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*Original Article*

# A Population Model for Management of Atlantic Flyway Resident Population Canada Geese

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**ABSTRACT** Highly abundant resident Canada geese (*Branta canadensis*) cause property damage throughout their range. Effective reduction and management of these populations requires knowledge of their population dynamics and responses to management actions. We used data from New Jersey, USA, and other resident Canada goose populations to produce stage-structured matrix models for resident Canada geese from both urban and rural landscapes. We ran stochastic simulations to assess 3 management activities for Atlantic Flyway Resident Population Canada geese: harvest, nest treatment, and cull. Unrealistic harvest rates, in excess of 10% for urban geese, would be needed to reduce the urban population to target levels within 10 years in the absence of other management activities. Nest treatment to prevent hatching is less controversial than culling adults, but as many as 62% of eggs in urban areas would need to be treated annually to sufficiently reduce the mean stochastic population growth rate. Cull would be the most effective way to achieve the population goal, but current cull rates are insufficient to reduce the urban population. Although reduction of urban geese was a challenge, current management activities in rural populations appeared to be sufficient to reduce populations. We also provide a simple spreadsheet tool for managers who want to explore management options for other resident Canada goose populations by inserting relevant vital rate estimates for their populations and manipulating management activities. © 2016 The Wildlife Society.

**KEY WORDS** Atlantic Flyway, *Branta canadensis*, Canada geese, cull, egg addling, harvest, New Jersey, population dynamics.

Resident Canada geese (*Branta canadensis*) have become common in much of the landscape of the Atlantic Flyway. The population goal for Atlantic Flyway Resident Population (AFRP) Canada geese is 700,000 birds, but the current population estimate is approximately 1,000,000 (Atlantic Flyway Council 2011). High densities of geese create water quality, disease, and aesthetic concerns associated with their feces, as well as conflicts arising from aggressive defense of nests and young, damage to lawns and crops, and collisions with vehicles (Conover and Chasko 1985, Dolbeer 2009). Localized populations of problem geese may be dealt with by harassment, but harassing geese is expensive and only tends to move the geese and associated problems from one location to another (Castelli and Sleggs 2000). Reducing the population size would provide more widespread and lasting relief of some of the conflict and damage to private and public lands.

Current management of Canada geese relies on reducing recruitment, survival, or both. Treating nests by oiling or addling eggs to prevent hatching can reduce recruitment, but models suggest that considerable effort is needed to achieve population control with nest treatment alone (e.g., >71% of eggs treated; Coluccy et al. 2004). To reduce survival of resident geese, early and late Special Resident Population Hunting Seasons and Resident Population Hunting Zones have been established and subsequently liberalized in the Atlantic Flyway (Atlantic Flyway Council 2011). Unfortunately, the highest densities of the most problematic geese are in urban areas where hunting opportunities are limited (Balkcom 2010), and more liberal harvest has been ineffective at reducing survival in some populations (Sheaffer et al. 2005). Another strategy to reduce survival is to cull geese during the molt when they are flightless. Although

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culling has been effective at reducing goose abundance in Minnesota and Michigan, USA (Keefe 1996, Smith et al. 1999), this method is often contentious (Kokel 2004).

In order to assess management options, we constructed a population model for AFRP Canada geese in New Jersey, USA, and used it to analyze alternate management activities. New Jersey has the highest density of AFRP geese at 4.2 birds/km$^2$, with 80,833 total birds estimated in 2012 based on spring surveys (Ted Nichols, New Jersey Division of Fish and Wildlife, unpublished data). The implementation of control measures has been widespread, but Canada geese are still nearly twice the state's population objective of 41,000 birds (Atlantic Flyway Council 2011) and public demand for further control is high. In addition, the New Jersey Division of Fish and Wildlife has maintained intensive AFRP breeding population surveys (Heusmann and Sauer 1997, 2000) as well as long-term banding (Castelli and Trost 1996, Beston et al. 2014) and recruitment studies (Guerena 2012), which provide abundant data to parameterize a population model. Our goal was to compare the effectiveness of harvest, nest treatment, and cull in managing the population. Coluccy et al. (2004) performed similar analyses for a resident population in Missouri, USA. Our effort expanded on theirs in several ways, including separately analyzing urban and rural geese and allowing for covariation between juvenile and adult survival. We examined the effort needed to reduce both urban and rural populations by 50% within a 10-year timeline by manipulating harvest, nest treatment, and cull; and we determined what levels of take would be needed to maintain the population at its target size once it had been achieved.

