Articles

Canada Goose Gosling Mortality During Prefledging and Early Migration on Akimiski Island, Nunavut

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Abstract

Mortality rates for precocial avian species are highest during their first year of life. For harvested species, including waterfowl, it is particularly difficult to determine causes of mortality using standard mark–recapture techniques. The timing and cause of nonhunting mortality is difficult for researchers to distinguish, and therefore, difficult to incorporate into management decisions. We marked flightless Canada goose Branta canadensis interior goslings with radio transmitters to determine the timing of mortality prior to harvest during the fall migration. We tracked survival of 206 goslings for 2 mo from an average of 50 d of age to just prior to the fall migration departure from the breeding grounds in 1999 and 2000. The most parsimonious model from a set of candidate models describing probability of survival showed clear differences between years and suggested that survival was affected by gosling size (largest survived better) and hatch timing disparity. We indexed hatch timing disparity by measuring the difference between gosling hatch date and the date of the estimated peak in forage quality as determined by the normalized difference vegetation index. The latest hatched goslings presumably had the lowest quality forage available to them. Both size and hatch timing disparity concur with a mortality cause that is most likely from complications due to malnutrition. The estimated survival probability of goslings to 51 d post marking was 0.31 (95% confidence limit = 0.22 to 0.44) in 1999 and 0.69 (95% confidence limit = 0.57 to 0.83) in 2000. Managers can make better informed decisions concerning the utility of harvest regulation in the conservation of juvenile Canada geese by better understanding the timing, causes, and annual variation of their mortality.

Keywords: Canada goose; gosling; survival; Cox proportional hazard; hatch timing disparity; size; body condition

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Introduction

Survival of juveniles and eventual recruitment into the breeding population are necessary components for maintaining wild bird populations. Factors affecting the survival of young may limit the growth rate for populations, though their importance compared to factors limiting other vital rates (e.g., adult survival) may be moderated depending on the species’ breeding system, fecundity, and life history (Newton 1998). However, understanding the magnitude, timing, and factors contributing to juvenile mortality may be important for the conservation and management of bird populations, particularly in assessing the sustainability of harvest for harvested populations.

Wildlife managers generally accept that juvenile (those in their first year of life) geese Anserinae exhibit lower survival probabilities than adults. Researchers have demonstrated this for lesser snow geese Anser caerulescens (Calvert et al. 2017), brant Branta bernicla (Sedinger and Chelgren 2007; Hines and Brook 2008), greater white-fronted geese Anser albifrons (Timm and Dau 1979), Ross’s geese Anser rossii (Alisauskas et al. 2006), and Canada geese Branta canadensis (Sheaffer and Malecki 1998). Predileged goslings have higher mortality risk than adults because they are more susceptible to predators (e.g., MacInnes et al. 1974). Their smaller size and inability to escape predation using flight make it easier for predators to capture them. Juveniles are also more susceptible to adverse weather (see Wobeser 1981). With underdeveloped feathers and down, they may die of exposure in wet and cold conditions. They also have higher susceptibility to disease and parasites (Wobeser 1981; Johnson et al. 1992) due to incomplete immune system development, and they are more likely to die of complications due to malnutrition than adults (e.g., Ankney 1980). Their greater reliance on high-quality and abundant food during the rapid growth they undergo prior to fledging may also contribute to their vulnerability to mortality factors. For harvested populations, fledged juvenile geese are thought to be more vulnerable to being harvested than adults (Samuel et al. 1990; Francis et al. 1992) because of a greater need for food than adults (e.g., Harvey et al. 1995; for ducks: Dufour et al. 1993; Caswell and Caswell 2004) and they are likely less cautious (e.g., Menu et al. 2002; Hines and Brook 2008; but see Hill et al. 2003).

