Research Article

Effects of Abdominally Implanted Radiotransmitters with Percutaneous Antennas on Migration, Reproduction, and Survival of Canada Geese

JERRY W. HUPP,[1] *Alaska Science Center, United States Geological Survey, Anchorage, AK 99503, USA*
JOHN M. PEARCE, *Alaska Science Center, United States Geological Survey, Anchorage, AK 99503, USA*
DANIEL M. MULCAHY, *Alaska Science Center, United States Geological Survey, Anchorage, AK 99503, USA*
DAVID A. MILLER,[2] *School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA*

Abstract

*Abdominally implanted radiotransmitters with percutaneous antennas are increasingly used to monitor movements, survival, and reproduction of waterbirds. However, there has been relatively little assessment of the effects of such radios on avian demographic parameters or migration. We implanted either a 26- or 35-g abdominal transmitter with percutaneous antenna in 198 adult female lesser Canada geese (*Branta canadensis parvipes*) in Anchorage, Alaska during 2000 and 2001. We compared migration chronology, reproductive effort, and survival of radiomarked females to 118 control females marked with leg bands. Arrival dates following spring migration were similar among females in different treatments in 2001. However, in 2002, wind direction during late migration was less favorable, and arrival of females with 35-g radiotransmitters lagged 1–2 days behind that of control females. Nest initiation dates, clutch size, and mean egg volume were similar for 152 nests of females that lacked radios and 62 nests of radiomarked females. Estimated nesting propensity for females with operable radiotransmitters was 61% and 72% in 2001 and 2002, respectively. Apparent annual survival ($\phi = 0.82$, 95% confidence interval: 0.76 to 0.87) was similar among treatments in the first year after geese were marked. In the second and third years after marking, model-averaged estimates for survival of females with large radiotransmitters were 10% lower than estimates for control females. However, the effect of large radios on long-term survival was equivocal because of uncertainty surrounding treatment estimates. We conclude that abdominally implanted radiotransmitters with percutaneous antennas had small effects on migration chronology but no apparent effects on fecundity. Abdominal transmitters can provide unbiased estimates of anserine survival in the first year after deployment. Because of the potentially greater effects of larger transmitters on migration and long-term survival, we recommend that biologists minimize the size of implanted transmitters and deploy radios with caution if long-term survival of marked birds is a concern.* (JOURNAL OF WILDLIFE MANAGEMENT 70(3):812–822; 2006)

Key words

abdominal radiotransmitters, Branta canadensis*, Canada goose, migration, nesting, radio telemetry, survival, transmitter effects.*

Biologists often use radio telemetry to study avian migration, reproduction, or survival. A critical assumption of those studies is that the radiotransmitters do not affect the parameters that are estimated. Several studies have demonstrated that radiotransmitters that are externally attached to waterfowl can lower survival (Dzus and Clark 1996, Paquette et al. 1997, Schmutz and Morse 2000). Diminished survival may be caused by increased energetic expenditure during flight (Gessaman and Nagy 1988, Obrecht et al. 1988), behavioral changes (Greenwood and Sargeant 1973, Wooley and Owen 1978, Perry 1981, Pietz et al. 1993), higher predation (Wheeler 1991), greater susceptibility to harvest (Blouin et al. 1999), or reduced physiological condition (Greenwood and Sargeant 1973, Glahder et al. 1997) that can occur following radio attachment. Reduced fecundity of waterfowl marked with external radiotransmitters has also been observed as a result of lowered nesting propensity, delayed nest initiation, and smaller clutch size (Pietz et al. 1993, Rotella et al. 1993, Ward and Flint 1995, Paquette et al. 1997, Schmutz and Morse 2000, Demers et al. 2003).

An alternative to external attachment is surgical implantation of the transmitter in the abdominal cavity (Korschgen et al. 1984, Olsen et al. 1992). Abdominal implants appear to have fewer adverse effects on reproduction (Rottella et al. 1993, Garrettson and Rowher 1998), survival (Dzus and Clark 1996, Paquette et al. 1997), and behavior (Garrettson et al. 2000) than externally attached radiotransmitters, and they may be a superior alternative for demographic studies. Most assessments of implanted transmitters used radios in which the antenna was contained in the abdominal cavity. Implanting the transmitter antenna within the body cavity reduces reception range of Very High Frequency (VHF) radios (Olsen et al. 1992, Garrettson and Rohwer 1998, Boyd et al. 2000), and it precludes biologists from using satellite transmitters. To circumvent those limitations, Korschgen et al. (1996) developed a procedure in which the transmitter is implanted in the abdomen, but the antenna exits the body. Although used in studies of waterbird migration (Petersen et al. 1999, Boyd et al. 2000, Hatch et al. 2000), there has been relatively little evaluation of the effects of implanted radios with percutaneous antennas on vital rates of birds. Hupp et al. (2003) observed that such radios did not alter behavior of Canada geese. Esler et al. (2000) found no effect of the radios on survival of female harlequin ducks (*Histrionicus histrionicus*). However, there are no controlled studies of the effects of implanted transmitters with external antennas on survival of other waterfowl or on reproduction.

We examined the effects of implanted radiotransmitters with percutaneous antennas on migration chronology, reproduction, and survival of female lesser Canada geese in Anchorage, Alaska. Our

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[1] *E-mail: jerry_hupp@usgs.gov*
[2] *Present address: Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA 50010, USA*

goals were to compare spring arrival dates of birds with radiotransmitters to those without, and contrast timing of nest initiation, clutch size, and egg size of radiomarked versus leg-banded or unmarked females. We compared annual survival of radiomarked and leg-banded females for up to 3 years after marking.

Study Area

Canada geese spent April–October in an approximately 200-km^2 region of the Anchorage municipality. The population of about 3,000 birds was relatively discrete from other groups of Canada geese in Southcentral Alaska. Geese typically grazed on lawns of city parks, sports fields, and schoolyards between arrival and nest initiation in late April. During nesting, breeding-age geese secured territories in shrub bogs or other undeveloped habitats. Geese concentrated on local lakes during their molt in July. From August until fall departure, flocks grazed on lawns throughout Anchorage. Local wildlife managers removed eggs from nests and transported goslings away from the city to control the population. Consequently, the geese we studied were usually not accompanied by young.

Methods

Treatments

We used bow traps to capture nesting females in May of 2000 and 2001 and molt drives to catch flightless females in July of the same years. We transported captured females to a surgical facility where we measured body mass and randomly assigned birds to control, small transmitter, or large transmitter treatments. In each year we assigned 49–50 geese to each radiotransmitter treatment and 50–68 birds to the control treatment (Table 1). We marked geese in each treatment with a U.S. Fish and Wildlife Service metal leg band and a colored plastic tarsus band with a unique numeric code. Females in the small transmitter treatment received a 26-g VHF radio transmitter that was cylindrical, 4 cm long, 1.5 cm in diameter, and 1.3% of the average body mass of 1,990 g. A 35-g VHF transmitter that was 5 cm long, 3 cm in height, 1.5 cm at the widest dimension, and 1.8% of mean body mass was implanted in females in the large transmitter treatment. The large transmitters had the same dimensions and mass as PTT-100 implant satellite transmitters made by Microwave Telemetry (Columbia, Maryland). All transmitters had a 14-month operational life and they increased pulse rate in the event of the bird's death. Holohill Systems, Limited (Carp, Ontario, Canada) manufactured the radiotransmitters.