# METHODS

## Population Model

We modeled the population dynamics of AFRP Canada geese in New Jersey using a stage-based matrix model (Leslie 1945; Fig. 1). We used a prebreeding matrix with 6 age classes. We tracked only the female segment of the population and assumed a sex ratio of 1:1 at hatching.

## Survival Estimates

We estimated separate mean values for survival of adults and juveniles originally banded at urban and rural sites (Beston et al. 2014). Beston et al. (2014) estimated survival for New Jersey AFRP Canada geese and included all sources of mortality. We used their estimates of survival and harvest rates, along with estimates of cull (Stephanie Slonka, U.S. Fish and Wildlife Service, unpublished data), to estimate survival in the absence of harvest and cull. Assuming all mortality sources were independent $S = (1 - c)(1 - h)(1 - m)$, where $S$ is the total observed survival, $c$ is the cull rate, $h$ is the harvest rate, and $m$ is mortality in the absence of harvest and cull. To simulate annual survival, we multiplied the simulated survival in the absence of harvest and cull by the complements of the simulated harvest and cull rates.

$$\begin{array}{cccccc} F_1 & F_2 & F_3 & F_4 & F_5 & F_{6+} \\ S & 0 & 0 & 0 & 0 & 0 \\ 0 & S & 0 & 0 & 0 & 0 \\ 0 & 0 & S & 0 & 0 & 0 \\ 0 & 0 & 0 & S & 0 & 0 \\ 0 & 0 & 0 & 0 & S & S \end{array}$$

$$\text{where} \quad F_i = bp_i \times ns \times (1 - nd) \times \frac{cs}{2} \times h \times s_g \times s_j \times (1 - c) \times (1 - ha_j)$$

$$\text{and} \quad S = s_a \times (1 - c) \times (1 - ha_a).$$

**Figure 1.** Prebreeding, stage-structured, matrix population model for Canada geese (*Branta canadensis*), where *bp* = breeding propensity, *ns* = nest success, *nd* = nest treatment rate, *cs* = clutch size at hatch, *h* = hatchability, *c* = cull rate, *ha* = harvest of juvenile (*j*) or adult (*a*) geese, and *s* = gosling survival from hatch to fledge (*g*) or annual survival of juvenile or adult geese.

## Recruitment Estimates

We based recruitment parameter estimates of nest success, clutch size, hatchability, and gosling survival to fledging for AFRP Canada geese in New Jersey on estimates from Guerena (2012). Guerena (2012) did not differentiate between urban and rural geese, and therefore we used the same parameter estimates for both populations, with the exception of gosling survival (see below). We only used estimates from 1985 to 1989 and 1995 to 1997 to parameterize nest success because 2009–2010 nesting data were collected during a period when anthropogenic nest treatment became a more commonly used population reduction tool (Guerena 2012). We assumed nest treatment was independent of other sources of nest failure and that there was no compensation. Therefore, the total nest success is the product of the natural nest success rate and the complement of the nest treatment rate.

Gosling survival to fledging is arguably the most difficult recruitment parameter to measure; it is estimated infrequently and those estimates vary considerably in the literature (Stolley et al. 1999). We, therefore, estimated gosling survival in urban and rural sites by averaging the annual estimates of gosling survival from New Jersey (Guerena 2012), with those from an urban population in Connecticut, USA (Conover 1998) and those from a rural population in Pennsylvania, USA (Jacobs and Dunn 2004), respectively.