Researchers usually estimate annual survival and harvest rates of geese from mark–recapture studies with recapture in years after banding or from the reporting of recovered tagged individuals by hunters. Goslings are generally marked at about 5 to 8 wk posthatch, before they are flighted: adults are also flightless at this time while undergoing the annual postbreeding wing molt (see Leafloor et al. 2000). Therefore, it is impossible to discern the timing and causes of mortality from most mark–recapture studies of marked goose populations. Researchers usually estimate survival for an annual cycle from initial marking to the recapture of marked individuals. Unless hunters harvest and report geese, the mortality cause is also generally not known.

For the Canada geese B. c. interior breeding on Akimiski Island, Nunavut, a demographic conundrum exists where the harvest probability of juveniles was estimated by researchers to be extremely low and often lower than for adults (i.e., recovery probability of goslings, maximum = 0.0121 vs. adult average = 0.198: Hill et al. 2003). Hill et al. (2003) estimated that gosling harvest probability was highest when survival was also highest and showed that goslings that were in the best condition and had the largest structural size for their age at the time of capture/banding were most likely to be harvested; a counterintuitive result. Harvest studies have concluded that for ducks, it is usually those juveniles and adults that are in relatively poor condition that are most susceptible to harvest (Hepp et al. 1986; Dufour et al. 1993). Hill et al. (2003) speculated that in years of low gosling survival (as estimated by mark–recapture–return analysis) most goslings did not survive long enough to migrate to areas where hunters could harvest them on their southward migration. This was consistent with the speculation by Leafloor et al. (1996) that malnutrition was the likely mechanism causing excessive gosling mortality prior to or just after fledging on Akimiski Island. However, both Hill et al. (2003) and Leafloor et al. (1996) used indirect evidence to conclude that mortality resulting from malnutrition was the cause of the puzzling vital rates observed for Akimiski Island Canada geese. Though the evidence for these speculations about malnutrition was compelling, the researchers could not use it to quantify the timing or cause of gosling mortality. Understanding the mechanisms affecting the survival and recruitment of juvenile geese for this island population may be key in understanding its alarming decline in abundance from 75,600 breeding birds in 1985 (Leafloor et al. 1996) to 17,677 in 2010 (Brook et al. 2015). Our objective was to directly examine the timing and potential drivers of mortality for Canada goose goslings from Akimiski Island, Nunavut, in the postbanding to prefledging period in 1999 and 2000.

Study site

Goslings were captured along the north shore of Akimiski Island (centroid 53°0’47”N, 81°19’16”W) in western James Bay in 1999 and 2000. The gosling brood rearing habitats along the coast consist of intertidal marsh dominated by salt-tolerant grass Puccinellia phryganodes and the sedge Carex subspathacea and supratidal and freshwater meadow marshes dominated by grasses Festuca rubra and sedges Carex aquatilis and Juncus balticus that are favored by foraging goslings. The study area is well described, and more detail can be found in Blaney and Kotanen (1999), Leafloor et al. (2000), Hill et al. (2003), and Kotanen and Abraham (2013).

Methods

Field methods

To determine gosling age at radio marking (at 5 to 8 wk of age), we tagged goslings from pipped eggs and...
those that had just hatched (< 1 d) with individually numbered size 1 Monel web tags to identify date of hatch. Details of nest searching and osprey tagging are described in Leafloor et al. (2000) and Brook et al. (2015). We captured groups of flightless geese after peak hatch, when goslings were 41–61 d old, in coastal habitats using a helicopter drive technique (Leafloor and Rusch 1997). We attempted to catch whole flocks of adult geese with their goslings whenever possible and tried to avoid flocks that were too large to be safely maintained in the nets or that appeared to have few or no goslings. We sexed goslings using cloacal examination (Hanson 1962) and fitted them with standard aluminum leg bands and an individually coded plastic tarsus band. We weighed goslings that had been web-tagged in the nest with a spring scale to the nearest ± 1 g, and measured skull length, culmen1, tarsus (± 0.1 mm), and the ninth primary length (± 1 mm) following Dzubin and Coop (1992). We fitted no more than one male and one female from any nest with a transmitter. Radio transmitter (13 g; Advanced Telemetry Systems, Isanti, MN) expected battery life was 180 d and transmitters were a maximum of 1.5% of gosling mass (average percentage of mass: male, 0.7%; female, 0.8%) at the time of marking; less than the 3% guideline recommendation (Kenward 2001). Transmitters were equipped with a mercury mortality switch that activated an increased (× 2) pulse rate after the radio had been motionless for at least 4 h. We used anesthetic technique to attach transmitters to the back of goslings about 5 cm below the base of the neck with a stainless steel anchor and three 3-0-monofilament sutures (Mauser and Jarvis 1991). Before we attached transmitters, we removed feathers and sterilized the skin with 2% chlorhexidine gluconate (Germiphene Corp., Brantford, ON). The Ontario Ministry of Natural Resources animal care committee approved the transmitter attachment method (protocol 99-54).