We modified an approach described by Korschgen et al. (1996) to implant transmitters in radiomarked birds (Mulcahy and Esler 1999, Hupp et al. 2003). Briefly, we induced anesthesia via 4% isoflurane in oxygen for approximately 5 minutes, then we reduced the concentration of isoflurane to a level (2–3%) needed to maintain anesthesia for the duration of surgery. A veterinarian made a 3-cm incision on the ventral midline, breached the right abdominal air sac, and placed the transmitter in the air sac. The antenna exited caudally through the body wall near the right pubic bone and synsacrum, and it extended approximately 26 cm outside of the body. The veterinarian sutured a 100% nylon mesh bag that surrounded the transmitter to the body wall, and placed an additional suture through the body wall into a synthetic collar at the base of the antenna. The abdominal incision was closed in 2 layers with absorbable sutures. We anesthetized control females with isoflurane for 10 minutes in a manner similar to that of radiomarked females. We allowed both control and radiomarked females to recover from anesthesia for 1–3 hours; they were fully alert when released at capture sites. Capture and surgical protocols were reviewed and approved by the Alaska Science Center Animal Care and Use Committee.

Table 1. Numbers of adult female Canada geese marked in control and radiotransmitter treatments, and periods geese were captured, Anchorage, Alas., USA, 2000–2001. A total of 316 females were marked.

Capture year	Control		Small transmitter		Large transmitter	
	Nesting[a]	Molt[b]	Nesting	Molt	Nesting	Molt
2000	14	54	14	36	13	36
2001	7	43	7	42	7	43

[a] Females marked during nesting were captured on nests in May.
[b] Females marked during molt were captured in July.

Resightings, Recaptures, and Recoveries

We observed marked birds from April to October of 2001–2003, and during April 2004. We made resightings by systematically visiting all parks, sports fields, schools, or other open areas that geese were likely to use during the first 2–3 weeks after their arrival in April. We used spotting scopes and binoculars to read numeric codes of plastic bands. We made our most intensive resighting efforts in spring in case some failed breeders departed Anchorage to molt elsewhere. We avoided tracking of females with functional radiotransmitters during the first 10 days after arrival so that our estimates of arrival chronology were based only on visual observations. However, during that interval, we did monitor the presence of radio signals from a 200-m-high ridge near Anchorage. That enabled us to determine when a goose with a working radio had arrived, but it did not provide an indication of where in the city it was located; thus, it did not affect our efforts at visual relocation. In 2001–2003 we also conducted systematic searches for marked geese in September and October.

We recaptured marked birds during molt in July 2001–2003. We conducted capture drives on the same suite of lakes each year, and we examined captured females for missing leg bands or broken antennas. We replaced missing bands prior to 2003.

Nesting Biology

We located nests by systematically searching local shrub bogs several times during the 2001 and 2002 nesting seasons. We also located nests of females with functional radiotransmitters by radio tracking. We tried to visually relocate radiomarked females weekly during nesting to confirm their reproductive status. As we approached nests, we examined females to determine if they were radiomarked, part of the control group, marked during earlier studies of Anchorage geese, or unmarked. Upon discovery of a nest, we recorded the number of eggs in the nest bowl, measured length and width of eggs, and estimated embryo age by candling (Weller 1956) or floating eggs. We revisited nests at approximately 7-day intervals until they failed or hatched.

Data Analysis

Migration chronology.—We examined migration arrival dates in 2001 and 2002 during a 10-day interval following the first sighting of a marked goose in Anchorage. We restricted the analysis of migration chronology to the initial 10 days of arrival because geese remained in larger flocks during that time and residual snow cover helped concentrate birds on smaller areas of open ground. That combination enabled us to examine a high proportion of geese that were present in Anchorage on a daily basis and to detect new arrivals. After the initial 10-day period, geese became dispersed as the onset of nesting approached, and marked birds were likely not detected as quickly upon their arrival. Also, after that period we started to radiotrack birds with functional radios to obtain visual sightings and to assess reproductive status. Thus, first sighting date for radiomarked birds that had not yet been seen was not based solely on systematic visual searches. We considered the first sighting of a marked goose in spring to be indicative of its arrival date. We compared the lag between detection of a bird's radio signal from the ridge near Anchorage and its first visual sighting to assess how quickly after arrival we observed radiomarked females. We were unable to make a similar assessment for control birds, but we evaluated the number of times each was sighted during the arrival period (corrected for the number of days between a bird's first sighting and the end of the arrival period) and compared the mean estimate to the radiomarked sample to determine if birds in one group were more visible, and thus likely to be detected sooner.

We expressed the first sighting for each bird as the day of the arrival period when it occurred (i.e., 1, 2, ...,10). We addressed 2 questions. Was the number of days that lapsed until first sighting similar among birds in different treatments? And, if migration of birds in one treatment lagged relative to others, was the delay constant across the arrival period? We compared timing of arrival for marked birds in different treatments via a Cox hazards analysis. We conducted the analysis in SAS using PROC PHREG (Allison 1995) and modeled the hazard function for each treatment and day after the start of the arrival period. We examined the interaction between day and treatment to assess whether differences among treatments were constant over the arrival period. We conducted pair-wise comparisons between treatments when the treatment effect was significant. We censored geese that were first seen after the 10-day arrival period. We conducted separate Cox hazard analyses for the 2001 and 2002 field seasons. Because arrivals in 2002 included birds marked in 2000 and 2001, we first tested for cohort differences within treatments, and we pooled data if year of marking had no effect.

Nesting biology.—We estimated nest initiation dates by backdating 26 days from hatch for successful nests, and we assumed a laying rate of 1.5 days/egg based on Cooper (1978) and incidental observations of laying rates in 4 nests. We determined initiation date of failed nests by backdating based on embryo age at the time of discovery. Clutch size was the maximum number of eggs observed in nests that reached incubation. We eliminated 3 nests with >8 eggs because we assumed they were parasitized by conspecifics. We collected 43 eggs from Canada goose nests in 2000, removed egg contents and measured internal volume, regressed egg volume on egg length and width (Hoyt 1979), and used that model [$\text{volume} = 4.26 + 0.00046 \times (\text{length} \times \text{width}^2)$; $r^2 = 0.96$] to estimate volume of eggs discovered at nests in 2001 and 2002. We averaged volume among eggs for nests with complete clutches. Hatching success was the percentage of eggs that hatched in successful nests.

We only used data from a nest if the female was observed and we could determine whether she was radiomarked, a control bird, leg-banded in previous studies, or unmarked. We included nests of unmarked and previously leg-banded females in the control group. We did not include nests of females that were neck-collared during earlier studies (York et al. 2000) in the event there was an unknown effect of collars on nesting. We used PROC GLM in SAS to model the effects of treatment, year of nesting, and the interaction between year and treatment on Julian date of nest initiation and mean egg volume. Models that examined variation in clutch size included the effects of treatment, year of nesting, nest initiation date, and any interactions that involved a treatment effect. We used an information-theoretic approach (Burnham and Anderson 2002) to identify the most parsimonious models that explained variation in nesting parameters. We used Akaike weights to gauge support among the candidate models, including a null model that included an intercept but no terms for predictor variables. We also examined the frequency distribution of nests among different clutch sizes for birds with radios and those without. We used a chi-square goodness-of-fit test to assess whether the number of nests of radiomarked geese in each clutch size class differed from an expected number derived from the distribution of nests for geese without radios.

