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NECKBAND RETENTION FOR LESSER SNOW GEESE IN THE WESTERN ARCTIC

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Abstract: Neckbands are commonly used in waterfowl studies (especially geese) to identify individuals for determination of movement and behavior and to estimate population parameters. Substantial neckband loss can adversely affect these research objectives and produce biased survival estimates. We used capture, recovery, and observation histories for lesser snow geese (*Chen caerulescens caerulescens*) banded in the western Arctic, 1993–1996, to estimate neckband retention. We found that neckband retention differed between snow goose breeding colonies at Wrangel Island, Russia, and Banks Island, Northwest Territories, Canada. Male snow geese had higher neckband loss than females, a pattern similar to that found for Canada geese (*Branta canadensis*) and lesser snow geese in Alaska. We found that the rate of neckband loss increased with time, suggesting that neckbands are lost as the plastic deteriorates. Survival estimates for geese based on resighting neckbands will be biased unless estimates are corrected for neckband loss. We recommend that neckband loss be estimated using survival estimators that incorporate recaptures, recoveries, and observations of marked birds. Research and management studies using neckbands should be designed to improve neckband retention and to include the assessment of neckband retention.

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Plastic neckbands have been used extensively to individually mark various species of geese throughout the world (Bell et al. 1993, Dick 1991, Nilsson and Persson 1991). Neckbands have been used to study migration (Koerner et al. 1974, Raveling 1978, Trost et al. 1980, Craven and Rusch 1983, Hestbeck et al. 1991), behavior (MacInnes and Lieff 1968), population dynamics (Rusch et al. 1985, Hestbeck and Malecki 1989, Schmutz and Ely 1999), population size (Hestbeck et al. 1990, Sheaffer and Jarvis 1995), and to evaluate management techniques (Smith 1996). Resightings of neckbanded geese have been used to estimate important population parameters, especially survival rates (Rusch et al. 1985, Hestbeck and Malecki 1989). However, the loss of marks results in an underestimate of survival rates and a decrease in precision (Arnason and Mills 1981, Pollock 1981, Nichols and Hines 1993). This loss may be especially important in studies of long-lived species, such as geese.

Quantitative estimates of neckband loss in Canada geese have been reported by a number of authors (Sherwood 1966, Raveling 1978, Craven 1979, Hestbeck and Malecki 1989, Samuel et al. 1990, Campbell and Becker 1991, Wiebe et al. 2000). Additionally, several studies of neckband retention have been conducted recently on lesser snow geese (Johnson et al. 1995) and on other species of geese in the Pacific Flyway (Campbell and Becker 1991, Schmutz and Ely 1999, Wiebe et al. 2000). Limitations of early studies were related to sample size, length of study, or analytical methods (Samuel et al. 1990). In general, most of these studies estimated neckband retention using birds recaptured during banding operations. Few studies have assessed neckband retention by combining information from recaptured and hunter-killed (recovered) birds (Zicus and Pace 1986) or by using resightings of neckbanded birds (Samuel et al. 1990).

The analysis of neckband retention data is complicated because the actual time of neckband loss is unknown and neckband retention times become censored. Two forms of censoring are typical of neckband retention studies. Right-censoring represents a minimum estimate of neckband retention time and occurs when birds with neckbands still attached are recaptured or recov-

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ered (harvested or found dead, and reported). These situations provide minimum retention times because the neckband is still considered alive when the goose is released or recovered. Interval-censoring occurs when a goose is observed with its neckband but is subsequently recaptured or recovered without a neckband. For these situations, minimum and maximum retention times are known. Samuel et al. (1990) described some of the analytical difficulties, limitations, and biases associated with neckband retention data. They recommended using statistical methods based on survival analysis (e.g., Kalbfleisch and Prentice 1980, Cox and Oakes 1984) designed specifically to analyze data when the exact time of failure (neckband loss) is unknown. These methods may be advantageous because they also use the observation data on neckbanded birds to help determine when neckbands may be lost.

Our objectives were to estimate the neckband retention rates for lesser snow geese banded at nesting areas on Wrangel Island, Russia, and Banks Island, Northwest Territories, Canada, and to identify factors that significantly influenced neckband retention. Data used in our analyses were part of a larger experimental study using vaccinated geese to determine the impact of avian cholera on the survival rates of lesser snow geese in the Pacific Flyway (Samuel et al. 1999).

