# EFFECTS OF NECK COLLARS AND RADIOTRANSMITTERS ON SURVIVAL AND REPRODUCTION OF EMPEROR GEESE

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***Abstract:*** Neck collars have been used widely for studies of goose population biology. Despite concerns about their negative impacts, few studies have employed designs capable of clearly demonstrating these effects. During a 1993–98 study of emperor geese (*Chen canagica*), we contrasted survival and reproduction of geese marked with tarsal bands to those marked with either small neck collars, large neck collars, or small neck collars with attached radiotransmitters. Annual survival of adult females marked with tarsal bands varied among years and averaged 0.807 ± 0.140 ($\bar{x}$ ± SE). Survival of geese with other types of markers also varied among years but was lower (0.640 ± 0.198). Collars with radiotransmitters lowered breeding propensity, as indexed by resighting rates. Although clutch sizes of tarsal banded birds were similar to those for unmarked birds, other markers reduced clutch sizes by about 1 egg. Egg mass and hatch date were not affected by marker type. Future studies of goose demographics should seriously consider use of alternative markers.

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***Key words:*** breeding propensity, *Chen canagica*, clutch size, egg size, emperor goose, environmental variance, mark–recapture, neck band, radiotelemetry, survival.

Our understanding of population biology of many species has been enhanced by observing marked individuals through time (Lebreton et al. 1992, Lebreton and North 1993). Radiotelemetry is a popular method of marking. Another more economical method is to mark animals with uniquely coded plastic tags or bands. Both methods require the assumption that markers do not influence the demographic traits of marked individuals.

Individually coded, plastic neck collars have been used in studies of geese for decades (Helm 1955). Although some geese occur in habitats where tarsal bands can be applied and viewed regularly (Ward et al. 1997), individuals in many populations can be easily identified only when marked with neck collars. Concerns about negative effects of neck collars were voiced since inception of their use (Aldrich and Steenis 1955, Lensink 1968, Ankney 1975, Craven 1979, MacInnes and Dunn 1988*a*), but researchers have continued with their use because few studies have demonstrated negative effects of neck collars and alternative marking methods are limited in their applicability. A primary limitation in previous studies has been the difficulty of measuring demographically important parameters for alternatively marked geese. Two studies of Canada geese (*Branta canadensis*) directly addressed negative effects of neck collars on survival by comparing those with neck collars and leg bands to those with just leg bands (Samuel et al. 1990, Castelli and Trost 1996). While Samuel et al. (1990) found reduced survival of neck-collared geese in only 2 of 6 cohorts of juveniles and no adult cohorts, Castelli and Trost (1996) clearly demonstrated lower survival of both age classes of neck-collared geese. In another study on Canada geese, MacInnes and Dunn (1988*a*) demonstrated that neck-collared geese returned to breeding areas at a lower rate than leg-banded geese. However, the confounding of survival, fidelity, and breeding probabilities inherent in determining the number of returning geese inhibited inference about which demographic parameters were most affected. In previous studies of emperor geese, low survival estimates caused concern that neck collars adversely affected survival of marked geese (Schmutz et al. 1994, 1997); however, lack of an alternately marked sample inhibited strong inference.

We initiated a study of the reproductive ecology of emperor geese in 1993. To address concerns about potential negative effects of neck collars, we banded each goose with 1 of 4 different marker types: plastic tarsal bands, small neck collars, large neck collars, or small neck

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collars with attached radiotransmitters. We tested whether marker type affected survival and breeding propensity of geese using sighting data of nesting geese and mark–recapture analysis. We also compared the timing of nesting, clutch size, and egg mass of geese with different marker types.

## METHODS

We conducted this study in an approximate 65-km$^2$ area along the Manokinak River on the Yukon–Kuskokwim Delta (YKD), Alaska during 1993–98. The habitat is flat, coastal tundra, and geese commonly nest along shorelines, on islands, and in graminoid meadows (Petersen et al. 1994). Geese also raise their broods and undergo wing molt within this study area.