We also evaluated pre- and posttreatment differences in clutch size for females that were captured and radiomarked during nesting, then observed nesting 1 year later. A 95% confidence interval (CI) was computed surrounding mean difference in clutch size between years. We concluded there had been no change in clutch size following radiomarking if the CI encompassed zero. Median clutch size (5 eggs) was similar in each year of study. Therefore any changes in clutch size were because of transmitter effects rather than annual variation.

We estimated nesting propensity of females with active radios in 2001 and 2002. We first estimated daily nest survival rates (DSR) for all discovered nests by using the maximum likelihood estimator of nest survival in program MARK (Dinsmore et al. 2002). Candidate models included effects of years, date, nest age, and treatment. In addition, we included a separate effect for the date eggs were removed from nests during the citywide effort to control the population because a large proportion of nests were destroyed on that day. Models that best explained variation in DSR were selected based on AIC_c (Burnham and Anderson 2002). We corrected our estimates of nesting propensity of radiomarked females for nests that were destroyed or abandoned prior to discovery by computing detection likelihoods based on the probability of a nest surviving to the age at discovery given the estimated DSR. We used a Horvitz–Thompson estimator (Horvitz and Thompson 1952, Dinsmore et al. 2002) to estimate the number of nests initiated by females with working radios. We restricted our estimate to females with working radios because our approach assumed that all nests would have been found had they not failed. We used bootstrap simulations (Efron and Tibshirani 1994) to calculate confidence intervals on estimates of nest initiations based on our best model for nest survival using MATLab (Mathworks, Inc., release 12.1, $n = 1,000$ simulations).

Survival.—We used Cormack–Jolly–Seber capture–recapture models (Lebreton et al. 1992) in program MARK (White and Burnham 1999) to estimate apparent annual survival (ϕ) and resighting probabilities (p) for radiomarked and control birds based on resightings and recaptures from 2001 to 2004. Apparent annual survival (hereafter, survival) was the likelihood that a bird that was alive in year i returned to Anchorage in the following year. We assumed there was no permanent emigration from the study area. The resighting interval extended from arrival of geese in April until their departure in October. We counted mortalities that took place while geese were in Anchorage as losses that occurred between that resighting interval and the next.

We coded each combination of cohort and treatment as a separate group, giving us 6 groups and 5 encounter periods (including initial captures in 2000). We modeled survival for the 2000 cohort for up to 3 years after marking, and survival of the 2001 cohort for up to 2 years after marking. We could not separately estimate ϕ and p in 2004, the final year of the study (White and Burnham 1999). To select an approach to modeling p, we used program MARK to conduct a preliminary analysis in which each model had the same terms for estimation of ϕ (groups and time were fully crossed) but where terms were varied for estimation of p. Specifically, we examined models where resighting likelihoods were allowed to differ in the following ways: 1) among treatments, 2) between radiomarked and control females, 3) between radiomarked females in their first year after capture when radios were functional versus control geese and radiomarked females in second and third years after capture when radios were no longer functional, 4) among years, 5) for each combination of group and time, and 6) as a null model in which p was invariant. Following examination of the data, we also included an a posteriori model in which we derived a separate parameter estimate for those groups and periods when some marked geese were present but not seen ($p < 1.0$), versus groups and periods with perfect resighting likelihoods ($p = 1.0$).

Following selection of a standardized approach for estimation of p, we examined 32 candidate models of the effects of radio-transmitters on survival. Our interests were whether 1) survival of radiomarked females differed from control birds, 2) survival in any treatment changed over time after marking, 3) size of radio affected survival, and 4) there was an interaction between treatment and body mass that would indicate smaller birds were more severely affected by radios. We also examined differences in survival between cohorts and among years that were unrelated to treatment effects; assessed a null model in which survival did not vary among treatments, between cohorts, and across years; and included a model in which survival varied for each group and time. We examined survival models that included group and time effects first. We then included body mass at molt as a covariate in the top models to evaluate whether treatment effects were similar among birds of different mass. Molt body mass was similar ($t = 1.38$, 281 df, $P = 0.17$) for birds marked in 2000 (2,011 g, SE = 16.7 g) and 2001 (1,981 g, SE = 14.4 g), therefore we did not adjust for annual differences. Molt body mass of 26 nest-trapped females was measured when they were recaptured at molt in the same year they were marked during nesting. We regressed the change in body mass between capture events against the day of incubation when those females were captured on the nest, and we used that model (mass change = 127.1 − 13.6 × day of incubation; $r^2 = 0.29$) to estimate molt body mass for the 36 nest-trapped females that were not recaptured at molt. We used a logit link function for all models. We considered models that had the lowest QAIC_c values ($\Delta\text{QAIC}_c < 2.0$) provided the best estimates of survival, and examined Akaike weights to gauge relative support for each model (Burnham and Anderson 2002). We used weighted model averaging to derive estimates of ϕ for each group and encounter period.

Results

Migration Chronology

In 2001, we sighted 106 (79%) of the 135 marked individuals seen in that year during the initial 10 days of arrival. We observed 74% of females with operable radios within 1 day of the date their signal was first detected, and during the initial 10 days sighted 89% of the females whose radios were detected during that period. During the arrival period, females in radiomarked or control groups were each sighted an average of 0.62 times for each day they were present ($t = -0.12$, 104 df, $P = 0.90$). The number of days from the start of the arrival period until first sighting was similar among treatments (Table 2; Fig. 1).

Of the 211 marked geese seen in 2002, we sighted 164 (78%) during the 10-day arrival period. Sixty-five percent of females with working radios were seen within 1 day of first signal detection, and 86% of females whose signals were detected in the first 10 days were also seen in that period. We sighted radiomarked females an average of 0.64 times for each day they were present, whereas control females were sighted an average 0.57 times ($t = -1.67$, 162 df, $P = 0.1$). Within treatments, arrival dates in 2002 were similar regardless of whether a bird was marked in 2000 or 2001 (Wald $\chi^2 \leq 2.1$, $P \geq 0.35$). Therefore we combined birds marked in different years to examine the treatment effect. Timing of arrival differed among treatments, and the interaction between day and treatment indicated those differences were not consistent over the arrival period (Table 2). Females with small transmitters arrived slightly later ($P = 0.10$) than control females. The difference in arrival dates between control females and females with large radios was greater ($P = 0.005$) as the latter lagged behind control females by 1–2 days during most of the arrival period. However, we

Table 2. Cox hazards analysis of number of days until marked female Canada geese in each treatment group were first observed in Anchorage, Alas., USA, during April, 2001 and 2002. We expressed the first sighting of each bird as the number of days that had lapsed since the start of the 10-day arrival period. We modeled the hazard function for each treatment and day, and we examined the interaction between treatment and days to determine whether differences among treatments were constant over the arrival period. We censored observations made >10 days after the earliest resighting from the analysis.

Year	Effect	Parameter estimate	SE	Wald χ^2	P^a
2001	Treatment[b]	−0.21	0.61	0.12	0.73
	Treatment × days	0.02	0.05	0.23	0.63
2002	Treatment	−1.29	0.46	7.8	0.005
	Treatment × days	0.11	0.04	7.0	0.008

[a] Probability that the parameter estimate equals zero.