To monitor survival, we conducted aerial surveys using a Bell Jet Ranger helicopter or a Cessna 180 equipped with a Lotek SRX400 telemetry receiver and H antennae at an altitude of 500 m and at speeds of 80–120 km/h. Altitude and airspeed varied depending on weather conditions and the number of radio-marked goslings in an area. We retrieved transmitters emitting a mortality signal within 24 h of receiving the signal. We conducted flights along the north and south shores of Akimiski Island (Canada goose brood rearing areas) to locate prefledged goslings and the adjacent mainland coast of Ontario to locate birds that had migrated from the island (Patton 2001). In 1999, we conducted aerial surveys at intervals of 1–6 d from July 20 to August 30, and then once a week until October 12. In 2000, we conducted surveys at 1–5-d intervals from July 25 until September 27, with a final survey flight on October 5. Survey timing was irregular within and between years due to weather and aircraft availability issues.

Gosling size and condition
To reduce the number of gosling size-related variables, we conducted a principal component analysis on the morphometric measurements including measurements of the head, culmen, and tarsus length (Hotelling 1933). We used the first principal component of the correlation matrix as an index of structural size for individuals for each gender (the first principal component explained 84.7 and 75.5% of the total variance for males and females, respectively). We estimated a gosling size covariate by regressing the size variable on the gosling age at banding and used the resulting residuals as the age-controlled size covariate (male: $P < 0.0001$, $R^2 = 0.42$; female: $P < 0.0001$, $R^2 = 0.39$).

We estimated a body condition index for each gosling by scaling mass to the index of size. We estimated the scaled mass index (SMI) by first calculating the slope of the relationship between mass and the size index on the log–log scale using a standard major axis (SMA beta) regression (Peig and Green 2009; Marmillot et al. 2016). We estimated SMI, for each individual (i) using a power relationship of $Mass^S \times (size_{mean} / size_i)^{b_{SMA}}$ which scales predicted mass to the mean of size where $b_{SMA}$ is the scaling exponent estimated by the SMA regression (Peig and Green 2009, 2010). Because goslings were rapidly growing during the period of capture, we further modeled the SMI using a general linear regression to control for the age at banding and the length of the ninth primary. We used the resulting residuals (SMIr) as a size- and age-controlled index of mass.

Hatch timing relative to the peak in forage quality
We estimated an index of the timing of individual gosling hatch relative to an index of spring phenology. We estimated spring phenology timing from the date of the 50% normalized difference vegetation index (NDVI50) for each year (see Brook et al. 2015 for details), which was subtracted from gosling date of hatch. The NDVI50 is calculated from remotely sensed visible and near-infrared light reflected by vegetation (Tucker 1979) and is related to the date of peak nitrogen concentration in plants. It can provide a reliable measure of annual variation in the timing of the availability of high-quality forage for geese (Ryan et al. 2012; Doiron et al. 2013). This hatch timing disparity (HTD) covariate (often referred to as hatch timing mismatch; e.g., Doiron et al. 2013; Brook et al. 2015) provided an index of the difference between gosling hatch date relative to a date indexing the peak in forage species growth and development (i.e., quality).