STUDY POPULATIONS AND METHODS

Several breeding populations of lesser snow geese spend the winter in the Pacific Flyway (Johnson 1996). Two of the largest colonies of nesting birds are found at the Egg River on Banks Island, Northwest Territories, Canada, and on Wrangel Island in northeastern Russia, which is the only major snow goose colony in Asia (Bousfield and Syroechkovsky 1985, Syroechkovsky and Litvin 1986, Kerbes and Meeres 1999). Most of the Wrangel Island population migrates south along the Pacific coast to British Columbia and Washington, where the northern subpopulation winters in the Fraser and Skagit River deltas (Bousfield and Syroechkovsky 1985). The southern subpopulation continues south and winters in the Central Valley of California. Banks Island geese migrate through the prairies of western Canada and continue to the Central Valley of California for the winter (Hines et al. 1999). Spring migration begins from the Central Valley during February and March and birds reverse their autumn route, although most southern Wrangel Island geese migrate north through Montana and prairie Canada (Bellrose 1976, Armstrong et al. 1999).

We captured molting, flightless snow geese (Cooch 1953, Timm and Bromley 1976) on brood-rearing areas during July and August on Wrangel Island (1993–1995) and on Banks Island (1994–1996). At Wrangel Island, we captured geese by driving birds into corral nets using an all-terrain vehicle (Argo Magnum) or occasionally on foot. We employed helicopter-drive trapping techniques with portable nets to capture geese on Banks Island. All geese were marked with U.S. Fish and Wildlife Service aluminum leg bands and plastic neckbands. The northern subpopulation of Wrangel Island snow geese acquire red staining on their faces from feeding in the iron-oxide sediments of the Skagit–Fraser estuaries (Hohn 1955, Baranyuk and Syroechkovsky 1994). We used this characteristic to distinguish the commingled northern (red face color) and southern wintering subpopulations (white face color) banded at Wrangel Island.

Neckbands were made from 2-ply ultraviolet-resistant plastic, which measured 5.1 × 17.1 × 0.16 cm with rounded corners. The neckbands were rolled to an inside diameter of approximately 4.4 cm and were designed to overlap 2–3 cm where adhesive was applied to fasten the neckband. Neckbands used to mark snow geese at Wrangel Island (1993–1996) and at Banks Island (1994) were made by Spinner Plastics (Springfield, Illinois, USA). Neckbands used to mark snow geese at Banks Island (1995–1996) were made by Pro-Touch Engraving (Saskatoon, Saskatchewan, Canada). Each neckband bore a 3-character code (1 vertical and 2 horizontal; 1 letter and 2 numbers) that was legible ≤500 m with a 60× telescope (Craven 1979). We used red neckbands engraved to reveal white letters at Wrangel Island and black neckbands with white letters at Banks Island.

Snow geese recaptured at Wrangel and Banks islands during 1993–1999 were used to determine the status of neckbands at time of recapture. Band recovery reports obtained from the U.S. Geological Survey, Bird Banding Laboratory, Laurel, Maryland, USA, from 1993–2000 were used to identify hunters or other persons who recovered (reported harvested or dead) snow geese marked during our study. Questionnaires were sent to these individuals to determine whether the neckband was present at time of recovery (Craven 1979). Recapture records and questionnaires returned by hunters were used to identify records of neckbanded snow geese for retention analysis. Observation histories of these geese were examined to determine the date (if any) that each bird was last observed in the field (with a neckband). We used date of banding, date of recovery or recapture, neckband presence (or absence) at time of recovery or recapture, and date last observed in the field prior to recovery or recapture to estimate neckband retention rate. If the month and year of recovery were known but day was unknown, we assumed the goose was recovered on the 15th of the month (n = 6). We evaluated the effect that banding location, population, sex, neckband maker, and sampling method (recovered vs. recaptured) might have on estimates of neckband retention. As part of our experimental study on avian cholera, approximately 50% of the southern Wrangel and Banks Island neckbanded snow geese were vaccinated to protect them against avian cholera. Therefore, we also evaluated whether this experimental manipulation (vaccinated vs. nonvaccinated) affected neckband retention.