[b] Treatment was coded as 1, 2, or 3 for control, small, and large transmitter groups, respectively.

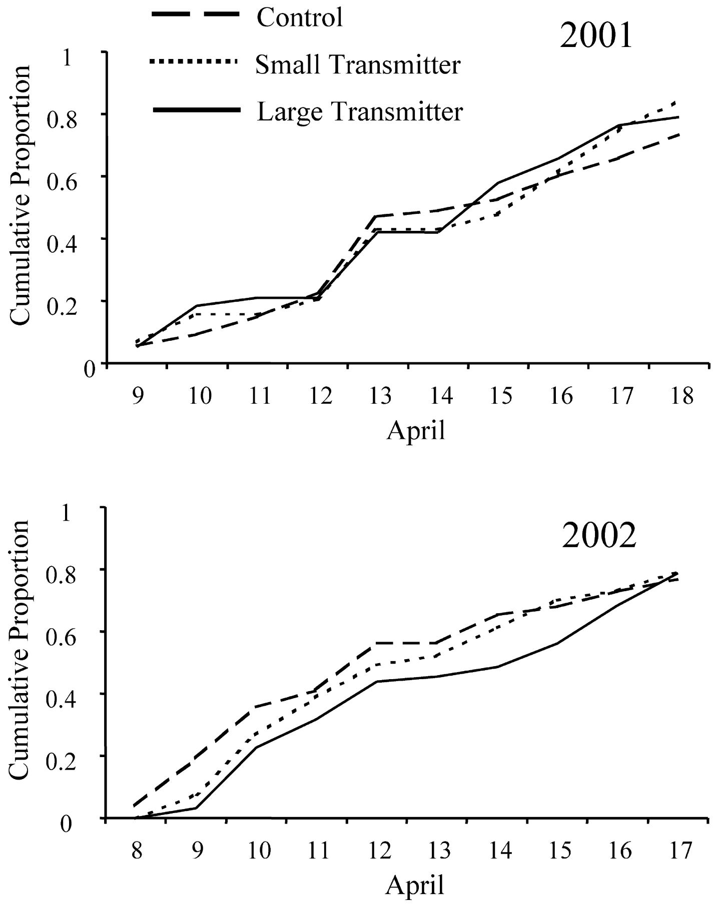

Figure 1. Spring migration chronology of female Canada geese in radio-transmitter and control treatments in Anchorage, Alas., USA, 2001–2002. For each treatment, we tallied the number of marked birds that were first seen on a given day, and we added the sum to the number of birds that were first seen on previous days. We expressed the cumulative total as the proportion of all marked birds in a treatment that were observed in that year. Geese that were not sighted during the initial 10-day arrival period are not shown. We based arrival dates in 2001 on first sightings of 39, 37, and 30 females in control, small transmitter, and large transmitter treatments, respectively. In 2002, we based first sightings on 60, 52, and 52 females in control, small transmitter, and large transmitter treatments, respectively.

sighted a comparable proportion of birds in each treatment by the end of the 10-day interval (Fig. 1).

Nesting Biology

We analyzed initiation dates for 152 nests of females that lacked radios and 62 nests of radiomarked birds. The most parsimonious model indicated that year of nesting had the greatest effect on nest initiation date (Table 3) because of earlier nesting in 2002. There was also slight support for a model that included terms for year and treatment. That was likely because mean nest initiation date (adjusted for annual variation) of females with small radios was approximately 2 days later than for females in other treatments (Table 4). The nest initiation curve for radiomarked females closely resembled that of females without radios (Fig. 2). The initiation curve was skewed to the right, likely because of renesting. We discovered renests of 1 control and 3 radiomarked females following failure of their earlier nests.

We measured mean egg volume and clutch size in 144 and 146 completed nests, respectively. The null model was the best supported of the models for egg volume, indicating constancy between years and among treatments (Table 3). However, there was some support for a model that included a year effect. Treatment differences in mean egg volume were negligible (Table 4). Nest initiation date accounted for most of the variation in clutch size (Table 3) because clutch size declined as the nesting season progressed. There was little support for models that included a treatment effect or an interaction between treatment and other main effects on clutch size. After adjusting for effects of nest initiation date, clutch sizes were similar among treatments (Table 4). The frequency distribution among different clutch sizes was similar between nests of radiomarked geese and other females ($\chi^2 = 4.5$, 5 df, $P = 0.48$), although there was a slightly higher proportion of 4-egg clutches, and slightly lower proportion of 6-egg clutches for radiomarked females (Fig. 3). We observed 13 females that were trapped and radiomarked during nesting and found on nests 1 year later. Mean difference in pre- and posttreatment clutches was 0.15 eggs (95% CI = –1.1–1.4 eggs). Hatching success for 120 eggs in nests of radiomarked females that survived to hatch was 94%. Hatching success for 340 eggs of females without radios was 92%.

Table 3. Candidate models that examined the effects of nesting year (YEAR) and treatment (TRT) on Julian dates of nest initiation and mean egg volume, and effects of year, treatment, and nest initiation date (DATE) on clutch size for female Canada geese in Anchorage, Alas., USA, 2001–2002. The null model (NULL) only included an intercept. Only the top 5 models and the null model are presented for clutch size.

Response variable	Model	K^a	AIC$_c$	ΔAIC$_c$	w_i^b
Nest initiation	YEAR	3	823.5	0.0	0.66
	YEAR, TRT	5	825.2	1.7	0.28
	YEAR, TRT, YEAR × TRT	7	828.7	5.2	0.04
	NULL	2	831.9	8.5	0.01
	TRT	4	832.6	9.1	<0.01
Egg volume	NULL	2	546.8	0.0	0.51
	YEAR	3	547.7	0.9	0.32
	TRT	4	550.2	3.3	0.10
	YEAR, TRT	5	551.2	4.4	0.05
	YEAR, TRT, YEAR × TRT	7	553.3	6.5	0.02
Clutch size	DATE	3	109.4	0	0.45
	YEAR, DATE	4	110.0	0.6	0.33
	TRT, DATE	5	112.6	3.3	0.09
	TRT, YEAR, DATE	6	113.3	3.9	0.06
	TRT, DATE, TRT × DATE	7	114.5	5.1	0.03
	NULL	2	127.1	17.7	<0.001

[a] Number of parameters in model.
[b] Akaike weight.

The daily nest survival model with the lowest AIC$_c$ value included variation in nest survival across nest ages and dates within years, and different survival rates on the dates of egg removal (AIC$_c$ = 693.5, $w_i = 0.31$). The best model that included a treatment effect was weakly supported (AIC$_c$ = 697.0, $w_i = 0.06$) indicating there was little difference in DSR among treatments. During nesting, 44 females had functional radios in 2001, whereas 50 females had working radios in 2002. We located nests of 15 and 21 of those females in 2001 and 2002, respectively. After correcting detection rates based on nest survival, we estimated that nesting

Table 4. Mean estimates for Julian date of nest initiation, egg volume, and clutch size of female Canada geese in control, small radiotransmitter, or large radiotransmitter treatments, Anchorage, Alas., USA, 2001–2002.