All data presented in this paper were gathered from marked birds that were captured with bow traps while incubating eggs in mid June or with corrals when flightless during wing molt in late July or early August. To each goose, we attached 1 of 4 different types of markers, all of which had unique alpha-numeric codes and were made from a poly-vinyl plastic (Spinner Plastics, Illinois, USA). In 1993, we attached large neck collars (44 mm tall, 11.6 g) to geese as in earlier studies (Petersen 1992, Schmutz et al. 1994). In 1994–96, we attached small neck collars (34 mm tall, 9.1 g) or small neck collars with attached radiotransmitters to geese. Radiotransmitters weighed approximately 10 g with an overall marker mass of approximately 19 g and their 17 cm antennae were oriented downward along the breast. In 1994–97, we applied plastic bands to the tarsi of another sample of geese. We refer to groups of birds wearing these markers as large collars, small collars, radios, and tarsals. All geese were also marked with a standard, metal, U.S. Fish and Wildlife Service leg band.

Each year we searched for nests throughout the incubation period in a set of contiguous plots. At every located nest, we counted numbers of eggs, measured lengths and widths of eggs (usually during the initial visit), floated eggs in water briefly to estimate hatching dates (Westerkov 1950, Walter and Rusch 1997), and read marker codes with binoculars or spotting scopes. By gently flushing birds from nests, we could ascertain the presence or absence of any marker for nearly every bird.

Upon capturing geese during their wing molt each year, we checked for the presence or absence of all markers, and these data allowed us to assess rates of marker loss. Such an assessment was necessary because our method for estimating and comparing survival rates of emperor geese with different markers assumed that marker loss did not differ among marker types.

We conducted 2 sets of analyses relevant to marker effects. In the first, we applied Cormack-Jolly-Seber models to our capture–resight data (Lebreton et al. 1992) to estimate the effect of different marker types on survival and resighting probabilities of geese. Survival estimates ($\hat{\phi}$) represent annual rates from 1 nesting period to the next. Typically, resighting probabilities are interpreted as the probability of sighting a bird given that it is alive. In our study, resighting probabilities actually represented a confounding of the following biologically meaningful parameters: breeding propensity (probability of breeding), fidelity (probability of returning to our plots to nest), and true resighting probability (probability of sighting a marked bird, given that it was alive, it bred, and its nest was located within our nest plots). This analysis included geese found on nests during 1994–98, and all marker types were present in all years. We excluded data from 1993 because only large collars were applied in that year and there was no group with which to contrast survival and resighting rates.

We assessed goodness-of-fit of our data to the most general model (survival and resighting parameters for each marker type and year) by comparing its deviance to a bootstrap estimate of the deviance (Schmutz and Ely 1999; G. C. White, Colorado State University, personal communication). Because of some lack of fit of the general model to the data, we then calculated a variance inflation factor, $\hat{c}$ (White and Burnham 1999), which equaled 1.283, and adjusted our parameter estimates and model selection accordingly (Burnham and Anderson 1998).

We constructed a set of reduced models (fewer parameters) and compared models with $QAIC_c$ (Akaike's information criterion [AIC] corrected for small sample size and variance inflation; Burnham and Anderson 1998). Reduced models constrained year, marker, or both year and marker effects on survival and resighting rates to be invariant. The model with the smallest $QAIC_c$ value was considered best. We also calculated a $QAIC_c$ weight that reflects the rel-

ative likelihood of each considered model (Buckland et al. 1997) and aids in model selection and parameter estimation when multiple models similarly fit the data. We used program MARK and a logit link function for model comparisons and parameter estimation (White and Burnham 1999). Because the best model indicated survival varied among years, we calculated an average annual survival rate weighted by the inverse of the total variance. We partitioned the total estimated variance of this mean estimate into the environmental (process) and sampling variances following Burnham et al. (1987).

In our second set of analyses, we examined clutch size, egg mass, and timing of nest initiation in the subset of birds we trapped while on nests and also observed on nests in a subsequent year. Data from the year in which they were captured represented reproductive performance when not encumbered with any marker. By pairing with data from the next year they were observed on nests, we calculated the difference between years within individuals for each reproductive parameter and used 1-tailed paired *t*-tests to examine whether clutch size, egg mass, or timing of nesting had declined in association with wearing a particular marker type.

For estimates of clutch size, we excluded any eggs that were apparently laid external to the nest as these were likely laid by conspecific females (Petersen 1991). We used mass, length, and width data from 40 eggs collected shortly after laying to derive coefficients for Hoyt's (1979) equation for estimating egg mass. We then used this equation to estimate egg mass for all measured eggs. We calculated mean estimated egg mass within clutches for use in paired *t*-tests. Timing of nesting was represented by our estimated hatching dates derived either from direct observation or egg flotation (Westerkov 1950, Walter and Rusch 1997).