Statistical Analysis

Analysis Based on Survival Methods.—Dates of bandings, observations, recaptures, and recoveries allowed for the development of 2 types of data: right- and interval-censored. Birds with neckbands present at the time of recovery or last recapture represented right-censored data. Birds that lost their neckbands prior to a recapture or recovery provided interval-censored data. Although the exact failure time was unknown, an interval could be identified that encompassed the period of neckband loss. The lower limit of this interval was the last date a bird was observed in the field (with a neckband) prior to recapture or harvest. If no observations were made, the date of banding defined the lower limit. The upper limit of this interval was the date of recovery or first recapture without a neckband. Although some snow geese were recaptured on >1 occasion, we used only the last recovery or recapture of these birds in our analysis. For right-censored data, observations obtained after the last recapture were not used because only birds with neckbands present could be observed, violating the assumption of independence between censoring time and survival time (Cox and Oakes 1984).

We followed the methods described by Samuel et al. (1990) and used program SURVREG (Preston and Clarkson 1983) to obtain generalized Kaplan-Meier (Turnbull 1976) estimates of neckband retention. Natural logs of the Kaplan-Meier cumulative hazard rates were plotted against ln(time); if these plots approximated a straight line, the Weibull function was considered to be an appropriate model for the data (Cox and Oakes 1984). In addition, the survival and ln(survival) estimates from Kaplan-Meier were graphically compared with Weibull estimates to assess goodness-of-fit (Kalbfleisch and Prentice 1980, Byar 1982). We used LIFEREG (SAS Institute 1989) to test for covariates that significantly (P < 0.05) influenced retention of neckbands for the parametric Weibull model. For the Weibull distribution, the survival function which describes the probability of neckband retention as a function of age (t), is $S(t) = \exp(-\alpha t^{\gamma})$. The LIFEREG procedure estimates a scale parameter σ and intercept μ, where $\sigma = \gamma^{-1}$ and $\alpha = \exp(-\mu/\sigma)$. The hazard rate, which describes the instantaneous rate of neckband loss, decreases with age if $\sigma > 1$, increases with age if $\sigma < 1$, and follows an exponential distribution (constant hazard) if $\sigma = 1$. Covariates tested for the Weibull estimates were banding location (Wrangel and Banks islands), population (northern Wrangel, southern Wrangel, and Banks islands), sex (male and female), neckband maker (Spinner and Pro-Touch), sampling method (recovered and recaptured), and whether the goose was vaccinated against avian cholera (vaccinated and nonvaccinated). When a covariate was selected during regression analysis, the data were partitioned by that covariate to obtain Weibull parameter estimates for that cohort.

Analysis Based on Binomial Probability Methods.—We used logistic regression (Hosmer and Lemeshow 1989) to analyze the proportion of geese retaining neckbands for 5 time intervals after banding (Table 1) to facilitate comparing our results with previous neckband studies and to identify factors that influenced neckband retention (Samuel et al. 1990). Stepwise logistic regression (Dixon et al. 1988) was used to determine significant (P < 0.05) covariates (banding location, population, sex, sampling method, neckband manufacturer, vaccination status, and time interval) associated with neckband presence or absence at the time of last recapture or recovery. All variables except time were analyzed as categorical responses. When a covariate was selected during regression analysis, we used the binomial method described by Nichols and Hines (1993) to estimate neckband retention. This method has been recommended because it can be incorporated into a joint analysis of sighting probabilities, survival rates, and neckband

Table 1. Number of lesser snow geese (*n*) and proportion of neckbands (%) retained within categories of banding location, sex, and months since banding. Neckband retention data were obtained from hunter reports and recaptures of lesser snow geese banded on Wrangel (1993–1996) and Banks (1994–1996) islands.

	Banding location							
	Wrangel Island				Banks Island			
Months since	Female		Male		Female		Male	
banding	*n*	% Retained	*n*	% Retained	*n*	% Retained	*n*	% Retained
0–8	51	98.0	56	92.9	30	90.0	37	86.5
9–20	43	100.0	31	87.1	33	81.8	15	93.3
21–32	46	84.8	36	66.7	13	53.8	4	50.0
33–44	15	100.0	17	82.4	9	66.7	6	16.7
45–72	14	71.4	8	37.5	7	57.1	3	0.0

retention rates (Nichols et al. 1992, Nichols and Hines 1993). This method was further extended by Fabrizio et al. (1999) to test for early tag loss, which occurred immediately after marking.