	Control[a]			**Small radio**			**Large radio**		
Reproductive measure	***N***	$\bar{x}$	**SE**	***N***	$\bar{x}$	**SE**	***N***	$\bar{x}$	**SE**
Nest initiation date[b]	152	124.5	0.56	31	126.5	1.2	31	124.3	1.2
Mean egg volume[c]	101	107.7	0.67	19	107.9	1.4	24	109.1	1.3
Clutch size[d]	103	4.8	0.14	19	4.5	0.33	24	4.9	0.29

[a] The control group includes unmarked geese and birds that were leg-banded in previous studies.

[b] Julian date of nest initiation. Least-squares means are adjusted for annual variation.

[c] Egg volume (cm^3) averaged across eggs for nests that had completed clutches.

[d] Number of eggs in nests that reached incubation. Least-squares means are adjusted for variation due to nest initiation date.

propensity of radiomarked females was 61% (95% CI: 48–82%) and 72% (95% CI: 62–88%) in 2001 and 2002, respectively.

Survival

No geese died during handling or surgery or in the 2-week postimplant interval for which Mulcahy and Esler (1999) recommended censoring mortalities as possibly surgically related. One female died 18 days after surgery and was eliminated from the survival analysis because the antenna was not properly sutured and the transmitter rotated in the body cavity. A second female died approximately 5 months after surgery when adhesions near the transmitter caused an obstruction of the small intestine. Mortality that could be directly attributed to implantation of transmitters was 1%.

Only 5 females (2 control, 3 with small transmitters) lost plastic tarsus bands among 276 encounters of marked birds during molt recaptures up to 3 years after marking. We did not adjust survival rates for band loss because loss was minor, occurred for both radiomarked and control females, and because 4 of 5 missing bands were replaced when they were encountered. Only 1 antenna of the 94 radios examined at molt capture in the first year after deployment was broken. There were 2 broken antennas among the 55 radios examined 2 years after deployment.

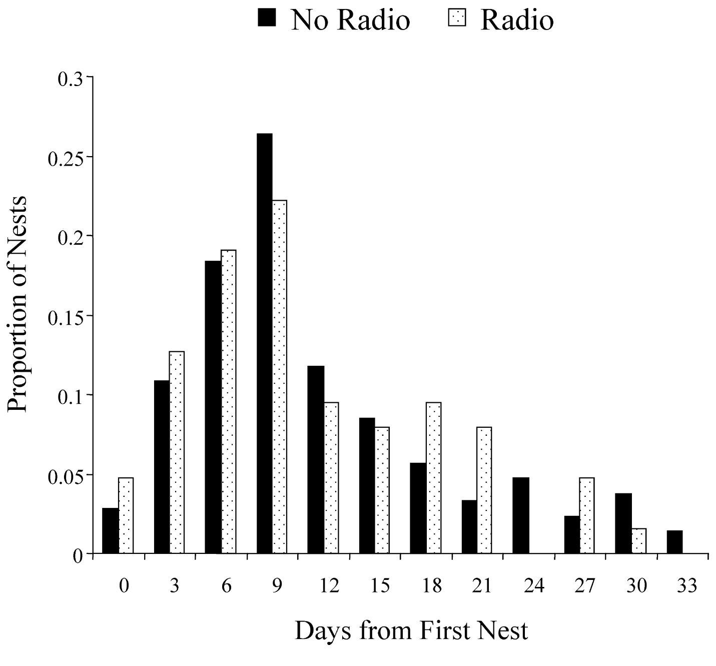

Figure 2. Nest initiation chronology of female Canada geese with and without radiotransmitters in Anchorage, Alas., USA, 2001–2002. We combined data across years and scaled it to the earliest observed nest in each year. The proportion of nests that were initiated for each treatment group in a 3-day interval are presented for 152 nests of females without radiotransmitters and 62 nests of females with implanted radios.

Resighting probabilities were high and often equaled 1.0 (Table 5). In the preliminary analysis of resighting parameters, the best-supported model ($AIC_c = 1{,}038.4$, $w_i = 0.99$) had separate parameter estimates for each combination of groups and periods in which all birds present were sighted ($p = 1.0$) versus those where p was <1.0. Other models were not supported ($w_i < 0.01$) indicating that resighting probability was not related to treatment, whether a bird had a functional radio, or year. For each of the candidate models used to examine survival, we constrained p to 3 parameters: 1) groups and periods when $p = 1.0$, 2) groups and periods when p was <1.0, or 3) the terminal period when ϕ and p could not be separately estimated.

To correct for overdispersion in the data (White 2002), we used a variance inflation factor of 1.58 based on the median $\hat{c}$ analysis of a model in which groups and time were fully crossed for estimation of ϕ, and p was estimated via the above standard constraints used for all models. In our comparison of candidate survival models, 4 models ranked highly (Table 6) with the 2 best

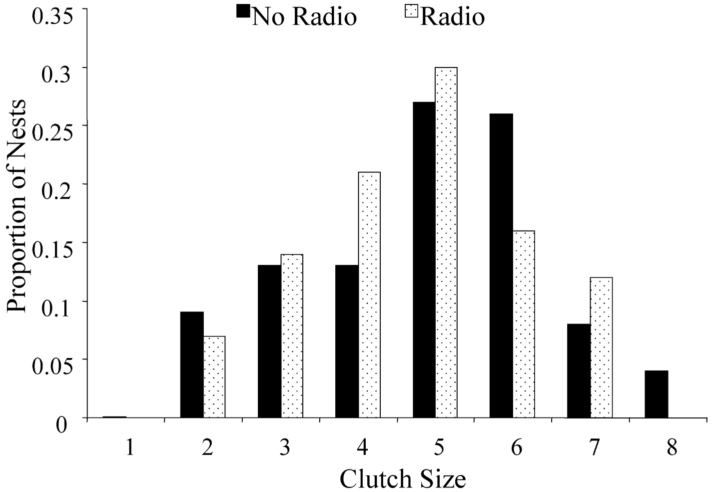

Figure 3. Clutch size distribution for female Canada geese with and without radiotransmitters in Anchorage, Alas., USA, 2001–2002. We based clutch size only on nests that survived to incubation. We combined data across years, and the proportion of nests observed with each clutch size is expressed for 103 nests of females without radios and 43 nests of females with implanted radios.

Table 5. Return rates and resighting probabilities (*p*) for marked female Canada geese in Anchorage, Alas., USA, 2001–2004. Return rate is the proportion of birds in a cohort and treatment that were alive in year *i* and resighted in year $i + 1$. Resighting probability is the likelihood that a goose that was alive in year *i* was also seen in Anchorage that year. Resighting probabilities could not be estimated in the final year of the study (2004).

		Treatment											
		Control				**Small transmitter**				**Large transmitter**			
Estimate	**Year marked**	**2001**	**2002**	**2003**	**2004**	**2001**	**2002**	**2003**	**2004**	**2001**	**2002**	**2003**	**2004**
Return rate	2000	0.78	0.74	0.75	0.67	0.88	0.58	0.62	0.63	0.78	0.66	0.56	0.57
	2001		0.78	0.59	0.67		0.82	0.75	0.65		0.82	0.57	0.56
p	2000	1.0	0.97	1.0		0.97	0.84	0.92		1.0	1.0	1.0	
	2001		1.0	0.94			1.0	0.95			0.96	0.93	

models nearly equally supported. Each of the top models indicated that in the first year after marking, survival of radiomarked females was similar to or slightly higher than survival of control females, and that survival increased with body mass (Fig. 4). None of the top models included an interaction between treatment and body mass. In 3 of the 4 top models, survival of marked females in all treatments diminished in the second and third year after marking. However, there was disagreement among the models regarding differences in survival between radiomarked and control females during those years. In the most parsimonious model, second- and third-year survival of control females and geese with small radios were similar and averaged 14% higher than survival of females with large radios (Fig. 4). However, in the nearly equally weighted model, there were no treatment differences in second- and third-year survival (Fig. 4). The other 2 models that received support also indicated that second- and third-year survival of radiomarked females was lower than for control geese (Fig. 4). Overall, second- and third-year survival of females in either 1 or both transmitter treatments was lower than that of control females in 8 of the top 10 models (Table 6).

