fewer birds than the most experienced observers (4+ years of experience) and observers with intermediate experience (2–3 years) saw 32.6% ± 8.4% fewer birds than the most experienced observers (Table 3). As documented previously, the combination of average experience increasing across the period of the survey and the tendency for experienced observers to record more loons than inexperienced observers, caused a positive bias in the population trend which was reflected by the decrease in the year coefficient when experience was added to a model (Table 2).

Thaw-degree days entered three of five models in the best subset, and the interaction between survey and thaw-degree-day entered into one additional model, indicating some evidence that thaw-degree days had a greater effect on the Late Survey than the Early Survey (Table 2). Based on model-averaged coefficients, 10.4% ± 7.8% and 6.7% ± 8.3% more loons were observed with each unit increase in the thaw-degree days in the Late Survey and Early Survey, respectively (Table 3). To put this into perspective, most years (80%) fell within a range of 11 to 130 thaw-degree days, and the model-averaged coefficient predicts a 28% increase in the Late Survey population index across the extremes of this range. However, the model-averaged coefficients for thaw-degree days were not significantly different from 0 on either survey

TABLE 4. Estimated Yellow-billed Loon population trend and power to detect a trend based on simple log-linear regressions of Early and Late Surveys analyzed separately, and based on model averaging of mixed-effects models that combine surveys and account for sources of bias and noise. All values are presented as percentages.

Statistic	Early Survey ($n = 12$ years)	Late Survey ($n = 18$ years)	Combined model-averaged estimate[a] ($n = 18$ years)
Percent annual change ($\pm$SE)[b]	1.2 $\pm$ 2.6	–0.1 $\pm$ 1.5	–0.9 $\pm$ 1.2
Power to detect -2.5% annual change	16	39	55
Power to detect -3.4% annual change	26	62	81
Power to detect -6.7% annual change	73	99	>99

[a] Unconditional estimate based on model averaging of Models 1–5 in Table 2; combines the two surveys and incorporates effects of observer experience and thaw degree-days.

[b] Percent annual change = (EXP[year coefficient] $-$ 1) $\times$ 100%, where the year coefficient is from log-liner regression.

(Table 3). Presumably part of the variation explained by thaw-degree days was also explained by observer experience. Both had a positive relationship with population index in simple regression (Fig. 3 and 5) and both had a negative effect on the year coefficient in mixed-effects models, but the effect of thaw-degree days on the year coefficient was negligible in models that also contained observer experience.

Observer type entered only two of five models in the best subset (Table 2). The model-averaged coefficient indicated that passenger-observers recorded 16% $\pm$ 13% fewer loons than pilot-observers on average, and the effect was not distinguishable from 0 (Table 3). The lack of importance of observer type in models that also account for experience is consistent with the tendency for detections by pilot-observers and passenger-observers to become more similar as observers gain experience.

By default, all models contained year, because it was the parameter of interest, and survey type, because it accounted for the difference in size of the geographic area covered by the two surveys. The Early Survey covered 50% less area and its population index averaged 58% $\pm$ 9% lower than that of the Late Survey (Table 3). Observer identity, which was included as a random effect in all models and which quantifies the covariance among multiple annual indices from a single observer, was highly significant (all $P < 0.002$) in models without experience (Models A–D) and at least marginally significant ($P = 0.04$ to 0.08) in models with experience (Models 1–5; based on log-likelihood tests under restricted maximum likelihood, Littell et al. 1996).

Predicting number present in average and warm springs. We wished to adjust the average population size estimate for the Late Survey by the additional number of loons present in the warmest year relative to the average year. Thus, we used Model 5 to predict the number present in the warmest relative to average year, where Model 5 for the Late Survey was Population Index = 32.4 $-$ 0.013 Year + 0.136 Thaw-degree Days $-$ 0.385 First-year Experience Category $-$ 0.376 Intermediate Experience Category. When observer experience and year were held constant, the difference in predicted number present during the Late Survey at average thaw-degree days ($\bar{x} = 65.1$) versus maximum thaw-degree days (maximum = 200) indicated that 14.1% of those loons predicted in the warmest year were not predicted to be present in an average year.