We expected that annual environmental variation could cause yearly variation in reproductive parameters unrelated to marker effects. To account for this potential confounding variable, we first calculated a within-year mean for clutch size, average egg mass per clutch, and hatch date for the population of unmarked nests observed each year ($\bar{x}$ = 318 unmarked nests per year). We then used an individual's clutch size, egg mass, and hatch date to calculate deviations from the relevant yearly mean (MacInnes and Dunn 1988*b*). If a marker did not affect reproductive performance, we expected to see no change between nesting attempts in an individual's deviations from the overall unmarked populations each year, even though its actual observed clutch size might vary across years. These pairs of deviations for each individual were the metrics used in the paired *t*-tests, with a test conducted for each marker type. This analysis of deviations is therefore examining whether clutch size, egg mass, or hatch date of given bird is different when encumbered with a marker relative to that when it was not, after accounting for other environmental variation in these parameters. The mean deviation for the sample of birds of a given marker type should be approximately 0 if the marker did not affect reproduction. These tests are approximate because of the lack of independence in calculating deviations among individuals; they rely on common estimates of annual means. Large collars were not included in the analysis of hatch date because we did not obtain accurate data on egg floats in 1993, the only year in which previously unmarked geese were banded with large collars.

## RESULTS

We recaptured 64 geese that had been marked with large collars and 73 with tarsal bands. None of these geese had lost their markers. We recaptured 27 geese marked with small collars, of which 1 had lost its collar by the time of its capture 2 years after it was marked. Similarly, we recaptured 7 geese marked with small collars and attached radiotransmitters and 1 of these had lost its marker when recaptured 2 years after marking.

Our mark–resight analysis included 36 geese with large collars, 52 with small collars, 57 with radios, and 87 with tarsal bands. Resighting rates did not vary among years within markers but differed among marker types, as estimated with the best model ($QAIC_c$ weight = 0.486). Resighting rates were much lower for small collars with attached radios (0.209 ± 0.078) than for small collars, large collars, or tarsal bands (0.585 ± 0.057). Using this same model, survival of all marked geese varied among years, and survival of tarsal-banded geese ($\hat{\phi}$ = 0.807, $\widehat{SE}_T$ = 0.140) was greater than survival of geese with other markers ($\hat{\phi}$ = 0.640, $\widehat{SE}_T$ = 0.198; Table 1). The sum of $QAIC_c$ weights for models with survival of tarsal-banded geese was different than that of geese with other markers was 0.661. A model in which survival of tarsal-band-

Table 1. Annual survival rates ($\phi$) of emperor geese marked with tarsal bands, small neck collars, large neck collars, or small collars with attached radiotransmitters estimated with Cormack-Jolly-Seber models (Lebreton et al. 1992). Using the best model based on $QAIC_c$ (Burnham and Anderson 1998), survival varied among years for all markers and differed between tarsal bands and a pooling of all other markers. Estimates for each of the other 3 marker types are from a more general, poorer fitting model. Averages were weighted by the inverse of the total variance, where the total variance is the sum of the environmental (process) variance and the sampling variance associated with each estimate (Burnham et al. 1987). Standard errors are the square roots of the total ($S\hat{E}_T$) and process ($S\hat{E}_E$) variances.

| Marker type | 1994–95 | | 1995–96 | | 1996–97 | | Average | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\phi$ | $S\hat{E}$ | $\phi$ | $S\hat{E}$ | $\phi$ | $S\hat{E}$ | $\phi$ | $S\hat{E}_T$ | $S\hat{E}_E$ |
| Tarsal bands | 0.740 | 0.107 | 0.935 | 0.059 | 0.678 | 0.106 | 0.807 | 0.140 | 0.108 |
| All other markers | 0.568 | 0.094 | 0.869 | 0.098 | 0.493 | 0.084 | 0.640 | 0.198 | 0.175 |
| Small collars | 0.602 | 0.100 | 0.895 | 0.090 | 0.555 | 0.104 | 0.689 | 0.185 | 0.158 |
| Large collars | 0.498 | 0.123 | 0.847 | 0.114 | 0.449 | 0.102 | 0.596 | 0.218 | 0.186 |
| Small collars with transmitters | 0.613 | 0.168 | 0.899 | 0.090 | 0.566 | 0.150 | 0.727 | 0.191 | 0.137 |