Model-averaged estimates for each treatment in each time period supported similar survival rates between radiomarked and control females in the first year after marking, and lower survival of females in all treatments in subsequent years (Fig. 5). Across cohorts, model-averaged estimates of second- and third-year survival of females with small or large radiotransmitters were 4% and 10% lower, respectively, than survival of control females. However, the magnitude of differences among treatments was not greater than the uncertainty surrounding second- and third-year estimates of survival (Fig. 5). In 2003, return rates of control females from the 2001 cohort were 21% lower than for control females from the 2000 cohort (Table 5). That likely contributed to the lower second- and third-year survival estimates for the control group and increased variance surrounding long-term survival estimates for that treatment. We did not consider that specific cohort and year effect for control females in our candidate models. In the abbreviated 2004 resighting period, return rates of control

Table 6. Model selection for effects of treatment, years since initial capture, and body mass on apparent annual survival (ϕ) of adult female Canada geese in Anchorage, Alas., USA, 2000–2004. Each model used the same set of 3 constrained resighting parameters: 1) groups and years when $p = 1.0$, 2) groups and years when *p* was <1.0, and 3) the final year of study (2004) when *p* could not be separately estimated from ϕ. Models were ranked using Akaike's Information Criterion corrected for overdispersion and small sample size ($QAIC_c$). Only the top 15 of 32 candidate models and the null model are presented.

Model	**$QAIC_c$**	**$\Delta QAIC_c$**	**w_i[a]**	**K[b]**	**Deviance**
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, S_{3rd}, C_{2nd}, C_{3rd}) + (L_{2nd}, L_{3rd}) + M\}$[c]	647.5	0.00	0.19	7	633.4
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, L_{2nd}, S_{3rd}, L_{3rd}, C_{2nd}, C_{3rd}) + M\}$	647.5	0.03	0.19	6	635.4
$\{(S_{1st}, L_{1st}) + (S_{2nd}, S_{3rd}, L_{2nd}, L_{3rd}) + C + M\}$	648.4	0.92	0.12	7	634.3
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, L_{2nd}, S_{3rd}, L_{3rd}) + (C_{2nd}, C_{3rd}) + M\}$	648.7	1.23	0.10	7	634.6
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, S_{3rd}, C_{2nd}, C_{3rd}) + (L_{2nd}, L_{3rd})\}$	650.1	2.62	0.05	6	638.0
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, S_{3rd}, L_{2nd}, L_{3rd}, C_{2nd}, C_{3rd})\}$	650.1	2.63	0.05	5	640.0
$\{(S_{1st}, L_{1st}) + C_{1st} + (S_{2nd}, S_{3rd}, C_{2nd}, C_{3rd}) + (L_{2nd}, L_{3rd}) + M\}$	650.4	2.90	0.23	8	632.2
$\{(S_{1st}, L_{1st}) + (S_{2nd}, S_{3rd}, L_{2nd}, L_{3rd}) + C\}$	650.9	3.44	0.03	6	638.8
$\{(S_{1st}, L_{1st}) + C_{1st} + (S_{2nd}, S_{3rd}, C_{2nd}, C_{3rd}) + (L_{2nd}, L_{3rd})\}$	651.1	3.57	0.03	7	636.9
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, S_{3rd}, L_{2nd}, L_{3rd}) + (C_{2nd}, C_{3rd})\}$	651.3	3.76	0.03	6	639.2
$\{[(S_{1st}, L_{1st}, C_{1st}) \times M] + [(S_{2nd}, S_{3rd}, C_{2nd}, C_{3rd}) \times M] + [(L_{2nd}, L_{3rd}) \times M]\}$	651.3	3.82	0.03	9	633.1
$\{(S_{1st}, L_{1st}, C_{1st}) + (S_{2nd}, L_{2nd}, C_{2nd}) + (S_{3rd}, L_{3rd}, C_{3rd})\}$	652.1	4.59	0.02	6	640.0
$\{(S_{1st}, L_{1st}, C) + (L_{2nd}, L_{3rd}, S_{2nd}, S_{3rd})\}$	652.4	4.88	0.02	5	642.3
$\{[(S_{1st}, L_{1st}) \times M] + [(S_{2nd}, S_{3rd}, L_{2nd}, L_{3rd}) \times M] + [C \times M]\}$	652.4	4.90	0.02	9	634.2
$\{(S_{1st}, L_{1st}) + (S_{2nd}, L_{2nd}) + (S_{3rd}, L_{3rd}) + C\}$	652.5	5.04	0.02	7	638.4
$\{\cdot\}$[d]	658.1	10.6	0.001	4	650.1

[a] Akaike weight.

[b] Number of estimated parameters in model.

[c] Treatment effects are represented as S, L, and C for small transmitter, large transmitter, and control groups, respectively. Subscript indicates an effect for first, second, or third year after marking. A treatment effect that lacks a subscript indicates that survival was similar across years. Effects constrained within parentheses had similar survival and were modeled as a single parameter. An additive effect of body mass (M) is indicated when mass is added to the model. An interaction with body mass is indicated when terms in parentheses are crossed with mass.

[d] Null model for constant survival across all groups and time periods.