We used program SURVIV (White 1983) to conduct separate analyses using this binomial approach for each of the cohorts identified by the logistic regression analysis. We followed the methods of Nichols et al. (1992) and Nichols and Hines (1993), except that we also used neckband presence or absence data obtained from hunters. Recaptures of neckbanded birds occurred at annual intervals following banding, and hunter recoveries occurred at annual intervals beginning approximately 0.5 years after banding. We parameterized the SURVIV analysis so that all retention rates were estimated as annual rates to facilitate testing for constant neckband retention and to evaluate lower neckband retention during the first 6 months following banding. For each cohort, we compared 3 different models using program SURVIV: a 6-parameter general model where annual retention rates were allowed to be unique, a 2-parameter early loss model where all but the 1st period (6 months) retention rates were constrained to be equal, and a 1-parameter constant model where all annual retention rates were constrained to be equal. Model comparisons were tested using Akaike's Information Criterion ($QAIC_c$; Burnham and Anderson 1998). We used 2-tailed *Z*-tests to compare ln-transformed estimates of retention rates (Bart and Robson 1982).

RESULTS

We neckbanded 2,667 snow geese on Wrangel Island (544 in 1993, 679 in 1994, 446 in 1995, and 998 in 1996) and 2,192 snow geese on Banks Island (228 in 1994, 969 in 1995, and 995 in 1996). We recaptured 118 neckbanded birds in subsequent years (88 on Wrangel Island and 30 on Banks Island). There were reports of 375 birds recovered by hunters (217 from Wrangel Island and 158 from Banks Island) and 53 birds found dead (32 from Wrangel Island and 21 from Banks Island). Of these 428 geese, we obtained information on the presence or absence of a neckband for 381 birds: 235 from Wrangel Island (94% of those reported) and 146 from Banks Island (82% of those reported). We found an additional 14 neckbands (4 from Wrangel Island and 10 from Banks Island) in the field unassociated with any carcasses. We found 7 of these on the breeding grounds and 7 on the wintering grounds. We used 317 of the snow geese neckbanded on Wrangel Island and 157 neckbanded on Banks Island in our analyses. Of the Wrangel birds, 130 were from the northern and 187 from the southern populations. Males constituted 213 (44.9%) and females 261 (55.1%) of the total sample, and there were almost 2 times more nonvaccinated ($n = 304$) than vaccinated ($n = 170$) birds. Recoveries made up 363 (76.6%) of our sample, and 111 (23.4%) were recaptures. More of the neckbands in our analyses were manufactured by Spinner ($n = 339$) than by Pro-Touch ($n = 135$).

Survival Analysis.—We used the Weibull model with stepwise regression techniques to identify covariates that significantly influenced neckband retention rates. Banding location ($P < 0.001$) and sex ($P < 0.001$) were selected during stepwise regression for all geese ($n = 474$). We partitioned the data by banding location and sex to obtain survival estimates from the Kaplan-Meier and Weibull models using these cohorts. The estimated scale parameters of the Weibull models were <1 ($P < 0.05$) for all the identified cohorts

Table 2. Estimated scale (σ) and intercept (μ) parameters of Weibull models and constant annual neckband retention rates ($\hat{\theta}$) estimated by program SURVIV (White 1983). Cohorts were determined from regression of neckband retention data collected from hunter reports and recaptures of lesser snow geese banded on Wrangel (1993–1996) and Banks (1994–1996) islands.

Cohort	Weibull model[a]					Binomial[b]	
	n	σ	SE	μ	SE	$\hat{\theta}$	SE
Wrangel Island female	169	0.469	0.104	7.866	0.239	0.958	0.014
Wrangel Island male	148	0.638	0.101	7.495	0.160	0.871	0.024
Banks Island female	92	0.616	0.109	7.344	0.169	0.838	0.032
Banks Island male	65	0.631	0.123	6.940	0.183	0.756	0.058

[a] Weibull model survival function: $S(t) = \exp(-\alpha t^{\gamma})$, where $\alpha = \exp(\mu/\sigma)$, σ = scale parameter, μ = intercept parameter, $\gamma = \sigma^{-1}$, t = time (days).

[b] Constant annual neckband retention model estimated using program SURVIV (White 1983) and based on the binomial methods proposed by Nichols et al. (1992) and Nichols and Hines (1993).

(Table 2), demonstrating that the rates of neckband loss (hazard rate) increased with time.