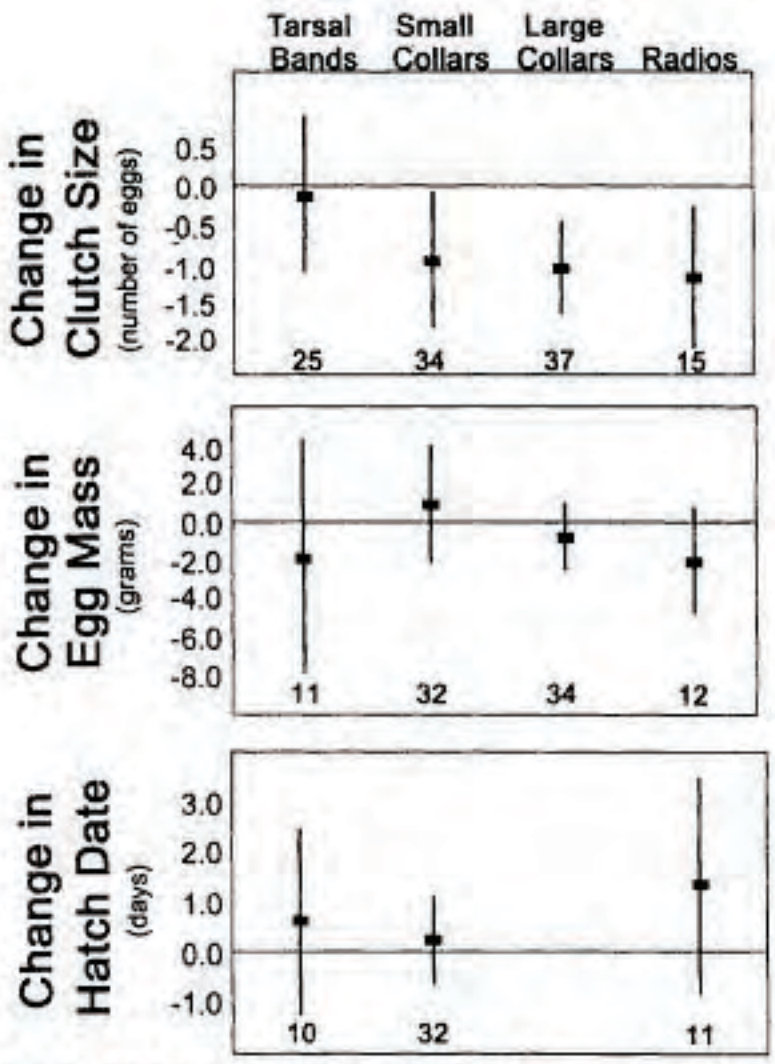


Fig. 1. Clutch sizes, estimated mean egg mass within clutches, and hatch dates of emperor geese observed nesting 2 times on the Yukon–Kuskokwim Delta, Alaska, 1993–98. For each reproductive parameter, observed differences are shown between a goose's first nest when it had no marker and its subsequent nesting effort when it had worn a marker for at least 10 months. The actual value used to represent a reproductive parameter (e.g., a goose's clutch size) is the deviation of that individual's clutch size from the mean clutch size for the unmarked population during the year that nest was observed. Thus, the differences between nesting attempts shown here represent differences in deviations from the mean performance of the unmarked population. Vertical lines represent 95% confidence intervals of means, and sample sizes are shown below each group.

ed geese was equal to that of all other markers fit less well ($QAIC_c$ weight = 0.339).

Clutch sizes of tarsal-banded geese were similar to what they produced when unmarked (0.23 ± 0.49 egg mean decrease, $t_{24} = 0.233$, $P = 0.408$). In contrast, clutch sizes for the 3 other marker types dropped by approximately 1 egg, as compared to what they produced when unmarked ($t_{36} = 3.613$, $P = 0.004$ for large collars; $t_{33} = 2.260$, $P = 0.007$ for small collars; $t_{14} = 2.812$, $P = 0.009$ for small collars with radios; Fig. 1). Maximum mean difference in egg mass before versus after marking was 1.93 g for radiomarked geese, which was <2% of overall egg mass ($t_{11} = 1.595$, $P = 0.069$). Changes in egg mass for other markers were indistinguishable from no change ($t_{10}$, $t_{31}$, and $t_{33} < 0.86$, $P \geq 0.20$; Fig. 1). Hatch dates were not consistently different before versus after marking for tarsals, small collars, or radios (Fig. 1).