We used age-specific breeding propensities reported for a resident population of Canada geese in Missouri (Coluccy et al. 2004). Variance estimates were unavailable for breeding propensities; therefore, we did not simulate stochasticity in those vital rates.

## Simulations

We used package popbio (Stubben and Milligan 2007) in R v3.1.1 (R Core Team 2014) to conduct stochastic population simulations. We used beta distributions to generate random values for vital rates that were restricted to the interval from 0 to 1 (e.g., survival, nest success) and the lognormal distribution for clutch size. We also included the observed covariation between adult and juvenile survival.

To compare our model predictions to the estimated population trends for New Jersey from the Atlantic Flyway Breeding Waterfowl Survey (Heusmann and Sauer 1997, 2000), we simulated management during 1994–2011 based on estimated harvest rates and reported cull and nest treatment. We fit a linear model to annual estimates of

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harvest to describe the increasing trend in harvest through time. We simulated harvest rates by drawing random values that varied around this trend line based on the residual variation in harvest estimates after regression. We set the initial population size to 61,230 geese—the Atlantic Flyway Breeding Waterfowl Survey estimate from 1994—and we used our model to estimate mean population growth rates, $\bar{\lambda}$, over this time period for urban and rural geese (see Table 1; Beston et al. 2014).

To assess management actions designed to reduce abundance, we ran population simulations under various management regimes. We set the initial population to its stable stage distribution for each scenario. We calculated the proportion of geese culled or eggs treated annually that would be required to reduce the mean expected population by 50% in 10 years (mean population growth rate, $\bar{\lambda} = 0.93$). We performed this calculation for rural and urban populations with mean adult ($\geq$1 yr old or coded as After Hatch Year at banding) harvest rates varying from 0 to 0.1 by 0.01 increments. To ensure that juvenile harvest rates appropriately reflected changes in adult harvest rate, we calculated mean harvest rates for juvenile geese (<1 yr old or coded as Hatch Year or Local at banding) for each scenario using linear relationships between adult and juvenile harvest rates for urban and rural Canada geese (Fig. 2; Beston et al. 2014). We also used stochastic simulations to determine the necessary proportion of geese culled or nests treated annually to achieve a stable population ($\bar{\lambda} = 1$) over 10 years in each population under the same harvest scenarios.

We performed a life-stage simulation analysis to examine the relative effects of variation in different vital rates on λ (Wisdom et al. 2000). The distributions of vital rates and management activities were based on their observed variation. Variances for cull and nest treatment rates were estimated from the time period 2008–2011 because estimates were reliable and relatively stable during this period. For both rural and urban geese, we generated 1,000 matrices using the current harvest, cull, and nest treatment rates and calculated their associated asymptotic λs and the elasticities of the vital rates. We compared elasticity rankings across simulated matrices and regressed λ against the vital rates to assess the proportion of variation in λ that could be attributed to each vital rate.

**Table 1.** Estimated mean ($\mu$) and variance ($\sigma^2$) of vital rates for Atlantic Flyway Resident Population Canada geese (*Branta canadensis*) used in a stage-structured matrix population model. Time frame and location of data are noted in footnotes.

| | Urban | | Rural | | Combined | |
|---|---|---|---|---|---|---|
| **Vital rate** | $\mu$ | $\sigma^2$ | $\mu$ | $\sigma^2$ | $\mu$ | $\sigma^2$ |
| Juv survival[a] | 0.853 | 0.019 | 0.736 | 0.018 | | |
| Ad survival[a] | 0.758 | 0.011 | 0.786 | 0.013 | | |
| Gosling survival[b] | 0.667 | 0.033 | 0.434 | 0.007 | | |
| Nest success[c] | | | | | 0.655 | 0.014 |
| Clutch size[c] | | | | | 4.699 | 0.262 |
| Hatchability[c] | | | | | 0.858 | 0.002 |
| Breeding propensity[d] | | | | | | |
| Age 1 | | | | | 0.039 | |
| Age 2 | | | | | 0.336 | |
| Age 3 | | | | | 0.710 | |
| Age 4 | | | | | 0.930 | |
| Age 5 | | | | | 0.975 | |
| Age 6+ | | | | | 1.000 | |

[a] Beston et al. (2014).