Log-cumulative hazard rates obtained from the generalized Kaplan-Meier model plotted against ln(time) approximated a straight line for each of the selected cohorts. Visual comparison of the retention curves and ln(retention) curves indicated that the Weibull model reasonably approximated the Kaplan-Meier nonparametric model of neckband retention (Fig. 1) for each of the selected cohorts except Wrangel males. For Wrangel males, the ln(retention) Kaplan-Meier curve was considerably lower than the ln(retention) Weibull curve starting approximately 4 years after marking. We also considered 2 alternative survival models (gamma and lognormal), but based on model parameters and ΔAIC values neither of these described any of the retention curves as well as the Weibull model. In all of the cohorts, the Weibull model had the lowest AIC, and for all cohorts except for the gamma model for Banks females the ΔAIC values > 5. Overall, we believe the Weibull function provided a reasonable model for our neckband retention data. We visually inspected the fit of the Weibull function and the shape of Kaplan-Meier models during the first year after banding to determine whether early neckband loss occurred immediately after tagging (Beverton and Holt 1957, Fabrizio et al. 1999). The Kaplan-Meier models showed no evidence of substantial neckband loss (<3%) during the first 6–9 months for female Wrangel and Banks Island geese. More substantial neckband loss occurred during the first 6–9 months for Wrangel Island males (3%) and for Banks Island males (>10%). However, for all the cohorts, the Weibull model provided a reasonable fit to the Kaplan-Meier model, indicating the Weibull model was sufficient and that tag loss immediately following banding was either not substantial or could not be detected from our data.

Binomial Probability Models.—Stepwise logistic regression using the complete dataset identified time since banding ($P < 0.001$), banding location ($P < 0.001$), and sex ($P = 0.002$) as factors affecting neckband retention. We estimated annual neckband retention for these cohorts (Table 2) by using the binomial neckband loss model (Nichols and Hines 1993) and program SURVIV. Binomial estimation indicated that for all cohorts the constant models had lower (>5.7 units) $\Delta QAIC_c$ values than the general models. For Banks males, the general model was ill-conditioned, probably because of sparse data on neckband presence >4 years after banding. The constant loss models also had lower (2–3 units) $\Delta QAIC_c$ values than the early loss models for all cohorts. We concluded that constant neckband retention provided the most reasonable binomial model for the recovery and harvest data. The constant annual retention rate ($\hat{\theta}$) was greatest for female geese from Wrangel Island ($\hat{\theta} = 0.958 \pm 0.014$ [SE]), and least for males from Banks Island ($\hat{\theta} = 0.756 \pm 0.058$; Table 2). Paired comparisons of annual neckband retention rates (Table 2) indicated that Wrangel Island females were higher than Banks Island males ($Z = 3.022$, $P = 0.002$), but were not significant for Wrangel Island females versus Banks Island females ($Z = 1.886$, $P = 0.06$), Wrangel Island females versus Wrangel Island males ($Z = 1.854$, $P = 0.064$), Banks Island males versus Banks Island females ($Z = 1.279$, $P = 0.20$), Banks Island males versus Wrangel Island males ($Z = 1.596$, $P = 0.11$), and

