NECK-BAND RETENTION FOR CANADA GEESE IN THE MISSISSIPPI FLYWAY

MICHAEL D. SAMUEL, U.S. Fish and Wildlife Service, National Wildlife Health Research Center, 8006 Schroeder Road, Madison, WI 53711
NONDOR T. WEISS, Department of Wildlife Ecology, 226 Russell Labs, University of Wisconsin, Madison, WI 53706
DONALD H. RUSCH, Wisconsin Cooperative Wildlife Research Unit, 221 Russell Labs, University of Wisconsin, Madison, WI 53706
SCOTT R. CRAVEN, Department of Wildlife Ecology, 226 Russell Labs, University of Wisconsin, Madison, WI 53706
ROBERT E. TROST,1 Department of Wildlife Ecology, 226 Russell Labs, University of Wisconsin, Madison, WI 53706
F. DALE CASWELL, Canadian Wildlife Service, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada

Abstract: We used capture, harvest, and observation histories of Canada geese (Branta canadensis) banded in the Mississippi flyway, 1974–88, to examine the problem of neck-band retention. Methods for the analysis of survival data were used to estimate rates of neck-band retention and to evaluate factors associated with neck-band loss. Sex, age of bird at banding, rivet use, and neck-band type significantly influenced neck-band retention. For most of the resulting cohorts (e.g., sex, age, rivet, and neck-band type categories), neck-band retention rates decreased through time. We caution against using small samples or data collected during short-term studies to determine retention rates. We suggest that observation data be used in neck-band retention studies to increase the efficiency of estimating retention time.

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The use of neck bands to mark geese individually has become a common technique to study migration (Koerner et al. 1974, Raveling 1978, Trost et al. 1980, Craven and Rusch 1983), behavior (MacInnes and Lieff 1968), and population dynamics (Rusch et al. 1985, Hestbeck and Malecki 1989). Resightings of neck-banded Canada geese have been used to estimate important population parameters, especially survival rates (Rusch et al. 1985, Hestbeck and Malecki 1989). However, marker loss results in an underestimate of survival rates and a loss of precision (Arnason and Mills 1981). This loss may be especially important in studies of long-lived species, such as Canada geese.

Quantitative estimates of neck-band loss in Canada geese have been made by Sherwood (1966), Raveling (1978), Craven (1979), and Hestbeck and Malecki (1989). However, only the studies of Fjeldland (1973) and Zicus and Pace (1986) have assessed long-term retention (complement of loss). An additional limitation

1 Present address: South Carolina Cooperative Fish and Wildlife Research Unit, Clemson University, Clemson, SC 29632.
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of these studies has been the lack of sufficient samples to evaluate adequately the effects that age, sex, or other attributes might have on neck-band loss. Fjelland (1973) reported annual retention rates from 194 records of recaptured Canada geese. Zicus and Pace (1986) analyzed annual neck-band retention by combining re-captured and hunter-killed Canada geese (161 records) for 134 individual geese (M. C. Zicus, pers. commun.).

The analysis of neck-band retention is further complicated because actual time of neck-band loss is unknown. Therefore, some estimate of the time period when the neck band was actually lost usually is needed. Methods of estimating neck-band retention rates have been based primarily on the proportion of the recovered (recaptured or shot) birds retaining a neck band at specific time intervals (usually annually). This method poses several analytical problems because (1) large time intervals may produce biased estimates of survival times (Heisey and Nordheim 1990), (2) geese recovered with neck bands during a specific time interval represent a minimum (right censored) estimate of the actual retention time, and (3) geese recovered without a neck band represent a maximum estimate of the actual retention time. Correct calculation of retention rates as a simple proportion is only possible when no individuals are censored during the time intervals (Cox and Oakes 1984:6). This condition is impossible for neck-banded geese.