Food per capita
We estimated an index of food per capita to simultaneously index the food available to goslings and the competition for that food. We measured above-ground biomass at five sites along the north shore of Akimiski Island on July 27, 1999, and August 6, 2000, choosing the sample date at the end of the gosling
capture period. Each site contained six separate sampling locations. Three were located on monotypic swards of *P. phryganodes* in the lower intertidal zone and three on monotypic *F. rubra* in the upper intertidal/supratidal zone. We selected these species because they are the most widespread and abundant of the preferred forage species present in those zones favored by broods (Gadallah and Jefferies 1995; Kotanen and Abraham 2013). Each sample consisted of the aboveground biomass in a 100-cm$^2$ area (Hik and Jefferies 1990) and reflected what was available to goslings during their critical growth period. We calculated the biomass index from the average of the three aboveground biomass measures (g/m$^2$) of each species from grazed swards, then added the two species-type averages together for each site and averaged over all sites for each year. To estimate per capita biomass (see Brook et al. 2015), we divided the above index by a population index estimated annually from an aerial survey of breeding Canada geese on Akimiski Island (number of Canada goose pairs; Leafloor et al. 1996, 2004). We estimated standard errors using the delta method.

**Gosling survival models**

We modeled gosling survival using Cox regression models (proportional hazard; Cox 1972) using PROC PHREG (Allison 2010). We established an a priori set of candidate models (Table 1) using the covariates explained above and included age at banding, year hatched, and gosling sex. We tested for correlation among individual covariates using Pearson correlation to ensure highly correlated variables were not included in the same model. We tested the proportionality assumption of the regression model by assessing if covariates interacted with time (i.e., if covariates were not proportional) using the ASSESS function in PHREG (Allison 2010).

We used Akaike’s information criterion (AIC$_C$) to select among candidate models and made inference from models where ΔAIC was < 2.0 (Burnham and Anderson 2002) and covariate estimates were informative (Arnold 2010). Tests for year- and sex-related differences for each covariate were done using generalized linear models. We considered beta coefficients significant when 95% confidence limits (CLs) did not include 0 or when testing differences did not overlap.

**Results**

We radio-marked 106 goslings in 1999 and 100 in 2000 (Table 2; Data S1, *Supplemental Material*). Table 3 provides a summary of measurements of goslings for each sex. The NDVI$_{50}$ date was May 13 in 1999 and May 28 in 2000 for Akimiski Island with goslings hatching after this index of peak forage quality each year; the largest HTD was in 1999 (Table 4). Tests of sex-related differences for each of the model covariates were not significant alone and when including year as a factor.

**Table 1.** A list of candidate models used to evaluate gosling survival for Canada geese *Branta canadensis* marked with radio transmitters on Akimiski Island, Nunavut, in 1999 and 2000. We made survival estimates for the period from an average of 51 d after hatch to a maximum 71 d post–radio-transmitter marking. Age-corrected size is a size covariate corrected for the gosling’s age in days at capture for radio-transmitter marking. Hatch timing disparity (HTD) is the difference in days between hatching hatch date and an estimate of peak nutritional value of goose food as indexed by the remotely sensed 50% normalized difference vegetation index. We measured food per capita by an estimate of grazed biomass divided by an estimate of the number of Canada goose breeding pairs from a survey each year.