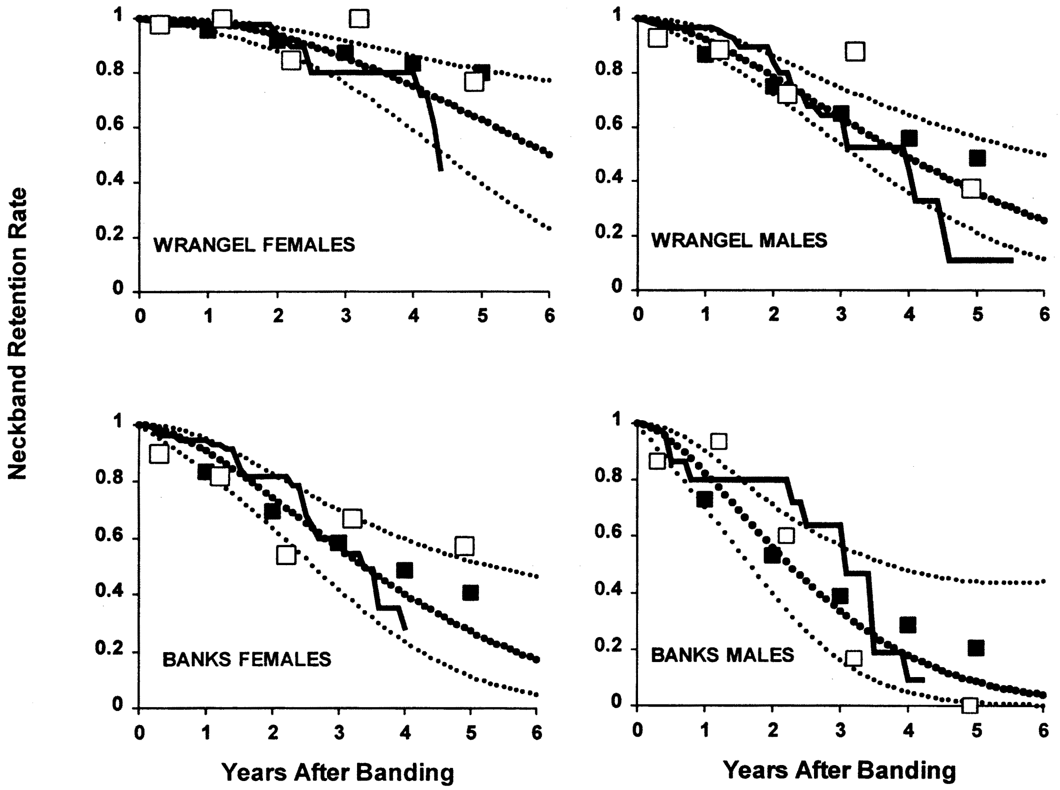

Fig. 1. Neckband retention rates for 4 cohorts of geese banded at Wrangel and Banks islands and determined using Kaplan-Meier (solid lines), Weibull (thick dotted lines bounded by lighter-dotted 95% CI lines), and binomial (solid squares) methods. The proportions of observed neckbands retained for 5 time intervals are shown with open squares (also see Table 1).

Banks Island females versus Wrangel Island males ($Z = 0.252$, $P = 0.75$).

DISCUSSION

Most neckband retention studies in North America have reported on goose species (Table 3), with the largest emphasis on Canada geese. Studies have focused primarily on geese in the Pacific and Mississippi flyways, and not surprisingly the duration of most studies was <10 years. Most studies have relied on recaptures and/or hunter recoveries to estimate neckband retention using some form of binomial model (e.g., Robson-Reiger, SURVIV, logistic regression). Only 2 studies have used recaptures, recoveries, and observations to estimate neckband retention rates. Many studies concluded that males lost neckbands faster than females, and none concluded that females lost neckbands at a higher rate than males. Although the results from individual studies were quite variable, neckband retention appeared to be highest for Canada geese and greater snow geese (*Chen caerulescens atlantica*), followed by greater white-fronted geese (*Anser albifrons*), lesser snow geese, and tundra swans (*Cygnus columbianus*).

Neckband age, sex, and banding location were the most important and consistent factors affecting neckband loss for snow geese in our study. The distribution of neckband loss and identification of factors contributing to such loss can provide information on the causes of neckband failure, how survival estimates should be corrected, and how neckband retention may be improved. For example, neckband loss that occurs soon after marking (e.g., Nichols et al. 1992) may indicate poor attachment techniques or a propensity for the birds to remove the neckbands. Neckband loss that increases with neckband age probably indicates fatigue of the plastic material that may become brittle with age and crack, leading to eventual loss (Fjetland 1973, Raveling 1978, Craven 1979, Wiebe et al. 2000). Some studies (Table 3) have concluded that retention rates of neckbands were constant (Zicus and Pace 1986, Hestbeck and Malecki 1989, Campbell and Becker 1991, Schmutz and Ely 1999, Menu et al. 2000, Wiebe et al. 2000), but other studies have concluded that loss rates increase as neckbands age (Samuel et al. 1990, Campbell and Becker 1991, Nichols et al. 1992, Johnson et al. 1995). Most of the studies reporting constant rates of neckband loss have found either very high retention or have been limited by sample size or duration of time after neckbands were applied. Unfortunately, differences among these studies in sample size, study length, and analytical procedures may all substantially influence the determination of neckband retention rate and make direct comparisons difficult.