POWER TO DETECT A TREND

The power of the two ongoing aerial surveys to detect a -3.4% annual decline in the Yellow-billed Loon population index, when multiple regression models were used to combine the two surveys and reduce potential sources of noise and bias, was reasonably high at 81% (Table 4). More gradual annual declines are more difficult to detect, and steeper declines are easier to detect. For example, power to detect a -2.5% annual decline (40% total decline in 20 years) was only 55%, but power to detect a -6.7% annual decline (75% total decline in 20 years) was >99% (Table 4).

Model averaging and multiple regression provided greater power to detect a trend than separately analyzing the 12-year Early Survey or
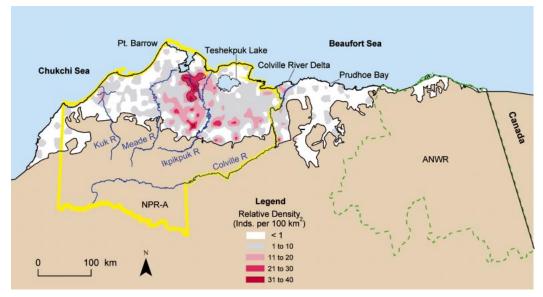
FIGURE 6.   Relative density of Yellow-billed Loons on the North Slope of Alaska. Based on Early and Late June aerial surveys during 1992–2003. Relative density is not corrected for visibility bias. Yellow and green lines represent the boundaries of the National Petroleum Reserve—Alaska (NPR-A) and Arctic National Wildlife Refuge (ANWR), respectively.

18-year Late Survey using simple log-linear regression of population index on year (26% and 62% power to detect −3.4% annual decline, respectively, Table 4).

RELATIVE DENSITY

Yellow-billed Loons are distributed patchily across the North Slope (Fig. 6). Most occur between the Meade and Colville Rivers. The contiguous concentration area (i.e., >11 individuals per 100 km^2) between the Meade and Ikpikpuk Rivers encompassed 38% of all Yellow-billed Loons recorded during the Late Survey (1992–2003) in only 8% of the study area, and the highest density subset therein (>21 individuals per 100 km^2), which is outlined in black in Fig. 6, encompassed 10% of all loons in only 2% of the study area. Summed across the North Slope, concentration areas encompassed 53% of sightings in 12% of the study area.

In all, 91% of recorded Yellow-billed Loons occur within the National Petroleum Reserve-Alaska, and 23% of those are in an area of high oil potential which is likely to be developed first (Fig. III-A-29 in BLM 1998, Map 105 in BLM 2003).

DISCUSSION

POPULATION SIZE

Our estimate of the current 12-year (1992–2003) average population size, an estimate which incorporates a correction factor to reduce detection bias, indicates only 2221 Yellow-billed Loons (95% CI: 1209–3233) are present on North Slope breeding grounds in early June. Additional Yellow-billed Loons, presumably non-breeders, apparently arrive on breeding grounds by late June, when the corrected population estimate (3369 individuals, 95% CI: 1910–4828) is somewhat, but not significantly, higher than in early June. An estimate of the number of nesting pairs, which is of particular interest in the conservation of Yellow-billed Loons, can be obtained by assuming that about 81% of the 3369 adult-plumaged birds on the breeding grounds in late June are territorial (as in Common Loons, *Gavia immer*; Evers 2004), and that roughly 59% of territorial Yellow-billed Loons attempt to nest in a given year (range 39% to 89% during 10 years at one site; Earnst 2004). This logic indicates that the North Slope supports <1000 nesting pairs in most years (range: 437–1214), and even if all Yellow-billed Loons on the

breeding grounds were territorial, the expected range would be only 593 to 1499 nesting pairs. It is likely that nesting pairs (North and Ryan 1988; SLE, pers. obs.) and some other territorial pairs have arrived by the time of the Early Survey, and that many later arriving individuals are younger, nonterritorial birds (probably 3–5 year-olds, as in Common Loons, Evers 2004).