<table>
<thead>
<tr>
<th>Model</th>
<th>ΔAIC</th>
<th>wi</th>
<th>cumwi</th>
<th>AIC</th>
<th>neg2LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>size + HTD</td>
<td>0.00000</td>
<td>0.4093</td>
<td>0.40926</td>
<td>817.613</td>
<td>813.613</td>
</tr>
<tr>
<td>size + food/capita</td>
<td>1.61488</td>
<td>0.1825</td>
<td>0.59180</td>
<td>819.228</td>
<td>815.228</td>
</tr>
<tr>
<td>size + SMIr + HTD</td>
<td>1.92149</td>
<td>0.1566</td>
<td>0.74838</td>
<td>819.535</td>
<td>813.535</td>
</tr>
<tr>
<td>HTD</td>
<td>3.63715</td>
<td>0.0664</td>
<td>0.81479</td>
<td>821.250</td>
<td>819.250</td>
</tr>
<tr>
<td>size + SMIr + size × SMIr</td>
<td>4.61214</td>
<td>0.0408</td>
<td>0.85557</td>
<td>822.225</td>
<td>816.225</td>
</tr>
<tr>
<td>SMIr</td>
<td>4.91013</td>
<td>0.0351</td>
<td>0.89071</td>
<td>822.523</td>
<td>818.523</td>
</tr>
<tr>
<td>SMIr + HTD</td>
<td>5.42553</td>
<td>0.0272</td>
<td>0.91787</td>
<td>823.039</td>
<td>819.039</td>
</tr>
<tr>
<td>age + HTD</td>
<td>5.57546</td>
<td>0.0252</td>
<td>0.94306</td>
<td>823.189</td>
<td>819.189</td>
</tr>
<tr>
<td>food/capita</td>
<td>6.17154</td>
<td>0.0187</td>
<td>0.96176</td>
<td>823.785</td>
<td>821.785</td>
</tr>
<tr>
<td>size</td>
<td>6.62937</td>
<td>0.0149</td>
<td>0.97664</td>
<td>824.243</td>
<td>822.243</td>
</tr>
<tr>
<td>size + SMIr</td>
<td>6.78651</td>
<td>0.0138</td>
<td>0.99039</td>
<td>824.400</td>
<td>820.400</td>
</tr>
<tr>
<td>SMIr + food/capita</td>
<td>7.50736</td>
<td>0.0096</td>
<td>0.99998</td>
<td>825.123</td>
<td>821.123</td>
</tr>
<tr>
<td>age</td>
<td>20.71593</td>
<td>0.0000</td>
<td>0.99999</td>
<td>838.329</td>
<td>836.329</td>
</tr>
<tr>
<td>age + SMIr</td>
<td>22.71568</td>
<td>0.0000</td>
<td>1.00000</td>
<td>840.329</td>
<td>838.329</td>
</tr>
<tr>
<td>sex</td>
<td>25.58958</td>
<td>0.0000</td>
<td>1.00000</td>
<td>843.203</td>
<td>841.203</td>
</tr>
<tr>
<td>Hatch day</td>
<td>25.64610</td>
<td>0.0000</td>
<td>1.00000</td>
<td>843.259</td>
<td>841.259</td>
</tr>
<tr>
<td>SMIr</td>
<td>25.70197</td>
<td>0.0000</td>
<td>1.00000</td>
<td>843.315</td>
<td>841.315</td>
</tr>
</tbody>
</table>

ΔAIC = the difference in Akaike’s information criterion between the best model and the model in question; neg2LL = −2 × log likelihood; wi = Akaike’s weight; LL = log likelihood; cumwi = cumulative Akaike’s weight; HTD = hatch timing disparity; SMIr = an index of gosling body condition.

However, several covariates show significant year-related differences (Figures 1 and 2).

The top three models were < 2 AIC$_C$ units and had ~ 75% cumulative AIC$_C$ weight. These models included the effects of age-corrected size, HTD, SMIr, and food per capita; however, the effects of food per capita in the second-ranked model (hazard ratio = 0.00) and SMIr in the third-ranked model (β = −0.00, SE = 0.000) were not significant. All effects in the most parsimonious model were significant: size (β = −0.28, SE = 0.115) and HTD (β = 0.05, SE = 0.017) with most of the variation in the survival function explained by the size covariate.