Nelson et al. (1980) found that higher legband loss rates, combined with high animal survival rates (Nelson et al. 1980:35–36), produced substantial biases in survival estimates from recovery data. These combinations are similar to the patterns of survival and neckband loss we observed for most geese, indicating that correction for neckband loss is important. Arnason and Mills (1981) and Pollock (1981) also showed that estimated survival and precision from Jolly-Seber models were biased by marker loss. Arnason and Mills (1981) recommended a simple correction to the Jolly-Seber survival estimate when tag loss was constant (independent of neckband age). Our analyses on snow geese (this study) and on Canada geese (Samuel et al. 1990) indicate that survival models using capture, recovery, and resighting data consistently detected increases in neckband loss with neckband age. In contrast, binomial models (Robson and Reiger 1966, Nichols and Hines 1993) that use only recapture and/or recovery data were less likely to detect changes in neckband loss. Although not reported here, we found that Robson-Reiger estimates were very close to those we obtained using the constant loss models in SURVIV. We believe the binomial model (including Robson-Reiger) approaches have less ability to detect nonconstant loss rates than survival (e.g., Kaplan-Meier or Weibull) methods, which also use resighting data to reduce uncertainty about when neckbands are lost. For our studies on snow geese and Canada geese, neckband retention rates estimated from the Robson and Reiger (1966) or binomial (Nichols and Hines 1993) procedures were negatively biased ≤2 years after banding and positively biased ≥4 years after banding, compared with retention estimates obtained from generalized Kaplan-Meier methods. Because of these biases, estimates of a constant annual neckband retention rate could provide a misleading correction of the Jolly-Seber survival estimates.

Kremers (1988) proposed a survival method to account for neckband loss that considers only the final observation or band recovery, but intermediate observations are lost when this approach is used. Nichols et al. (1992) described 2 methods to incorporate neckband loss into survival estimates including: (1) a 2-step method combining independently derived estimates of neckband retention and resighting survival estimates; and (2) a single cohort analysis using recapture data for neckband loss and resighting data for survival (Nichols and Hines 1993). Nichols et al. (1992) preferred the latter approach because it is based on a single model that should result in more precise estimates and includes direct estimation of sampling variances and covariances. This model can be expanded to include birds reported by hunters but does not incorporate resightings of birds with neckbands. We concur with the recommendation by Nichols and Hines (1993) that further statistical work is needed to develop methods that incorporate variable rates of neckband loss into the survival estimates.

Snow geese from Banks Island lost neckbands more quickly than geese from Wrangel Island. Because we found no difference in neckband retention between northern and southern Wrangel subpopulations and the southern Wrangel Island geese share wintering areas and overlap on spring migration routes with the Banks geese, the lower retention for Banks Island geese was unexpected. Unfortunately, the reasons for differential neckband loss among snow goose breeding locations in the western Arctic are difficult to determine. These patterns may be attributed to differences in behavior and interspecific interactions among breeding colonies, differences in color of neckbands used and their resistance to failure, differences in field methods and care in gluing neckbands, or to different neckband manufacturers (Wiebe et al. 2000). Although we found no significant retention differences for Banks Island geese between neckbands made by the 2 companies, we believe our data were insufficient to warrant strong conclusions. Our study and many of the recent studies on neckband retention in waterfowl (Table 3) have concluded that males lose neckbands faster

Table 3. Summary of neckband retention studies for geese and swans in North America.

Study	Species	No. banded[a]	Study length (yrs)[b] Band	Obs	Recap	Recov	Retention	Adult retention (%) 1 yr F	1 yr M	4 yr F	4 yr M
This study	Lesser snow geese–Banks Island	365	3	5	3	5	Decrease over time, F > M	90.8	82.5	40.2	17.7
This study	Lesser snow geese–Wrangel Island	333	4	6	4	6	Decrease over time, F > M	98.5	92.1	74.8	48.6
Johnson et al. 1995	Lesser snow geese	72	10		10		Decrease over time, F > M	83.0	53.0	50.0	5.0
Menu et al. 2000	Greater snow geese	402	6		6		Constant F only	97.0		88.5	
Fjetland 1973	Canada geese	86	3		6		Decrease over time, F > M	83.0	69.0	44.0	31.0
Craven 1979[c]	Canada geese	803	4		3	3	Not evaluated F = M	79.1	79.1	>60.0	>60.0
Zicus and Pace 1986	Canada geese		3		11	11	Constant loss F = M	92.8	92.8	74.2	74.2
Hestbeck and Malecki 1989	Canada geese	3,606	3		3		Constant loss F = M	99.3	99.3	97.2	97.2
Samuel et al. 1990[d]	Canada geese	79	14	14	14	12	Decrease over time, F > M	85.4–90.3	57.5–90.3	50.0–60.0	10.0–60.0
Campbell and Becker 1991[e]	Dusky Canada geese	342	6		6		Constant loss - F Decrease over time - M F > M	87.5	51.8–85.6	58.6	1.2–40.8
Wiebe et al. 2000	Small Canada geese	417	3		3		Constant loss F > M	82.6	65.0	46.6	17.9
Alisauskas and Lindberg 2001	Small Canada geese	337	7		8		Loss varied annually, F > M	84.0–100.0	22.0–100.0		
Schmutz and Ely 1999[f]	Greater white-fronted geese	204	3			3	Constant loss F = M	95.5	95.5	83.2	83.2
Wiebe et al. 2000	Greater white-fronted geese	510	5		5		Constant loss F > M	100.0	98.2		93.0
Alisauskas and Lindberg 2001	Greater white-fronted geese	739	7		8		Loss varied annually, F > M	82.0–100.0	72.0–100.0		
Nichols et al. 1992[f,g]	Tundra swans	119	25	25	24		Constant loss after 1 yr, F > M	100.0	88.6	45.1	11.0