We attempted to overcome the methodological limitations of previous studies by analyzing a large data set (>2,000 records) collected over a 14-year period. In addition, we employed statistical methods based on survival analysis. These survival methods (Kalbfleisch and Prentice 1980, Cox and Oakes 1984) are designed specifically to allow the analysis of data when the exact time of failure (neck-band loss) is unknown or when neck-band retention times are censored. Two forms of censoring are typical of neck-band retention (survival) studies. Right censoring occurs when birds with neck bands still attached are recaptured or harvested. These situations provide minimum retention times because the neck band is still "alive" when the goose is released or harvested. Interval or Type III censoring occurs when a goose is observed with its neck band but is subsequently recaptured or shot without a neck band. For these situations, minimum and maximum retention times are known. Allen (1985) also used these survival methods to estimate neck-band retention rates for swans (Cygnus columbianus) wintering in the Atlantic flyway.

Our objectives were to describe the neck-band retention rates of Canada geese in the Mississippi flyway and to identify factors that significantly influence neck-band retention. Data used in our analyses were part of a long-term study to determine the distribution, migration routes, and survival rates of Canada geese (primarily B. c. interior) in the Mississippi flyway. Coopera-tors from federal, state, and Canadian agencies have captured and observed geese at breeding, staging, and wintering areas within the Mississippi flyway since 1974. The number of geese neckbanded presently totals 85,000, and observations of marked birds total 350,000.

Our analysis of neck-band retention would not have been possible without the dedicated efforts of many individuals who assisted in the capture, banding, and observation of geese, and management of collected data. We also thank the many hunters who responded to our questionnaires. J. Bart, D. M. Heisey, B. D. Sullivan, and G. W. Swenson reviewed this manuscript and provided helpful comments.

METHODS

Captured geese were banded with U.S. Fish and Wildlife Service (USFWS) aluminum leg bands and plastic neck bands. Craven (1979) described the materials, methods of manufacture, and application of neck bands used in our study. Two general types of neck bands were used based on the availability of materials and efforts to improve neck-band design. Thick neck bands measuredes 6.7 × 17.7 × 0.16 cm and remained relatively rigid after shaping in boiling water. These neck bands were designed to overlap 1–2.5 cm where adhesive was applied to fasten the neck band. Some thick neck bands were also fastened with 2 steel rivets. Thin neck bands measuredes 6.7 × 30.5 × 0.06 cm, remained flexible after shaping, and coiled several times around the neck of each goose. Adhesive also was used to secure thin neck bands; however, no rivets were used to fasten thin neck bands. Each neck band bore a 4-character code that was legible ≤500 m with a 60× telescope (Craven 1979). Different neck-band colors were used to identify banding areas. However, because most neck bands were either blue (fall staging or wintering areas) or orange (breeding
areas), we only analyzed neck bands of these 2 colors.

Records of Canada geese neckbanded and recaptured in the Mississippi flyway, 1975–88, were used to determine the status of neck bands at time of recapture. Information obtained from USFWS Bird Banding Laboratory, Laurel, Maryland, was used to identify hunters who reported harvesting geese from 1975 to 1986 that were neckbanded in the Mississippi flyway. Questionnaires were sent to these hunters to determine whether the neck band was present at time of harvest (Craven 1979). Recapture records and questionnaires returned by hunters were used to identify records of neck-banded Canada 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 neck band. Field observations were limited to those made at reference areas in the Mississippi flyway (Samuel et al. 1986) and subsequently reported to the Wisconsin Cooperative Wildlife Research Unit. We used date of banding, date of harvest or recapture, neck-band presence (or absence) at time of harvest or recapture, and date last observed in the field prior to harvest or recapture to estimate neck-band retention rate. We also evaluated the effect that sex, age of each bird at time of banding, neck-band type (thick vs. thin), use (or not) of rivets to fasten the neck band, neck-band color, and sampling method (shot vs. recaptured) might have on estimates of neck-band retention. Geese ≤1 year old or >1 year old at banding were classified as immatures or adults, respectively.