For the most parsimonious model, the proportional hazard ratio for age-corrected size was 0.76 (95% CL = 0.606–0.950) meaning with an increase in one unit of age-corrected size, there was a decrease in the hazard of mortality of 24% (i.e., 1 − 0.76 × 100). The proportional hazard ratio for HTD was 1.05 (95% CL = 1.015–1.087), indicating that with an increase in one unit of HTD, there was 5% increase in the hazard of mortality. We estimated survival functions for gosling using the means of the covariates for each year of study (Figure 3) to illustrate the survival function difference between...
Table 2. The number of Canada goose Branta canadensis goslings marked and the number of confirmed mortalities (to 71 d post–radio-transmitter marking) during a study of gosling survival for goslings marked with radio transmitters on Akimiski Island, Nunavut, in 1999 and 2000. The table shows a difference in the number of mortalities between study years.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number marked</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>53</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Confirmed mortality</td>
<td>32</td>
<td>29</td>
</tr>
</tbody>
</table>

those years. There were clear annual differences in the estimated survival functions between the 2 y of study with 1999 being a relatively poor year for gosling survival and 2000 being distinctly better. The estimated survival probability to 51 d posttransmitter marking (maximum period comparable between years) was 0.31 (95% CL = 0.22–0.44) in 1999 and 0.69 (95% CL = 0.57–0.83) in 2000.

Discussion

Hill et al. (2003) found that condition had much less effect on survival for small goslings than it did for large goslings (i.e., small goslings as defined by Hill et al. (2003), had a zero probability of survival for the range of body condition they observed but condition was positively correlated to the survival probability of large goslings). Based on the results of the Hill et al. (2003) analysis, we predicted that condition was likely an important covariate explaining gosling survival for our study, but we found that gosling size alone was a more important covariate when estimating survival for the premigration period. However, we are cautious when comparing results from these two studies because of the differences in analysis type (known fate proportional hazard premigration period vs. Burnham annual survival analysis for Hill et al. 2003) and sample sizes (order of magnitude larger for Hill et al. 2003).

Researchers have considered gosling size and mass to be predictors of first-year survival (e.g., Canada geese [Hill et al. 2003; Brook et al. 2015], barnacle goose Branta leucopsis [Owen and Black 1989], brant [Sedinger et al. 1995; Sedinger and Chelgren 2007], lesser snow goose [Cooch 2002], and Ross’s geese [Slattery and Alisauskas 2002]). Factors affecting gosling size and mass (i.e., their growth rate and development) therefore are likely universal in determining juvenile survival for most goose species. Most of these studies, however, make inference from annual banding programs and cannot quantify the timing or causes of mortality. Our results appear in line with these and with those in Hill et al. (2003) generally. Our results also support the suggestion (Leafloor et al. 1996; Hill et al. 2003) that of all goslings marked at banding (goslings 5–8 wk old), the largest goslings are likely those available for harvest (i.e., survive long enough to be harvested during fall migration). Hill et al. (2003) found that the smallest goslings harvested by hunters were at or above the mean size of all goslings captured at banding, a striking indication of low survival of small goslings. Even if our survival estimates are negatively biased from a marker effect, it is unlikely that the bias would influence the relative strength of the covariate effects that we observed (including size) or would affect the annual comparisons we made.

We found that from the most parsimonious model, the HTD covariate was important in explaining variation in the survival function. The greater the length of time between the estimated peak in nutritional value of forage and gosling hatch, the greater the risk of mortality. Brook et al. (2015) showed that this covariate (i.e., mismatch) was an important explanatory variable for gosling growth rate for Akimiski Island goslings from hatching to recapture at about 5 wk of age. Brook et al. (2015) suggested that the mechanism through which HTD negatively impacted gosling survival was likely through nutrition limitation. Lindholm et al. (1994) demonstrated that a relative hatch date difference of 5–7 d between goslings may have large fitness consequences for Arctic-nesting geese due to the rapid decline in nutritional quality as Arctic forage species deteriorate with age. Further, Richman et al. (2015) showed through feeding trials on two species of wild goslings raised in captivity how nutritional quality and quantity limitation negatively impacted the growth and