In addition to nesting pairs and other adults on the breeding grounds, one biological population of interest includes any immatures or adults that remain at sea and are not counted during breeding season surveys. For example, 1–2 year-old Yellow-billed Loons are thought to remain in immature plumage and to stay at sea during the breeding season (North 1994), as do 1–2 year-old Common Loons (Evers 2004). Based on the demography of Common Loons, which breed on average at age 6 and have approximately 70%, 80%, and 92% annual survival at ages 1, 2–3, and >3 years, respectively (Evers 2004, M. Mitro, D. Evers, and M. Meyer, unpubl. data), and a Leslie matrix that assumes a stable population and some degree of senescence (modeled as annual survival of 88% after age 20), we estimate that approximately 19.8% of the population is 1–2 years of age during June surveys. In addition, predictions from our multiple regression model on Late Survey data indicate that 14.1% of adult-plumaged birds present on breeding grounds during the Late Survey in the warmest spring are absent during an average spring (presumably some fraction of the young, late-arriving birds). Thus, during an average year when the Late Survey estimate is 3369, an additional 554 adult-plumaged birds (14.1% of 3923) and 969 1–2 year-olds (19.8% of 4892) presumably remain at sea, giving a total of 4892 individuals for all Yellow-billed Loons on North Slope breeding grounds and associated age classes at sea.

Similarly, a reasonable approximation for Yellow-billed Loons on all Alaska breeding grounds plus birds at sea includes the Late June 12-year average of 3369 individuals on the North Slope, plus 730 in western Alaska (Platte 1999) and 50 on St. Lawrence Island (North 1994), plus 1–2 year-olds and 14.1% of adult-plumaged birds that remain at sea during an average year, for an overall estimate of 6024 individuals. This estimate's minimum 95% confidence interval, based only on the confidence interval of the Late Survey, is 3906 to 8143 individuals, and would be

larger if uncertainty in demographic rates were appropriately incorporated. These total North Slope and Alaska-wide population estimates, which are based largely on Common Loon demography, a simple population matrix, and the assumption that all adult-plumaged birds are present in the warmest springs, should be interpreted cautiously and modified freely as more complete demographic data for Yellow-billed Loons become available (Beissinger and Westphal 1998). If Yellow-billed Loons have lower productivity and therefore higher adult survival rates than Common Loons, as one might expect, then the percentage of birds in young age classes and those remaining at sea would be smaller; however, our Leslie matrix approach suggests the difference would be only 300–500 individuals lower than the estimate of 6024 individuals presented here.

Our Early and Late June estimates also depend on the accuracy of the estimated correction factor, indicating that intensive surveys detected 16% more loons than extensive surveys. Because of the small area sampled by transects within plots each year, it was necessary to pool the 3 years of intensive surveys (as the numerator) and 12 years of Early and Late Surveys (as the denominator) to estimate the correction factor. Data from the Early and Late Surveys adequately incorporate the values of years, spring phenologies, observers, and other factors that might influence extensive surveys across the 12 years of interest. Because intensive surveys were conducted in only 3 years, it is necessary to assume that results obtained in these 3 years are representative of those that would have been obtained during the 12 years of interest. Our corrected Early June population estimate of 2221 ± 460 corresponds well with a preliminary estimate of 2129 ± 342 individuals from the first year of an independent, lake-circling survey that recorded >350 loons on >2800 lakes across the North Slope (USFWS, unpubl. data). Nonetheless, a correction factor calculated separately for the two surveys and based on a larger sample of years, periods within years, and transects spread throughout the full study area would be more statistically sound and would clarify any differences between the two surveys. Likewise, although the detection probability during lake circling is thought to be very high, a correction factor based on ground surveys is also needed.

POPULATION TREND

There is no evidence of a significant population trend since 1986. However, the 95% CI around the model-averaged estimate was large (−3.6% to +1.8%), indicating that the estimated trend is not statistically distinguishable from a total 18-year population change of −48% or +38%, respectively.

Our investigation identified two factors that could produce a trend in the index ratio and thus a bias in the trend. First, observer skill improved from an observer's first to subsequent surveys. Thus, a tendency for higher observer turnover (and thus more first-year observers) later in the survey period could contribute to a misleading negative trend, or more experienced observers later in the period could contribute to a misleading positive trend. Biases due to a change in average observer skill over the survey period (Sauer et al. 1994, James et al. 1996), and an increase in observer skill with experience (Kendall et al. 1996) have also been documented in the North American Breeding Bird Survey (BBS). In aerial waterfowl surveys, differences between inexperienced and experienced observers could be due to any combination of several errors, such as looking beyond the 200-m survey strip, missing loons that were present, and misidentifying species.