[b] Rural: Guerena (2012) and Jacobs and Dunn (2004); Urban: Guerena (2012) and Conover 1998.

[c] Guerena (2012).

[d] Coluccy et al. (2004).

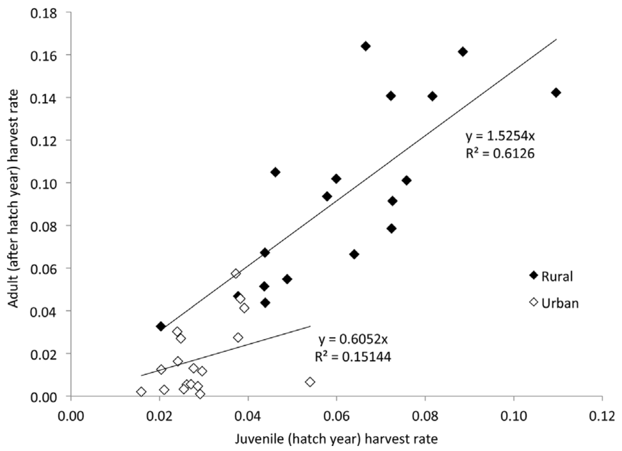

**Figure 2.** Linear relationships between annual estimates of juvenile and adult harvest rates of Atlantic Flyway Resident Population Canada geese in New Jersey, USA, 1994–2011. Data from Beston et al. (2014).

## Simulated Population Management for Resident Atlantic Flyway Canada Geese

In order to offer managers a quick and easy-to-use tool to explore population management of resident population Canada geese, we developed a population model and user interface in Microsoft Excel 2010 (Redmond, WA) that incorporates much of the behavior of the R population model. This tool, Simulated Population Management for Resident Atlantic Flyway Canada Geese (SPRAG), comprises a single sheet presenting the user interface and several hidden sheets where calculations and simulations are carried out. The user enters vital rates, population size, and levels of management activities. When sufficient data have been provided, the means and 95% confidence intervals of expected population size next year and λ are reported. If the user supplies a population objective, an estimate of the time to reach that objective is also provided.

Like the R model, variation in vital rates and management are propagated through the model to estimate uncertainty in outputs. The variance values are calculated using the coefficients of variation of the vital rates based on the estimates used in the R model rather than having users enter them directly. The estimates and their variances are then used to construct 10,000 simulated matrices from which output values are calculated. Unlike the R population model, the simulated matrices have only 2 stage classes—juvenile and adult—and there is no covariation between the survival rates of these classes. We compared output from the R population model with output from SPRAG for several sets