Table 3. Summary statistics of age and metrics of size and mass of male and female gosling Canada geese Branta canadensis marked with radio transmitters on Akimiski Island, Nunavut, in 1999 and 2000 for a study of gosling survival. Values are means with standard errors in parentheses.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>1999 (n = 98)</th>
<th>2000 (n = 108)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at radio-marking (d)</td>
<td>51.3 (0.43)</td>
<td>51.3 (0.42)</td>
</tr>
<tr>
<td>Skull length (mm)</td>
<td>93.0 (0.43)</td>
<td>96.0 (0.48)</td>
</tr>
<tr>
<td>Culmen (mm)</td>
<td>36.1 (0.20)</td>
<td>36.9 (0.21)</td>
</tr>
<tr>
<td>Tarsus (mm)</td>
<td>76.8 (0.47)</td>
<td>82.2 (0.46)</td>
</tr>
<tr>
<td>9th Primary (mm)</td>
<td>113.6 (3.91)</td>
<td>113.4 (3.98)</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>1664.2 (28.25)</td>
<td>1813.7 (31.60)</td>
</tr>
</tbody>
</table>

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survival of Canada and lesser snow geese from Akimiski Island. Therefore, we feel that the HTD covariate is best considered as an index of forage quality and likely models that contained it performed better than models that contained the food-per-capita index because the latter index does not include a measurement of quality. Further, we did not find a significant difference between years for the annual food-per-capita index compared to the clear annual difference in HTD corresponding to the annual differences in survival that we observed.

It is challenging to compare our results with other studies because most estimates for juvenile Canada goose survival (i.e., hatch-year or first-year survival) are from banding programs that estimate annual survival probability for the period from prefledging to the first anniversary of their banding (Table S1, Supplemental Material). However, for studies that most closely overlap the premigration period (Bruggink et al. 1994; Lawrence et al. 1998; Leafloor et al. 2000; Coluccy et al. 2004), none were as low as our 1999 estimate. For comparison with those reporting annual estimates, a 0.31 gosling survival probability to 51 d post–radio-marking, as we found in 1999, is roughly equivalent to an annual survival probability of 0.0002 (i.e., 0.31^{365/51}) assuming a constant survival probability. Though we based this estimate on likely invalid assumptions of constant mortality risk, it is a value much lower than that reported by Hill et al. (2003), who made the same assumptions. We also concluded (similar to Leafloor et al. 2000; Hill et al. 2003) that gosling survival probability as low as we found in 1999 is likely a characteristic of a declining population (i.e., insufficient gosling survival resulting in poor recruitment into the breeding population). However, the variation in survival probability that we observed in just 2 y of study suggests that stochasticity for gosling survival is likely also an important consideration for estimating population growth for this population and likely for most Arctic or sub-Arctic goose populations.

**Figure 1.** A histogram of the hatch timing disparity, which is the length of time in days between Canada goose Branta canadensis gosling hatch date and the date of the estimated peak in nutritional value of forage as indexed by the 50% normalized difference vegetation index. This covariate was used to model gosling survival in a study using radio-marked goslings in 1999 and 2000 on Akimiski Island, Nunavut, and shows annual differences in hatch timing disparity between study years. In both years, goslings hatched after the estimated peak in forage nutritional value.

**Figure 2.** A histogram of Canada goose Branta canadensis gosling size corrected for age. This covariate was used to model survival functions for goslings marked using radio transmitters in 1999 and 2000 on Akimiski Island, Nunavut. We estimated the gosling size covariate by regressing the size variable (from first principal component scores of head, culmen, and tarsus length) on the gosling age at radio marking and used the resulting residuals as the age-corrected size. The graph shows that the two study years were largely different but with some overlap.