A second factor that could produce a trend in the index ratio and thus a bias in the population trend is that more loons were observed during warm springs, suggesting that a larger fraction of the nonbreeding population may be present. During the 18-year Late Survey period, thaw-degree days tended to increase early in the period and decrease later, so timing of spring was a source of noise, rather than bias, in our overall trend. However, separate analyses of the first and second halves of the survey period, inspired by visual inspection of the uncorrected population indices (Fig. 2), would be seriously flawed if effects of spring phenology were ignored. In general, changes in the timing of breeding relative to surveys, and vice versa, may be under-emphasized as a source of bias in avian trends (Bromley et al. 1995, Crick and Sparks 1999).

We posit that the tendency for more loons to be recorded on the breeding grounds in warm springs than cold springs, and for this difference to be apparent on the Late Survey but not the Early Survey, is due to nonterritorial and per-haps other non-nesting loons arriving in the interval between surveys (mid-June) and with a greater fraction remaining at sea during years with severe springs. This pattern is also consistent with most territory holders arriving as early as ice conditions allow (North and Ryan 1988; SLE, pers. obs.), with the tendency for non-breeders to arrive later than breeders in other species (Evers 2004), and with concentrations of Yellow-billed Loons recorded offshore of breeding grounds during severe, but not mild, springs (Alexander et al. 1997). Ground-based work using telemetry or color-banded individuals is needed to assess this hypothesis.

We considered the possibility that higher numbers of loons recorded in warm springs was an artifact of higher loon visibility due to less ice cover rather than being due to the arrival of nonbreeders. However, it is not clear whether more ice cover would decrease visibility of loons on open-water lake edges or alternatively, increase visibility because of less open water available to be searched (Caughley 1974). We also considered the possibility that loons might be more visible in warm springs than cold springs due to behavioral differences. For example, Bromley et al. (1995) found that detection rates of arctic geese were higher during years of poor reproduction because failed breeders were more obvious than those with nests. However, because most arctic-breeding species reproduce more successfully in warm springs than cold springs (Newton 1977, Bromley et al. 1995, Ganter and Boyd 2000), the low visibility of nesting birds would produce a lower, not higher, estimate of number present during warm springs.

The U.S. population of Yellow-billed Loons warrants close monitoring because of its small population size and the relatively poor ability of long-lived species with low annual productivity to recover from declines (Gilpen and Soulé 1986, Hunter 1996). The Yellow-billed Loon is difficult to monitor with general waterfowl surveys because of low sampling intensity relative to loon abundance, annual variability in the proportion of nonterritorial birds present on the breeding grounds, and difficulty of estimating potential bias in the trend. By using multiple-regression models to combine the two surveys and incorporate some sources of bias and annual variation, we achieved relatively high power (81%) to detect a −3.4% decline and higher

power than a simple log-linear regression on either survey alone. However, if all potential sources of bias were not modeled accurately, estimated power could be <81% (Bart, Burnham, et al. 2004). Furthermore, if circumstances, such as a suspected change in habitat quality, indicate the need to detect a more gradual annual decline than 3.4% in this already rare species, or over a shorter period than 18 years, then power would likely be inadequate (e.g., 55% power to detect a 2.5% decline). A more precise trend estimate with less visibility bias, and thus less potential bias in the trend, may be possible with a survey method having higher detection probabilities. A lake-circling survey designed specifically for Yellow-billed Loons has been initiated, and although intended as a one-time effort to investigate habitat preferences, it could provide trend estimates if repeated at regular intervals. An alternate method of reducing bias may be to record distance and angle from each loon sighting to the aircraft during Late and Early Surveys and use distance methods in analysis (Buckland et al. 2001). This alternative, like lake circling, would necessitate increased sampling intensity to obtain an adequate sample of detections each year. An important consideration is whether assumptions of distance methods can be met, such as accurately estimating distance and angle during busy multispecies surveys, and obtaining 100% detection and perfect identification of species at the closest distance.