**Statistical Analysis**

**Analysis Based on Survival Methods.**—Data for each bird were used to determine the smallest interval during which neck-band loss occurred. The lower limit of this interval was the last date a bird was observed in the field with a neck band prior to recapture or harvest. If no observations were made of a neck-banded bird, date of banding defined the lower limit of this interval; the upper limit was the date of harvest or first recapture without a neck band. Although the exact failure time was unknown, the interval could be used to improve the survival estimate. Computational procedures for interval-censored data were based on the probability of an individual surviving at least \( t_1 \) days \( \Pr(t \geq t_1) \) and the probability of surviving beyond \( t_2 \) days \( \Pr(t \geq t_2) \). Then \( \Pr(t \geq t_1) = \Pr(t \geq t_2) \) provided the probability of interval censoring between \( t_1 \) and \( t_2 \). These probabilities could be subsequently written in terms of the cumulative survival distribution \( \{ F(T) \} \). Interval survival rates (Kaplan-Meier) or survival parameter estimates (Weibull, log-linear, or logistic models) were then determined using an iterative maximum-likelihood solution for the appropriate survival distribution (Cox and Oakes 1984). Birds with neck bands at the time of harvest or recapture represented a minimum (right-censored) estimate of neck-band retention. For right-censored data, \( t_2 \) was assumed to be large (typically infinity). Because \( \Pr(t \geq \infty) = 0 \), only the known survival probability \( \Pr(t \geq t_1) \) contributed to estimation of the cumulative survival distribution. Observations of neck-banded birds obtained after recapture were not used in our analysis because use of these observations likely would violate the assumption of independence between censoring time and survival time (Cox and Oakes 1984).

We used generalized Kaplan-Meier procedures (Peto 1973, Turnbull 1976) to obtain distribution-free estimates of the neck-band retention probabilities. Survival curves produced by the Kaplan-Meier method provided a nonparametric estimate of the actual distribution of survival (retention). This method was advantageous because no assumptions regarding the specific shape of the survival curve were required. However, the Kaplan-Meier method was difficult to use when testing hypotheses because the data must be partitioned for each biological factor considered and tested to determine survival rate differences. In contrast, parametric survival methods supported stepwise regression procedures used to identify covariates that significantly influenced survival. If the Kaplan-Meier survival estimates showed a close correspondence with a parametric model, the latter method could be useful for determining the overall shape of the survival curve and for testing the effect of important covariates on survival.

Parametric survival models incorporate ≥1 unspecified parameter to describe survival functions. Inherent differences in each model are based on the shape and complexity of the hazard function \( h(t) \), which describes the instantaneous probability of death (neck-band loss) at time \( t \). The 2-parameter Weibull model is a general form of the exponential model and is used in
Table 1. Number of Canada geese and proportion of neck bands retained within categories of age, sex, and months since banding, from hunter reports of Canada geese banded in Mississippi flyway, 1975–86 and histories of Canada geese recaptured in Mississippi flyway, 1975–86.

<table>
<thead>
<tr>
<th>Months since banding</th>
<th>Sex</th>
<th>Immature</th>
<th>M</th>
<th>Ad</th>
<th>% Retained</th>
<th>% Retained</th>
<th>Immature</th>
<th>F</th>
<th>Ad</th>
<th>% Retained</th>
<th>% Retained</th>
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</thead>
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<tr>
<td>0–6</td>
<td></td>
<td>180</td>
<td>95.0</td>
<td>218</td>
<td>91.7</td>
<td>141</td>
<td>90.1</td>
<td>181</td>
<td>89.5</td>
<td></td>
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<tr>
<td>7–18</td>
<td></td>
<td>106</td>
<td>87.7</td>
<td>193</td>
<td>74.1</td>
<td>103</td>
<td>79.6</td>
<td>177</td>
<td>88.7</td>
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<tr>
<td>19–30</td>
<td></td>
<td>61</td>
<td>60.7</td>
<td>107</td>
<td>47.7</td>
<td>51</td>
<td>70.6</td>
<td>105</td>
<td>75.2</td>
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<tr>
<td>31–42</td>
<td></td>
<td>35</td>
<td>42.9</td>
<td>86</td>
<td>19.8</td>
<td>36</td>
<td>58.3</td>
<td>75</td>
<td>58.7</td>
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<tr>
<td>43–55</td>
<td></td>
<td>17</td>
<td>23.5</td>
<td>50</td>
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<td>22</td>
<td>50.0</td>
<td>43</td>
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<td>56–144</td>
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<td>31</td>
<td>3.2</td>
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<td>24.0</td>
<td>71</td>
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</table>