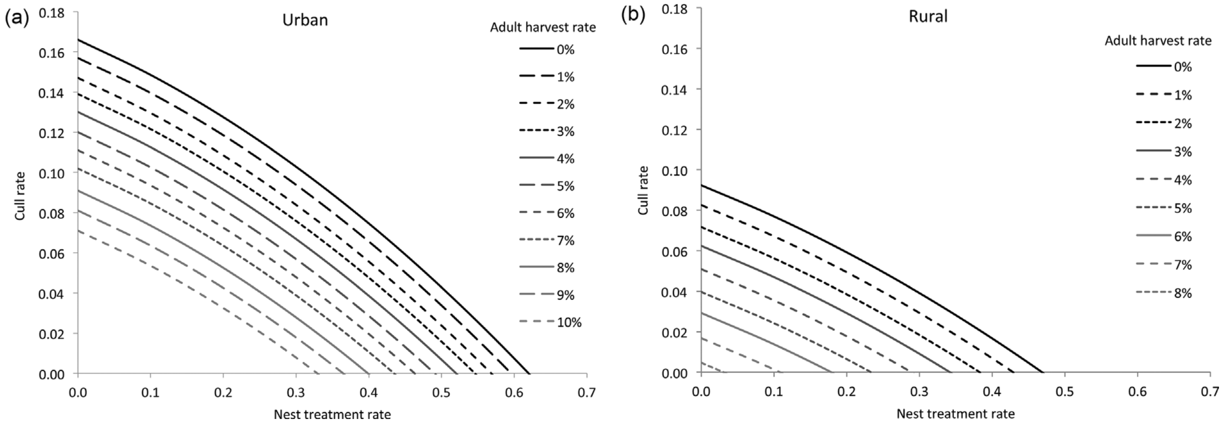

**Figure 3.** Annual rates of nest treatment and cull that would reduce the population size of (a) urban and (b) rural Atlantic Flyway Resident Population Canada geese in New Jersey, USA, by 50% to the population goal in 10 years from the 2012 population size. The juvenile harvest rate (not shown) for each scenario was calculated from the relationship between juvenile and adult harvest rate in the population of interest.

of vital rates in order to determine the consequences of these differences in model structure.

## RESULTS

In simulations based on management during 1994–2011, the mean stochastic λs of the models were 1.049 (95% of simulations: 0.975–1.120) and 0.928 (0.870–0.984) for urban and rural geese, respectively. The Atlantic Flyway Breeding Waterfowl Survey λ estimate for New Jersey during the same time period was 1.009.

Urban populations required greater intervention than rural ones to reduce or maintain the population under the same harvest rate (Fig. 3). In urban areas with no harvest, cull rates of up to 16.6% and nest treatment rates up to 61.9% were necessary to reduce the mean stochastic λ to 0.93, which is the level that would achieve the population goal in 10 years (Fig. 3a). In rural areas, the highest cull and nest treatment rates needed to reach the same goal were 9.2% and 46.7%, respectively (Fig. 3b). Current harvest, cull, and nest treatment rates resulted in mean stochastic λs of 1.047 (0.946–1.161) in urban populations and 0.909 (0.823–1.005) in rural populations.

In both rural and urban populations, survival accounted for most of the variability in asymptotic λ (Fig. 4). Because management activities (cull, nest treatment, and harvest rates) had low annual variability, the proportion of variation in population growth rate that they explained was inevitably low. Harvest and cull did, however, have high sensitivity (Table 2), thus having high potential influence on population growth. Survival of adult geese had the highest elasticity,