IMPLICATIONS FOR CONSERVATION

Species, such as the Yellow-billed Loon, having small geographic ranges, narrow habitat requirements, and patchy distributions, may be more susceptible to environmental perturbations than more widely distributed generalists (Hunter 1996). Most (53%) Yellow-billed Loon sightings occurred within 12% of the North Slope, and a single contiguous concentration area between the Meade and Ikpikpuk Rivers encompassed 38% of all Yellow-billed Loon sightings in 8% of the North Slope (Fig. 6). A distribution such as this, although it may contribute to the population's vulnerability, also provides a unique opportunity for conservation measures within a relatively small area to benefit a large fraction of the population.

Yellow-billed Loons are rare throughout North America and the world. The North American population includes 6024 in the U.S. (this study) and roughly 9975 in Canada (8000 on breeding grounds [Fair 2002] with 19.8% at sea). Among all avian species having >10% of their global breeding population in the mainland U.S., the Yellow-billed Loon is estimated to be among the 10 rarest birds in the U.S. and among 20 species with a North American population estimate ≤16 000 (Earnst 2004).

ACKNOWLEDGMENTS

LITERATURE CITED

ALEXANDER, S. A., D. L. DICKSON, AND S. E. WESTOVER. 1997. Spring migration of eiders and other waterbirds in offshore areas of the western Arctic, p. 6–20. *In* D. L. Dickson [ED.], King and Common Eiders of the western Canadian Arctic. Canadian Wildlife Service, Occasional Paper No. 94.

ANDERSON, D. R. 2001. The need to get the basics right in wildlife field studies. Wildlife Society Bulletin 29:1294–1297.

BART, J., AND S. EARNST. 2002. Double sampling to estimate density and population trends in birds. Auk 119:36–45.

BART, J., K. P. BURNHAM, E. H. DUNN, C. M. FRANCIS, AND C. J. RALPH. 2004. Goals and strategies for estimating trends in landbird abundance. Journal of Wildlife Management 68:611–626.

BART, J., S. DROEGE, P. GEISSLER, B. PETERJOHN, AND C. J. RALPH. 2004. Density estimation in wildlife surveys. Wildlife Society Bulletin 34, in press.

BEISSINGER, S. R., AND M. I. WESTPHAL. 1998. On the use of demographic models of population viability in endangered species management. Journal of Wildlife Management 62:821–841.

BROMLEY, R. G., D. C. HEARD, AND B. CROFT. 1995. Visibility bias in aerial surveys relating to nest

success of arctic geese. Journal of Wildlife Management 59:364–371.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM, J. L. LAAKE, D. L. BORCHERS, AND L. THOMAS. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, UK.

BUREAU OF LAND MANAGEMENT. 1998. Northeast National Petroleum Reserve-Alaska: integrated activity plan/environmental impact statement. Record of Decision. Bureau of Land Management, Anchorage, AK.

BUREAU OF LAND MANAGEMENT. 2003. Northwest National Petroleum Reserve-Alaska: final integrated activity plan/environmental impact statement. Bureau of Land Management, Anchorage, AK.

BUREAU OF LAND MANAGEMENT. 2004. Alpine satellite development plan. Final environmental impact statement. Bureau of Land Management, Anchorage, AK.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model selection and multimodel inference. 2nd ed. Springer-Verlag, New York.

BURROUGH, P. A., AND R. A. MCDONNELL. 1998. Principles of geographical information systems. Oxford University Press, Oxford, UK.

BUTLER, W. I., JR., J. I. HODGES, AND R. A. STEHN. 1995. Locating waterfowl observations on aerial surveys. Wildlife Society Bulletin 23:148–154.

BUTLER, W. I., JR., R. A. STEHN, AND G. R. BALOGH. 1995. GIS for mapping waterfowl densitiy and distribution from aerial surveys. Wildlife Society Bulletin 23:140–147.

CAUGHLEY, G. 1974. Bias in aerial survey. Journal of Wildlife Management 38:921–933.

CENTER FOR BIOLOGICAL DIVERSITY. 2004. Petition to list the Yellow-billed Loon, Gavia adamsii, as an endangered or threatened species under the Endangered Species Act. Center for Biological Diversity, Sitka, AK.

COCHRAN, W. G. 1977. Sampling techniques. 3rd ed. John Wiley and Sons, NY.