survival analysis because of its broad application (Lee 1980). The Weibull function is described by the equation \( S(t) = \exp\left(-\left(t/\beta_0\right)^{\beta_1}\right) \). The shape parameter of this model (\( \beta_1 \)) provides a monotonic description of the hazard function: if the estimated shape parameter (\( \hat{\beta}_1 \)) is < 1, hazard rates decrease through time; if \( \hat{\beta}_1 \) is > 1, hazard rates increase through time; and if \( \hat{\beta}_1 = 1 \), hazard rates are constant (Lee 1980). The shape parameter provides a statistic for testing the fit of the exponential model (H0: hazard rates are constant through time).

We used program SURVREG (Preston and Clarkson 1983) to obtain generalized Kaplan-Meier estimates of neck-band retention and to test for covariates that significantly (\( P < 0.05 \)) influenced retention of neck bands for the Weibull model. Covariates tested were age of bird at time of banding, sex, neck-band color, neck-band type (thick vs. thin), use of rivet to fasten neck band, and sampling method (shot vs. recaptured bird). When a covariate was selected during regression analysis, the data were partitioned by that covariate, and stepwise regression procedures were repeated until significant covariates were no longer entered into the model. Because all neck bands fastened with rivets were of the orange-thick variety, neck-band color and neck-band type were deleted from regression models that included only rivet-fastened neck bands.

Generalized Kaplan-Meier (Turnbull 1976) estimates of neck-band retention were compared with Weibull estimates to assess graphically goodness-of-fit for each Weibull model (Kalbfleisch and Prentice 1980). 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).

**Analysis Based on Probability Methods.**—We analyzed the proportion of geese that retained neck bands to facilitate comparison of our results with previous neck-band studies and to compare retention estimates with those obtained from survival methods. Logistic regression (Cox 1970, Lee 1980) was used to analyze the proportion of geese retaining neck bands for 6 intervals (Table 1) after banding. Stepwise logistic regression (Dixon et al. 1985) was used to determine significant (\( P < 0.05 \)) covariates (age, sex, rivet, neck-band type, neck-band color, sampling method, and time interval) associated with the presence or absence of neck bands at the time of recapture or harvest. All variables were analyzed as categorical responses, and interaction terms were also evaluated for each significant variable included in the logistic model. We estimated neck-band retention rates by assuming a constant loss rate (Robson and Reiger 1966). We used 2-tailed Z-tests of ln-transformed rates to compare estimates of retention rates (Bart and Robson 1982, Heisey and Fuller 1985). Appropriateness of the constant loss model was tested with a binomial dispersion test (Robson and Reiger 1966, Seber 1982). Zicus and Pace (1986) used similar methods for recaptured and shot Canada geese in Wisconsin, 1971–84.

**RESULTS**

**Survival Analysis**

Graphic comparisons indicated that the Weibull model provided an adequate representation of the Kaplan-Meier retention curves. Therefore, we used the Weibull model with stepwise
regression techniques to identify covariates that significantly influenced neck-band retention rates.