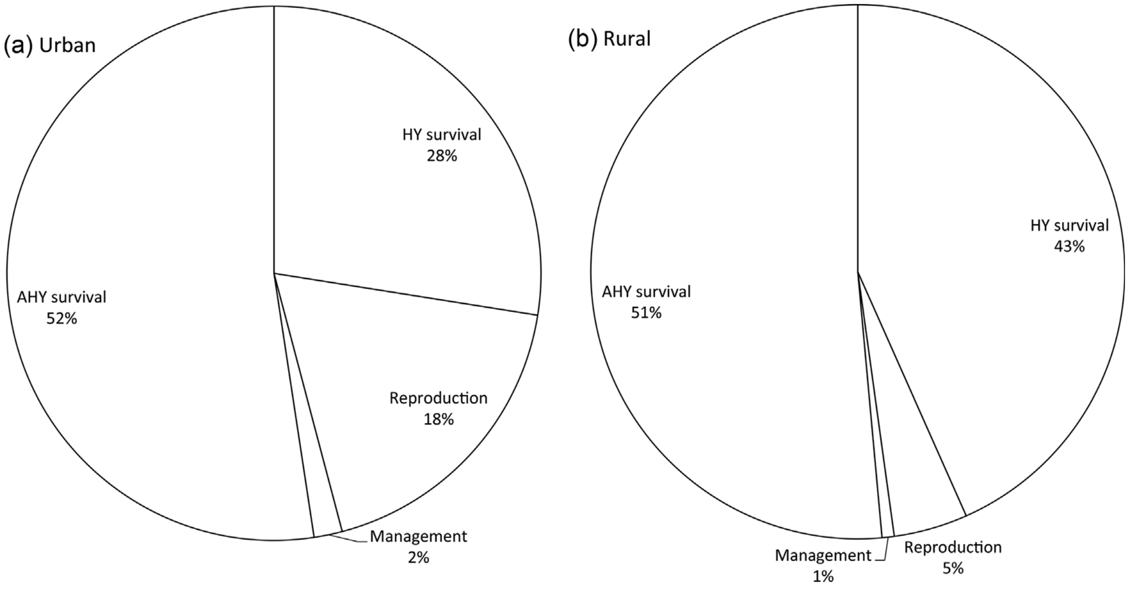

**Figure 4.** The proportion of variation in the asymptotic population growth rate (λ) explained by each vital rate in 1,000 population projection matrices constructed by randomly sampling the distribution of each of vital rate from (a) urban and (b) rural Atlantic Flyway Resident Population Canada geese in New Jersey, USA, under current (2008–2011) harvest, cull, and nest treatment rates. Recruitment includes nest success, clutch size, hatchability, and gosling survival. Management activities include harvest, cull, and nest treatment rates.

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**Table 2.** Sensitivity and elasticity of vital rates of urban and rural Atlantic Flyway Resident Population Canada geese in New Jersey, USA, based on 2008–2011 estimates of harvest, cull, and nest treatment rates. Because elasticities are calculated for vital rates instead of matrix elements, they do not sum to 1.

| | Urban | | Rural | |
|---|---|---|---|---|
| Vital rate | Sensitivity | Elasticity | Sensitivity | Elasticity |
| Juv survival | 0.264 | 0.213 | 0.213 | 0.167 |
| Ad survival | 1.096 | 0.787 | 0.992 | 0.833 |
| Gosling survival | 0.337 | 0.213 | 0.361 | 0.167 |
| Nest success | 0.343 | 0.213 | 0.239 | 0.167 |
| Clutch size | 0.048 | 0.213 | 0.033 | 0.167 |
| Hatchability | 0.262 | 0.213 | 0.182 | 0.167 |
| Breeding propensity | | | | |
| Age 1 | 0.150 | 0.006 | 0.061 | 0.003 |
| Age 2 | 0.101 | 0.032 | 0.047 | 0.017 |
| Age 3 | 0.068 | 0.046 | 0.036 | 0.027 |
| Age 4 | 0.046 | 0.040 | 0.027 | 0.027 |
| Age 5 | 0.031 | 0.029 | 0.021 | 0.022 |
| Age 6+ | 0.064 | 0.061 | 0.067 | 0.072 |
| Juv harvest | −0.228 | −0.003 | −0.171 | −0.016 |
| Ad harvest | −0.852 | −0.020 | −0.825 | −0.048 |
| Nest treatment rate | −0.228 | −0.003 | −0.159 | −0.003 |
| Cull rate | −1.096 | −0.038 | −0.972 | −0.038 |

followed by juvenile survival and rates associated with recruitment (Table 2). Harvest and cull had low elasticity because they were modeled as mortality rates.

The predictions of population growth from SPRAG were qualitatively similar to the output from the R population model. Using New Jersey vital rates and current harvest, cull, and nest treatment rates, the predictions of λs from SPRAG for urban ($\lambda = 1.051$, 95% CI = 0.921–1.196) and rural (0.954, 95% CI = 0.831–1.096) Canada geese were 0.004 and 0.045 greater than those from the R simulations, respectively. Replacing nest success, clutch size, and survival to fledging with estimates from an urban population in Connecticut (Conover 1998) and juvenile and adult survival with statewide estimates for Connecticut (Beston et al. 2015), the SPRAG estimate of λ (1.126, 95% CI = 0.991–1.279) was 0.014 less than the estimate (1.140, 95% CI = 1.047–1.242) from the population model implemented in R. In all cases, the confidence interval from SPRAG included the mean estimate from R, and the confidence intervals from SPRAG were larger than those from R. The SPRAG.xlsx file and its associated User Guide are available online at www.onlinelibrary.wiley.com (Supporting material, Files 1 and 2). The population model R code is available from the authors.