[a] Average number of birds banded in each sex cohort per banding year.
[b] Length of study period (years) for banding, observation, recapture, and recovery data.
[c] Craven (1979) reported neckband retention rates at 15- and 27-month intervals.
[d] Neckband retention rates varied depending on type of band used. See Samuel et al. (1990) for details.
[e] Male retention rates depended on the year of banding.
[f] Retention rates were combined for adult and juvenile birds.
[g] Observation data were used for survival estimation, but not for neckband retention estimation.

than females. Increased failure of neckbands on male geese has been suggested as a result of males aggressively pulling on their own neckbands and those of other geese primarily during courtship and territorial defense (Trost 1983, Campbell and Becker 1991, Johnson et al. 1995).

MANAGEMENT IMPLICATIONS

Ecological studies of waterfowl based on resighting neckbanded birds are commonly used because they offer considerable potential for understanding avian population dynamics. However, the utility of these studies for estimating survival rates is potentially limited unless neckband loss is negligible or the bias in survival estimates associated with loss is corrected. Many studies of neckband loss in waterfowl have used only recapture data to estimate retention rates. These methods are likely to be inefficient because resightings of neckbanded birds and recoveries are ignored, and data are grouped into time intervals. Researchers should also recognize that the analysis of small sample sizes (100–200 birds) will limit the power of some statistical techniques, such as the binomial methods, to detect changes in retention rates with neckband age or to evaluate other covariate factors. In addition, neckband retention estimates based on short-term studies may be misleading if retention rates do not remain constant. Therefore, we recommend that studies should be designed to routinely collect data on recaptures and hunter recoveries of birds, and to use resightings and survival methods for censored data to estimate neckband retention rates. We also suggest that further statistical research is needed to develop efficient methods for the joint estimation of bird survival and neckband retention.

Although considerable variation exists in the neckband retention rates reported for waterfowl, 2 patterns are particularly evident. First, many studies have shown that males lose neckbands at a faster rate than females. The reasons for higher loss in males are not completely clear but seem primarily related to aggressive interactions among conspecifics and to increased attention by males to their neckband. Second, many studies report that neckband loss rates are not constant with age. The principal pattern appears to be an increasing rate of loss with neckband age, indicating that neckbands are not failing randomly, but fail at a higher rate as they age. In most cases, this loss has been attributed to neckbands becoming increasingly brittle and cracked with age because of exposure to prolonged ultraviolet radiation or cold temperatures. Cracking also appears to occur from shot pellet damage or in conjunction with engraved characters in the neckband. In many cases, the rate of neckband loss appears to be substantial, especially for long-lived species such as geese and swans. The combination of high neckband loss rates and poor precision in estimating these rates may considerably reduce the usefulness of resighting data in determining survival rates, even after correcting for neckband loss. More research is clearly needed to clarify how neckband loss and standard errors affect corrected survival rate estimates and to determine how these parameters are related to other study design considerations such as the number of birds marked annually and resighting rates.

Considering the studies on neckband retention published since 1990, we particularly noted both the substantial neckband loss that has been documented for many species and the considerable variation that occurred among studies, even within the same species. Because neckbands are routinely used in waterfowl management and research studies, we recommend that additional consideration be given to developing methods that improve or standardize neckband retention. Given the substantial cost of marking, especially on Arctic breeding areas, and observing birds, further consideration is warranted on improvements that would increase neckband retention. These improvements should consider alternative materials that would be resistant to ultraviolet light and cold temperatures, alternatives to engraving that do not weaken plastics, and designs that are less susceptible to aggressive behavior by males.

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