Sex ($P < 0.001$) and rivet ($P = 0.007$) were selected during stepwise regression for all geese ($n = 2,205$). We partitioned the data by sex and repeated stepwise regressions with the remaining covariates (Fig. 1). For females ($n = 1,030$), age of bird at time of banding ($P = 0.027$) was the only significant covariate. Stepwise regression procedures performed with adult females ($n = 652$) failed to select additional covariates, whereas rivet ($P = 0.002$) was a significant covariate for immature females ($n = 378$). No significant covariates were found for immature females with nonriveted neck bands ($n = 370$). Small sample size ($n = 8$) prevented further analysis of immature females with riveted neck bands. For males ($n = 1,175$), age at time of banding ($P = 0.005$), rivet ($P = 0.006$), and neck-band type ($P = 0.046$) were identified as significant covariates for the Weibull model. Stepwise regression procedures performed with immature males ($n = 490$) failed to select additional covariates, whereas rivet ($P = 0.006$) and neck-band type ($P = 0.031$) were significant covariates for adult males ($n = 745$). For adult males with riveted neck bands ($n = 49$), no additional covariates were selected by the regression model. For adult males with nonriveted neck bands ($n = 696$), neck-band type ($P = 0.033$) was the only significant covariate.

To further evaluate the effect of rivets, we partitioned the data set by rivet use (123 ad with rivets, 2,057 geese without rivets) and performed further stepwise regressions with the Weibull model (Fig. 1). The sample of immature geese with riveted neck bands ($n = 25$) was small and was deleted from this analysis. No significant covariates entered the Weibull model for birds with riveted neck bands. For birds with nonriveted neck bands, sex ($P < 0.001$) had a significant influence on retention rates. The cohort of birds with nonriveted neck bands was partitioned by sex, and the stepwise regression was repeated. No significant age differences were found for females with nonriveted neck bands ($n = 948$); however, age differences were detected ($P = 0.003$) for males with nonriveted neck bands ($n = 1,109$). For immature males with nonriveted neck bands ($n = 413$), no additional covariates were selected by the regression model. Results of stepwise regressions for males with nonriveted neck bands were reported above.

Finally, adult females with nonriveted neck bands were combined with immature geese (M and F, $n = 808$) to determine if retention rates for immature females were more similar to those of immature males or adult females. Stepwise regression for this group of geese ($n = 1,386$) identified age ($P < 0.001$) as a significant covariate. For all immature geese, no significant covariates were identified.

We synthesized the results from these stepwise regressions by identifying the following cohorts (Fig. 1) for further analysis: adult birds with riveted neck bands; adult males with nonriveted, thick neck bands; adult males with nonriveted, thin neck bands; adult females with nonriveted neck bands; and immature geese. These cohorts were selected to achieve parsimony, although in some instances selections were subjective. We used the log-likelihood ratio statistic to make comparisons among the 3 parametric models (Weibull, log-linear, and logistic) for all selected cohorts to determine the best model. For all cohorts, fit of the Weibull model was significantly ($\chi^2 \geq 7.28$, 1 df, $P \leq 0.007$) better, except for adult geese with riveted neck bands ($\chi^2 = 0.86$, 1 df, $P = 0.354$). With the exception of adult geese with riveted neck bands,
the estimated shape parameter of the Weibull model was significantly >1 (P < 0.05) for all selected cohorts (Table 2), demonstrating that the rates of neck-band loss (hazard rate) increased through time and that the exponential model was inappropriate.

Visual comparison of the retention curves for each of the selected cohorts indicated that the Weibull model closely approximated the Kaplan-Meier nonparametric model of neck-band retention (Fig. 2). 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, providing additional evidence that the Weibull function was appropriate for our neck-band retention data.

**Probability Models**

Stepwise logistic regression showed that time since banding (P < 0.001), sex (P < 0.001), use of rivets (P = 0.004), age of bird at banding (P = 0.038), and interaction terms sex × age (P < 0.001), age × rivets (P = 0.045), and sex × rivets (P = 0.021) were significant factors affecting neck-band retention rates. Neck-band type (P = 0.046) also was a factor that significantly influenced neck-band retention for adult males with nonriveted neck bands.