# DISCUSSION

The model estimates of population growth rate for urban and rural AFRP Canada geese in New Jersey overestimated and underestimated, respectively, the observed population growth rate based on the Atlantic Flyway Breeding Waterfowl Survey. The better match with urban predictions suggests that the urban population may be larger than the rural population or its vital rates are better estimated. Possible sources of bias include the lack of variability in breeding propensity and the absence of a dispersal connection between urban and rural populations.

Unfortunately, the breeding propensity and its annual variation are not well-known for most vertebrate populations (Reed et al. 2004). Breeding propensity is probably highly variable in subarctic-nesting Canada geese, as is the case with snow geese (*Chen caerulescens*; Reed et al. 2004). However, resident geese nesting in temperate areas have minimal to no spring migration costs and usually have access to plentiful resources. Therefore, they may have a high breeding propensity with less annual variation than their subarctic nesting counterparts. Although breeding propensities had low elasticity, the potential for high variability in these rates means they could increase annual variability in population growth rate, decreasing stochastic $\bar{\lambda}$. Although the model appears to be performing well, at least for urban geese, efforts to estimate breeding propensity and to characterize its variance could improve the model.

Survival had higher elasticity than vital rates associated with recruitment. Harvest and cull had relatively large effects compared with nest treatment. Because we estimated cull rate for the state as a whole, we probably underestimated the cull rate for urban geese and overestimated it for rural geese. Correcting this bias would bring urban and rural estimates of population growth closer to one another and improve the predictive ability of the model.

Urban Canada goose populations are less responsive to liberalizing harvest than are rural geese (Sheaffer et al. 2005, Balkcom 2010, Beston et al. 2014), and even unrealistically high harvest rates for urban geese (e.g., 10%) were insufficient to reduce the urban population without additional management intervention. Furthermore, although our estimates of nest treatment needed to reduce the population size were lower than those found by Coluccy et al. (2004), they still represent a considerable proportion of nests. As more land becomes developed and closed to hunting, we expect the effect of harvest regulations on population growth to decrease and the required cull, nest treatment, or combination thereof to achieve population objectives to increase.

The simplified model provided by SPRAG is a reasonable alternative to the more complex model we implemented using R. The estimates of population growth provided by SPRAG are less precise, but they require fewer input data and no specialized knowledge of population model programming. Users with information about the temporal variance in their vital rates can access the hidden spreadsheets in SPRAG to adjust those values as well. Coupling analyses performed with SPRAG with the results from ongoing population surveys will give managers a clear picture of dynamics in local populations and allow them to tune vital-rate estimates to better predict changes in population size.

# MANAGEMENT IMPLICATIONS

Any management action that causes mortality to resident geese can be controversial because it involves a diverse set of stakeholders. Although cull is an unpalatable management activity to some stakeholders, it remains the most effective strategy to reduce overabundant resident Canada geese in urban landscapes. If cull were abandoned, nest treatment would need to increase dramatically, probably requiring

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agencies to actively recruit community participants or undertake some nest treatment themselves. Even if such a strategy could be implemented, significant relief from Canada goose damage using nest treatment alone would not be realized until several years after nest treatment began. Additionally, the effectiveness of liberalized harvest regulations in reducing populations will decline as more land is developed and a greater proportion of the goose population is unavailable for harvest. We recommend using banding data to estimate survival and harvest periodically and update the model to assess how changes in the human population are affecting AFRP Canada geese. Additionally, we hope the SPRAG model will be an easy-to-use tool that can aid managers in decision-making for resident Canada geese in the Atlantic Flyway, as well as demonstrate to landowners or municipal officials the trade-offs and efficacy of management actions.

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

**File S1**. Simulated population management for resident Atlantic Flyway Canada Geese (SPRAG.xlsx file).

**File S2**. Simulated population management for Resident Atlantic Flyway Canada Geese user guide (pdf.)