## DISCUSSION

The model that best fit our data indicated that adult females marked with tarsal bands had a 17% higher mean annual survival rate than those marked with neck collars or neck collars with attached radio-transmitters. The mean annual survival estimate for tarsal-banded geese is comparable to the adult survival rate that Schmutz et al. (1997) surmised for the unmarked population of geese based on other demographic parameters and information on population growth rates (Butler et al. 1995). Similarly, our survival estimate for geese with any of the 3 types of neck collars was equivalent to survival estimates from previous studies of emperor geese that used large collars (Petersen 1992, Schmutz et al. 1994).

Marker loss would influence our inference about marker effects if geese tended to lose 1 marker type more readily than another. Our limited data set indicated the loss of only 2 markers, and we feel this minimal loss did not affect our conclusions. Even these few observations may overestimate the real rate of marker loss because of a confounding relationship between effects and loss of markers. Specifically, if neck collars reduce survival, then a goose that loses its neck collar is more likely to survive long enough to be recaptured and then contribute to data used to measure collar loss. In an earlier study, Schmutz et al. (1994) observed that all 12 recaptured emperor geese retained their neck collars.

We note that our survival estimate for tarsal-banded geese may contain some negative bias due to permanent emigration from our study area. Two studies of goose survival used resighting or recovery data away from breeding areas and during times of presumed population panmixia to evaluate bias associated with resightings on breeding areas (Francis and Cooke 1993, Sedinger et al. 1997). The average bias in these 2 studies was about 5%, which if applied to our data, would yield an annual survival rate for adult females of about 0.85.

Our estimated resighting rates reflected the product of breeding propensity, fidelity to nest plots we searched, and the true probability of resighting a goose that nested within our plots. We searched our plots with a similar intensity among years and marker types, and thus, we do not believe that true resighting rates varied. Fidelity to nest sites was likely constant and quite high. For geese observed on nests in ≥2 years, we documented little movement among the 14 plots we monitored (7% moved beyond an adjacent plot). Similarly, in a study of black brant (*Branta bernicla nigricans*) that was able to separately estimate fidelity and resighting rates, Lindberg and Sedinger (1997) observed high rates of fidelity to nesting areas within a colony. We therefore conclude that most of the large differences in estimated resighting rates between geese marked with radios and other geese reflected differences in their breeding propensity. Similarly, breeding propensity of black brant nesting on the YKD was lowered by harness attachment of radiotransmitters (Ward and Flint 1995).

Once geese were marked with any marker other than tarsal bands, their clutch sizes in future reproductive attempts declined by about 1 egg. We did not observe comparable marker effects on egg mass or hatch date. These results are not surprising when considering that, for snow geese (*Chen caerulescens*), clutch size has a lower heritable component than egg size or laying date (Cooke et al. 1995). Therefore, aspects of a bird's environment, including being encumbered with a marker, should more readily impact clutch size than egg size or laying (and hatch) date.

We speculate that the negative effects of neck collars and radiotransmitters mounted on neck collars principally arise from a chronically increased energetic demand. An energetic mechanism for neck collar effects, including increased mortality, is directly implied by the presence of sublethal effects on reproduction. Both thermoregulatory and aerodynamic factors likely contribute to an increased energetic demand. During recaptures of some geese, we have observed feather wear caused by neck collars and such wear could increase thermoregulatory costs, particularly during winter. In an earlier study of survival based on neck collars, Schmutz et al. (1994) observed lower survival of emperor geese during overwinter than oversummer periods. Aerodynamic considerations may also be important during nonbreeding seasons when geese frequently fly. In a controlled study of free-flying rock doves (*Columba livia*), Gessaman and Nagy (1988) demonstrated that transmitters, and even just harnesses for transmitters, caused substantial increases in the energetic cost of flight. Neck collars may pose similar problems for emperor geese.

We are unsure as to the extent these negative effects may be manifested in other species when neck collars are used. Use of neck collars was discontinued on brant because of disturbed social behavior (Lensink 1968) and reduced survival was observed in non-migratory Canada geese (Castelli and Trost 1996). Many other studies have cited concerns about negative impacts of neck collars (Ankney 1975, Craven 1979, Zicus et al. 1983, MacInnes and Dunn 1988*a*, Schmutz et al. 1997). Our study validated many of those concerns. Investigators should seriously question any proposed use of neck collars for future studies. Neck collars are clearly useful for providing information on distribution, but their use is suspect when estimation of demographic parameters is desired.

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