**Figure 3.** The estimated survival probability for Canada goose Branta canadensis goslings marked with radio transmitters on Akimiski Island, Nunavut, in 1999 and 2000. Bars are 95% confidence limits. We estimated survival probability using Cox proportional hazard models from the most parsimonious model, which included the covariates of age-corrected size and hatch timing disparity. Age-corrected size is a size covariate corrected for the goslings age in days at capture for radio transmitter marking and hatch timing disparity is the difference in days between hatch date and an estimate of peak nutritional value of goose food as indexed by the remotely sensed 50% normalized difference vegetation index.
We were able to model gosling mortality on Akimiski Island, Nunavut, for the period from about 6 to 7 wk of age to just before departure for the southward migration. We are unaware of estimates of Canada goose gosling mortality for this period from any other study, though similar work has shown high mortality during this period for lesser snow geese (Cooch et al. 1991). This period does not likely capture all the nonhunting mortality (see Brook et al. 2015) for juvenile Canada geese during their first year, but likely encompasses their second most vulnerable period (i.e., the transition from walking to flying) following their first few weeks of life. About 70% of the goslings we marked with a radio transmitter died by 71 d postmarking during the worst year (1999) for which we measured survival. We predicted that about half the goslings marked at capture for radio marking died by the time southward migration started in early September (about 40 d post–radio marking) in 1999. Though the habitat is clearly damaged by overgrazing on Akimiski Island (Jefferies et al. 2006; Kotanen and Abraham 2013), the quality may be similarly as important as the quantity of forage for determining gosling survival (Gadallah and Jefferies 1995). Therefore, we suggest that factors affecting forage quantity differences beyond the time scale that we observed during our 2 y of our study (e.g., Brook et al. 2015) and those affecting forage quality (i.e., climate change impacts that may influence the annual variation in HTD) drive the relatively high gosling mortality observed on Akimiski Island (and likely elsewhere). These are likely important limiting factors for juvenile recruitment into the breeding population and for population growth of this population.

It may prove challenging to measure and incorporate the relatively large stochasticity that is likely to be present in juvenile recruitment into models designed to help improve the management of goose populations. Factors that influence the growth and survival of goslings may be beyond the immediate control by tools available to managers (i.e., climate change factors that influence the quality and quantity of forage through a disparity of hatch timing with green-up). However, incorporating the stochasticity of gosling survival into models of population growth rate (e.g., integrated population models) may improve overall population management and modeling (Arnold et al. 2017) of the nonharvest mortality of goslings, possibly helping to explain previously unexplained variation in harvest management models.

**Supplemental Material**

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**Data S1.** Microsoft Excel file of data from the mark–recapture histories of 206 Canada goose *Branta canadensis* goslings marked in 1999 and 2000 on Akimiski Island, Nunavut. Data include individual information including date hatched, date banded or marked, and last date observed as well as sex, fate, number of days survived, and age at banding. Data also include covariate information used to model survival including hatch timing disparity (difference between the hatch date and the date of 50% normalized difference vegetation index), sex, skull length, culmen length, tarsus length, ninth primary length, mass, grazed biomass (an index of goose food), and food per capita (grazed biomass divided by a population index).

Found at DOI: [https://doi.org/10.3996/102018-JFWM-098.S1](https://doi.org/10.3996/102018-JFWM-098.S1) (37 KB XLSX).

**Table S1.** A comparison of gosling survival estimates for Canada goose *Branta canadensis* hatched on Akimiski Island, Nunavut, in 1999 and 2000 with estimates from other locations. This is not an exhaustive list and is restricted geographically to the Mississippi and Atlantic flyways. Estimates from other locations include the time period and age range of goslings from which we made estimates.

Found at DOI: [https://doi.org/10.3996/102018-JFWM-098.S2](https://doi.org/10.3996/102018-JFWM-098.S2) (20 KB DOCX).

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**References**