We selected those cohorts identified from stepwise regression with the Weibull model and determined the annual rate of neck-band retention (Table 2), assuming constant loss (Robson and Reiger 1966). The estimated rate of neck-band retention (assuming constant loss) was greatest for adult geese with riveted neck bands (r̂ = 0.903 ± 0.027 [SE]) and least for adult males with nonriveted, thick neck bands (r̂ = 0.575 ± 0.050). Paired comparisons of neck-band retention rates were significantly different (Z ≥ 3.15, P ≤ 0.001) with some exceptions: all geese versus immature geese (Z = 0.855, P = 0.393), adults with riveted neck bands versus adult females with nonriveted neck bands (Z = 1.71, P = 0.087), and adult males with nonriveted, thick neck bands versus adult males with nonriveted, thin neckbands (Z = 1.75, P = 0.080). With the exception of adult geese with riveted neck bands, constant annual retention rates were significantly different (Z ≥ 4.02, P < 0.001) from the 0.928 ± 0.015 rate reported by Zicus and Pace (1986). The hypothesis of constant neck-band retention rates was rejected for all geese, adult males with nonriveted, thin neck bands, and adult females with nonriveted neck bands (Table 2). These results contrasted with those of Zicus and Pace (1986) who found constant neck-band retention rates.

**DISCUSSION**

Our data provided a unique opportunity to determine the underlying distributions of neck-band retention that are potentially obscured when samples are small or span short periods of
Fig. 2. Neck-band retention rates (%) for 6 cohorts of geese, determined from Kaplan-Meier (solid lines), Weibull (broken lines), and exponential (solid circles) methods. For the exponential model, annual rate of neck-band retention was estimated from Robson and Reiger (1966) procedure.

time. Analysis of our data was facilitated by the incorporation of resighting data and the application of survival analysis methods that accommodate these interval-censored data.

Sex, age of bird at banding, rivet use, and neck-band type were identified by both Weibull and logistic regressions as covariates that significantly influenced neck-band retention for
geese. We found no differences in neck-band retention attributable to neck-band color or sampling method. Fjötland (1973) and Trost (1983) also observed greater neck-band retention for females, but Craven (1979), Zicus and Pace (1986), and Hestbeck and Malecki (1989) detected no differences in neck-band retention based on sex or age. Zicus and Pace (1986) used a linear logit model to reanalyze Fjötland’s (1973) data, and they found no significant difference in retention between males and females.

Trost (1983) suggested that increased failure of neck bands on male geese was the result of increased aggressiveness primarily during courtship and territorial defense. Because breeding does not generally occur before geese are 3 years old (Bellrose 1980, Hardy and Tacha 1989), this hypothesis predicts that retention rates for immature males would be greater than for adult males, at least during the first 2 years of life. To examine the retention rates of young geese after the first 2 years of life, we compared the Kaplan-Meier distributions of neck-band retention for adult males without rivets to immature males for the time period \( t \geq 2 \) years after banding. Retention rates for males banded as immatures generally remained greater than for males banded as adults. We suspect that the neck bands of immature geese experienced less wear and damage during the first 2 years after banding and that reduced wear accounted for greater retention of neck bands even after these geese became adults. If neck-band loss was related to aggressive behavior by breeding males, differences in neck-band retention between sexually mature and immature geese likely were greater than we reported because nonbreeding 2- and 3-year-old birds were included in the sample of adult birds.

Neck-band retention for immature females, however, was less than that for adult females. Because immature females were generally smaller than immature males and adult geese, we suspected immature females lost the bands by pulling them over their heads. It followed that neck-band retention rates of immature and adult females would be similar after immatures attained adult size. We compared the Kaplan-Meier distributions of neck-band retention for adult females without rivets and immature females \( t \geq 1 \) year after banding. After 1 year, differences in neck-band retention between these cohorts were generally absent.