CRICK, H. P. Q., AND T. H. SPARKS. 1999. Climate change related to egg-laying trends. Nature 399: 423–424.

EARNST, S. L., R. PLATTE, AND L. BOND. 2005. A landscape-scale model of Yellow-billed Loon habitat preferences in northern Alaska. Hydrobiologia, in press.

EARNST, S. L. 2004. Status assessment and conservation plan for the Yellow-billed Loon (Gavia adamsii). USGS Scientific Investigations Report 2004–5258.

EVERS, D. C. 2004. Status assessment and conservation plan for the Common Loon (Gavia immer) in North America. Final draft. U.S. Fish and Wildlife Service, Hadley, MA.

FAIR, J. 2002. Status and significance of Yellow-billed Loon (Gavia adamsii) populations in Alaska. Report to The Wilderness Society and Trustees for Alaska, Anchorage, AK.

GANTER, B., AND H. BOYD. 2000. A tropical volcano, high predation pressure, and the breeding biology of arctic waterbirds: a circumpolar review of breeding failure in the summer of 1992. Arctic 53: 289–305.

GILPEN, M. E., AND M. E. SOULÉ. 1986. Minimum viable populations: processes of species extinction, p. 19–34. In M. E. Soulé [ED.], Conservation biology: the science of scarcity and diversity. Sinauer, Sunderland, MA.

GOODMAN, L. A. 1960. On the exact variance of products. American Statistical Association Journal (December):708–713.

HUNTER, M. L., JR. 1996. Fundamentals of conservation biology. Blackwell Science, Cambridge, MA.

JAMES, F. C., C. E. MCCULLOCH, AND D. A. WIEDENFELD. 1996. New approaches to the analysis of population trends in land birds. Ecology 77:13–27.

KENDALL, W. L., B. G. PETERJOHN, AND J. R. SAUER. 1996. First-time observer effects in the North American Breeding Bird Survey. Auk 113:823–829.

LITTELL, R. C., G. A. MILLIKEN, W. W. STROUP, AND R. D. WOLFINGER. 1996. SAS system for mixed models. SAS Institute Inc., Cary, NC.

NEWTON, I. 1977. Timing and success of breeding in tundra-nesting geese, p. 113–126. In B. Stonehouse and C. Perrins [EDS.], Evolutionary ecology. University Park Press, Baltimore, MD.

NORTH, M. R. 1994. Yellow-billed Loon. In A. Poole and F. Gill [EDS.], The birds of North America, No. 121. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, DC.

NORTH, M. R., AND M. R. RYAN. 1988. Yellow-billed Loon, Gavia adamsii, breeding chronology and reproductive success in arctic Alaska. Canadian Field-Naturalist 102:485–490.

NORTH, M. R., AND M. R. RYAN. 1989. Characteristics of lakes and nest sites used by Yellow-billed Loons in arctic Alaska. Journal of Field Ornithology 60:296–304.

PLATTE, R. M. 1999. Water bird abundance and distribution on Selawik National Wildlife Refuge and Noatak Lowlands, Alaska, 1996–1997. Unpublished report, U.S. Fish and Wildlife Service, Anchorage, AK.

SAS INSTITUTE. 2000. SAS/STAT user's guide. Vol. 2. Version 8. SAS Institute, Inc., Cary, NC.

SAUER, J. R., B. G. PETERJOHN, AND W. A. LINK. 1994. Observer differences in the North American Breeding Bird Survey. Auk 111:50–62.

SMITH, G. W. 1995. A critical review of the aerial and ground surveys of breeding waterfowl in North America. USDI National Biological Service, Biological Science Report 5. Washington, DC.

STEELE, R. G. D. AND J. H. TORRIE. 1980. Principles and procedures of statistics. 2 ed. McGraw-Hill, Inc., New York.

THOMPSON, W. L. 2002. Towards reliable bird surveys: accounting for individuals present but not detected. Auk 119:18–25.

U.S. DEPARTMENT OF INTERIOR. 1995. National Petroleum Reserve-Alaska landcover inventory: phase 1 western NPR-A. Final report. Pacific Meridian Resources, Sacramento, CA.

U.S. FISH AND WILDLIFE SERVICE. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management. Arlington, VA.