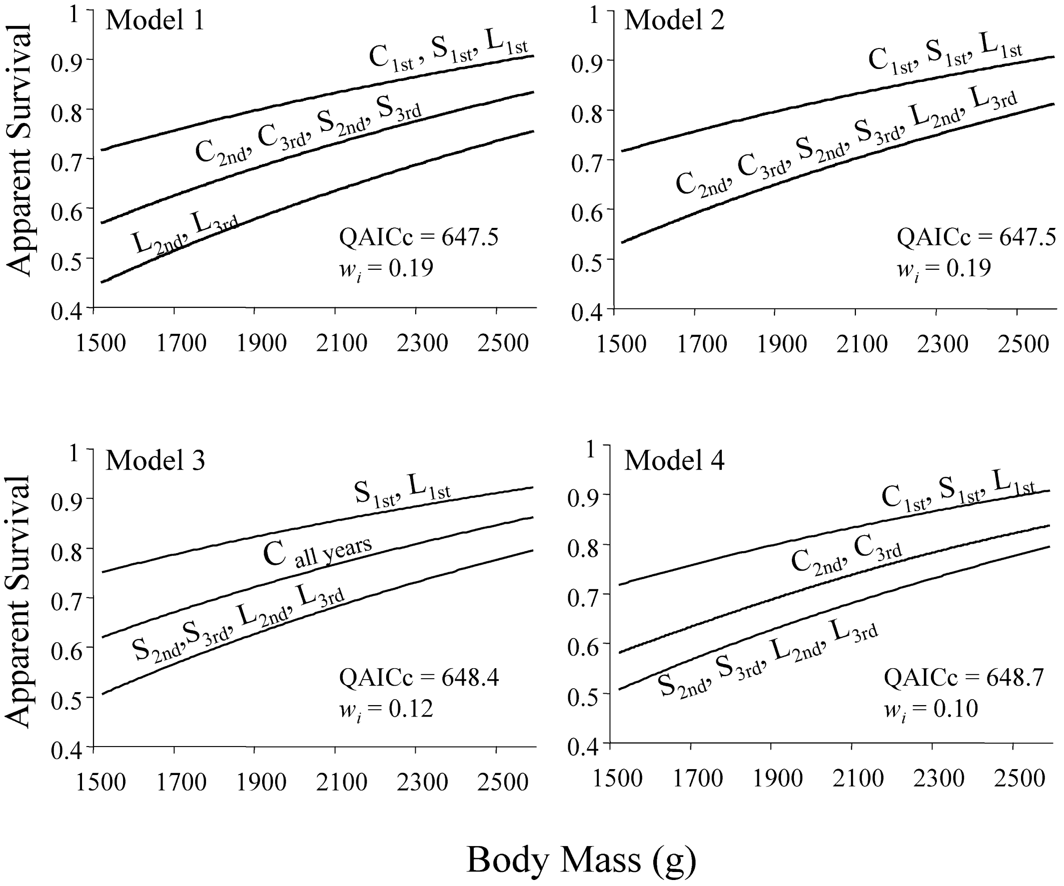

Figure 4. Probability of adult female Canada geese in Anchorage, Alas., USA, surviving from year *i* to year $i+1$ in relation to body mass, treatment, and number of years since initial capture, as modeled by the 4 most parsimonious of 32 candidate models. Apparent survival estimates were based on 316 geese marked in 2000 or 2001, and resighted 2001–2004. Females in control, small transmitter, and large transmitter treatments are indicated as C, S, and L, respectively. Year after initial capture is indicated as a subscript. For each model, survival was similar among combinations of treatments and time periods represented by a single line. Support of individual models is indicated by the Akaike's Information Criterion corrected for overdispersion and small sample size (QAICc), and the Akaike weight (w_i).

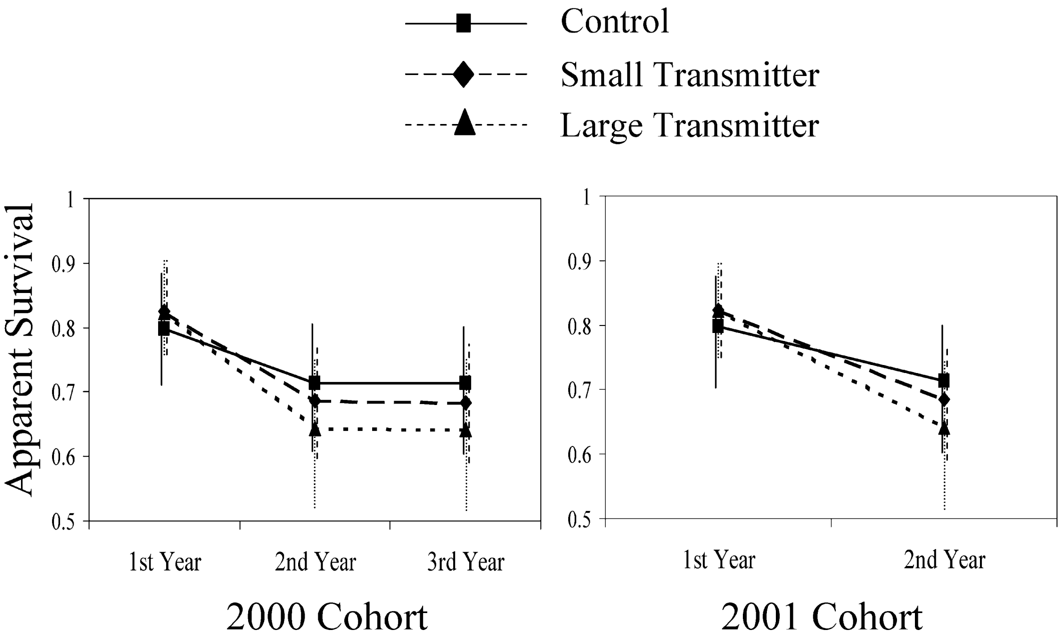

Figure 5. Model-averaged estimates of survival likelihoods for Canada geese in each treatment and cohort at different periods after marking. Parameter estimates were averaged across 32 candidate models that examined treatment, cohort, and year effects. Vertical lines are 95% confidence intervals on the estimates.

females were similar between the 2 cohorts. Averaged across cohorts in 2004, females with small or large radiotransmitters had return rates that were 5% and 16% lower, respectively, than control females (Table 5).

Discussion

Testing Transmitter Effects in Urban Geese

We studied transmitter effects in free-ranging geese and believe our results are more applicable to other populations than are data collected on captive individuals. Use of urban geese enabled us to contrast transmitter effects against a control group that lacked radios. Such comparisons are usually not possible in natural environments. Although our results are biased if the urban environment diminished differences among treatments, we do not believe that likely. Marked geese were subject to predation by local bald eagles (*Haliaeetus leucocephalus*) and harassment from domestic dogs. Hupp et al. (2003) observed few instances when humans fed geese. Anchorage geese spent winter months in western Oregon in the same agricultural habitats used by other populations of Canada geese (Jarvis and Cornley 1988). The distance Anchorage geese migrated between nesting and wintering areas (2,500 km) was comparable to that of other populations of geese that nest in southcentral or western Alaska, though shorter than migrations made by some arctic geese. Our study population was hunted both near Anchorage and on their wintering area. Apparent survival of control and radiomarked females in their first year after initial capture was similar to the 0.75–0.88 annual survival rates typically reported for adult female geese (e.g., Francis et al. 1992, Schmutz and Ely 1999, Madsen et al. 2002, Menu et al. 2002).

Antenna Breakage

A small number of the external antennas were broken off during our study. Mulcahy et al. (1999) found 41% of antennas on radiomarked harlequin ducks were broken within 1–2 years after initial capture. However, much of that loss was from transmitters that had a different design from those we used. We did not observe the extrusion of transmitters reported by Mulcahy et al. (1999). Our transmitter design differed from that study because we surrounded the transmitter with a mesh bag that was sutured to the body wall. That may have more firmly anchored the transmitter until scar tissue completely encased the radio. Demers et al. (2003) suggested that implanted transmitters with percutaneous antennas might not be suitable for use in geese because birds could pull on antennas and cause internal injuries. However, Hupp et al. (2003) saw little evidence that Canada geese pulled the external antennas of implanted transmitters, and the small number of broken antennas in our study suggests that was not a problem.

Effects of Radiotransmitters on Migration Chronology

Dates of first sighting in spring were usually indicative of arrival date. In both years, we visually sighted most radiomarked females within 1 day of detection of their radio signal. During the arrival period, sighting frequencies of radiomarked and control females were similar. Thus, we think the likelihood of detection upon arrival was similar for control geese and birds with radios.