Differences in retention rates of riveted versus nonriveted and thick versus thin neck bands demonstrated for the first time that neck-band materials influenced the retention of goose neck bands. Neck-band failure generally has been attributed to cracking and separation of the plastic. Allen (1985) noted that plastic neck bands used on swans began to crack at the edges and worked inward toward the letters. For adult male geese, thick, nonriveted neck bands were lost sooner than thin (nonriveted) neck bands. The performance of thick neck bands improved substantially, however, when the neck bands were riveted. Thick, riveted neck bands had greater retention rates for adult geese than for the other cohorts we examined. However, we could not adequately assess the long-term effects of rivets on thick neck bands because the small sample of riveted neck bands resulted in reduced precision of the retention rate estimates. We suspect thick neck bands were less susceptible to failure caused by cracking and that rivets reduced the probability of early failure caused by separation of glued surfaces. In contrast, thick, nonriveted neck bands used on Canada geese in the Atlantic flyway showed higher retention rates (Hestbeck and Malecki 1989) than neck bands on birds in our study.

The distribution of neck-band loss can provide information on the causes of neck-band failure and how neck-band retention may be improved. Neck-band loss that occurs soon after marking may indicate poor attachment techniques or a propensity for the birds to remove the neck bands. These factors might be present in our study, but we believe our data are inadequate for this evaluation because our sampling procedures are not likely to detect neck-band loss during brief time intervals. A uniform or constant loss rate might indicate a random process of neck-band loss that is unrelated to age of the neck band. Finally, an increasing rate of neck-band loss could indicate that neck bands are lost as the plastic fatigues. We found that neck-band loss increased with age of the neck band, and suspect plastic neck bands become brittle with age and crack, leading to eventual loss (Fjötland 1973, Raveling 1978, Craven 1979). However, Zicus and Pace (1986) and Hestbeck and Malecki (1989) concluded that retention rates of neck bands were constant. Differences among studies in sample size, study length, and analytical procedures probably had a substantial
influence on the test for constant neck-band retention. Observed differences in retention rates also might have resulted from differences in materials, manufacture, and application of neck bands among studies.

Arnason and Mills (1981) proposed a correction to the Jolly-Seber estimates of animal survival when tag loss was year specific but independent of tag age. In effect, their correction assumes that neck-band loss rates are constant. However, we found that constancy of neck-band retention could not be assumed. Neck-band retention rates estimated from the Robson and Reiger (1966) procedures (constant retention rate assumed) were negatively biased ≤2 years after banding and positively biased >4 years after banding, compared with retention estimates obtained from generalized Kaplan-Meier methods (Fig. 2). Because of these biases, estimates of a single annual neck-band retention rate, such as those reported by Raveling (1978), Craven (1979), Zicus and Face (1986), and Hestbeck and Malecki (1989), may provide a misleading correction of the Jolly-Seber survival estimates.

Nelson et al. (1980) evaluated the influence of leg-band loss on survival estimates when loss depended on band age. They found that high leg-band loss rates combined with high animal survival rates (Nelson et al. 1980:Tables 4 and 5) produced substantial biases in survival estimates from band recovery data. These combinations are similar to the patterns of animal survival and neck-band loss we observed for Canada geese, indicating that correction for neck-band loss is important. Kremers (1988) proposed a survival method to account for neck-band loss that considers only the final observation or band recovery. However, information from the intermediate observations is lost when this approach is used. Further research is needed to develop Jolly-Seber methods that incorporate variable rates of neck-band loss into the survival estimates.

Previous studies of goose neck-band retention have used only recapture or harvest data to estimate retention rates. These methods will be inefficient because resightings of neck-banded birds are ignored, and data are grouped into time intervals. In addition, neck-band retention estimates from short-term studies may be biased if retention rates do not remain constant. We recommend that future retention studies be designed to incorporate resightings and that survival or similar methods be used to estimate neck-band retention rates. Researchers should recognize that the analysis of small sample sizes (100–200 birds) will limit the power of most statistical methods to detect changes in retention rates with neck-band age or to evaluate other covariate factors. Therefore, studies should be designed to assess neck-band retention by routinely collecting data on recaptures and hunter recoveries of birds.

LITERATURE CITED


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