Whereas arrival dates were similar among treatments in 2001, arrival of females with large radios in 2002 lagged behind that of control females. Arrival of females with small radios was also delayed slightly in 2002. The difference between years may have been because of weather during migration. We examined wind direction and velocity in the Gulf of Alaska at the 850 millibar level during a 10-day period surrounding first arrival of geese in Anchorage (National Oceanic and Atmospheric Administration, unpublished data). In 2001, there were 6 days with strong (10–14 m/second) south winds, 2 days when winds were from the north, and 2 days with west or east winds. In contrast, in 2002 geese encountered northeast or northwest winds on 7 days during migration and had only 1 day of mild (<2 m/second) south winds.

Wind direction can affect migration chronology of arctic geese and impose higher flight costs (Ebbinge 1989). Radiomarked birds may have been less capable of meeting greater energetic demands imposed by less favorable winds if respiratory function was impaired because of the presence of the radiotransmitter in the abdominal air sac. Although we have observed that the abdominal air sac often reforms in the year after surgery (D. M. Mulcahy, U.S. Geological Survey, Anchorage, Alas., USA, unpublished data), the radiotransmitter and surrounding scar tissue could impede airflow. Large transmitters provided more surface area than small transmitters for formation of scar tissue that could block the abdominal air sac. We doubt that later arrival of females with large transmitters was caused by greater mass of those radios or by aerodynamic drag on antennas. The difference in mass (10 g) between transmitter treatments was small (<1%) relative to average female body mass. Likewise, if the effect were because of drag on antennas, we would have expected arrival dates for females with different sized transmitters to be the same because antenna exposure was similar.

Although females with large radios arrived later in 2002, the effect was small because they lagged only 1–2 days behind control females, and similar proportions of geese from each treatment were present by the 10th day. However, the effect could be greater for species that migrate longer distances or that have less favorable wing loading and higher energetic demands during flight than Canada geese.

Effects of Radiotransmitters on Reproduction

We could not compute nesting propensity for control females and therefore do not know if radiotransmitters diminished the likelihood of nesting. However, our estimates of nesting propensity for females with working radios (61–72%) were lower than the 82–88% nesting propensity for adult ($\geq$3 years of age) Canada geese reported by Cooper (1978) and MacInnes and Dunn (1988). Our estimate may be low because some females that were radiomarked during molt were likely yearlings that would have been 2 years of age when monitored during nesting. Nesting propensity for 2-year-old Canada geese is lower than for older birds (MacInnes and Dunn 1988, Moser and Rusch 1989). The lower estimate for 2001 may have resulted because Anchorage received 10 cm of snow near the peak of nest initiation. We believe that any effect of radiotransmitters on nesting propensity was relatively small and that most radiomarked birds attempted to nest.

We saw little evidence that implanted radios affected other measures of reproductive effort. Nest initiation dates, clutch size, and egg volume were similar among treatments. Initiation dates included first nests and probable renests because we could not separate the two. We did observe that a slightly lower proportion of radiomarked females produced 6-egg clutches, and a higher proportion laid 4-egg clutches than did females without radios. However, mean clutch size was similar among treatments, and the number of eggs females laid in the first year after they were radiomarked was equal to the number laid prior to implantation of radios. Radios may have affected egg production by some females, however the overall effect was small. Our findings of minimal effects on reproduction of implanted radiotransmitters with external antennas are comparable to studies by Rotella et al. (1993), Pietz et al. (1993), and Paquette et al. (1997) that used implanted radios with internal antennas. However, Meyers et al. (1998) suggested that satellite radios with external antennas impaired nesting in common murres (*Uria aalge*) and thick-billed murres (*Uria lomvia*). We concur with Pietz et al. (1993) that transmitter effects on reproduction may become more apparent in marginal habitats or when birds are in poor condition.

Effects of Radiotransmitters on Survival

Although Mulcahy and Esler (1999) observed that 3% of 204 radio-implanted harlequin ducks died during surgery or within 2 weeks of release, we had no surgical or immediate postrelease mortalities of Canada geese. We observed a small number of mortalities that could be attributed to implantation of transmitters beyond the 2-week interval that Mulcahy and Esler (1999) recommended for censoring birds that die soon after radio deployment. Implantation of radios is relatively safe for geese when conducted by trained veterinarians and procedures recommended by Mulcahy and Esler (1999) are used. Although we used an urban surgical facility, implantation of radiotransmitters in geese in field settings has also resulted in low rates ($\leq$1%) of immediate postrelease mortality (D. M. Mulcahy and J. W. Hupp, U.S. Geological Survey, Anchorage, Alas., USA, unpublished data). However, high mortality rates have been observed shortly after implantation of satellite transmitters in murres (Hatch et al. 2000), indicating some avian taxa are adversely affected by implanted radios.

Survival of radiomarked females was comparable to that of control females in the first year after marking. This is the period of interest to most biologists because it is the interval when avian radios are usually functional. Our finding of no first-year effect of radiotransmitters on survival is similar to that of Esler et al. (2000), who also found that implanted transmitters with percutaneous antennas did not affect survival of harlequin ducks. We contrast these results with studies that have found deleterious effects of externally attached radiotransmitters on avian survival (Marks and Marks 1987, Dzus and Clark 1996, Bro et al. 1999, Schmutz and Morse 2000). Implanting radiotransmitters with percutaneous antennas eliminates external attachments and exposure of the radio package that may lower survival because of increased energetic cost of flight (Gessaman and Nagy 1988, Obrecht et al. 1988) or altered behavior (Greenwood and Sargeant 1973, Wooley and Owen 1978, Perry 1981, Pietz et al. 1993).

Whereas we did not detect an effect of transmitters on survival in the first year after marking, long-term effects of radios were equivocal. We observed slightly lower survival or return rates, especially among females with large radios, from 2–4 years after marking, and we believe there may have been a subtle chronic effect of radiotransmitters on survival. However, we emphasize that the magnitude of any difference was not greater than the uncertainty surrounding estimates of second- and third-year survival. Although we cannot conclude a transmitter effect existed, we believe biologists should be aware of a potential long-term consequence of radio implantation. At least 2 mechanisms could have caused lower long-term survival among radiomarked birds. One is that geese may have experienced chronic low-grade infections if bacteria entered along the antenna and reached the peritoneal cavity. Second, we observed that the synthetic rubber coating had deteriorated on some transmitters that we recovered $>$1 year after marking. Long-term erosion of the coating could affect survival after the first year if compounds that were harmful to the bird were released. We do not know the toxicity of compounds released during breakdown of the coating or if they were transported beyond tissue surrounding the radiotransmitter. The greater effect of large transmitters is consistent with this hypothesis because they had a larger surface area and more coating. However, until further studies are completed, biologists should use implanted radiotransmitters with caution if long-term survival of marked individuals is a concern.

Management Implications

Biologists must assess whether the method of radiotransmitter attachment they use will affect the data they collect. Although their use requires services of a veterinarian and additional logistical arrangements for field surgeries, abdominally implanted radiotransmitters can provide unbiased measures of anserine reproductive effort and survival in the first year after capture. Larger transmitters may have subtle effects on migration chronology and long-term survival. The size of implanted radiotransmitters should be minimized to reduce potential adverse effects. Further evaluation of the effects of abdominally implanted radiotransmitters on flight performance of birds is needed. We encourage biologists to conduct pilot studies to assess effects of implanted transmitters before deploying radios in species where they have not previously been used.

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