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# TAIGA BEAN GOOSE

# HARVEST ASSESSMENT FOR THE CENTRAL MANAGEMENT UNIT: 2018

***Prepared by the AEWA European Goose Management Platform Data Centre***

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## Summary

In 2016 the European Goose Management International Working Group (EGM IWG) began development of an adaptive harvest management program for Taiga Bean Geese (TBG). In 2017, the EGM IWG adopted an interim harvest strategy consisting of a constant harvest rate (on adults) of 3% for the Central Management of Taiga Bean Geese. The interim strategy is intended to provide limited hunting opportunity while rebuilding the population. Recent efforts have involved development of a dynamic strategy in which the harvest rate can vary each year with changes in population size, and in which multiple, possibly competing, management objectives can be addressed. This report provides examples of dynamic harvest strategies and compares them with the interim, constant harvest-rate strategy. Until such time that a dynamic strategy is adopted by the EGM IWG, the annual harvest quota and its allocation among Range States is predicated on the interim strategy. Based on a January count of 38,717, the harvest quota for the 2018 hunting season is 1,610 Taiga Bean Geese (compared to 2,335 for the 2017 season). We emphasize that these quotas include both harvest during the regular season and derogation shooting. We acknowledge that the January 2018 count of Taiga Bean Geese in the Central Management Unit was likely biased low, as counts in the autumn and spring in Sweden were higher. Additionally, the size of the harvest during the fall and winter of 2017-18 is unknown, due to an inability to differentiate taiga and Tundra Bean Geese in the harvest, compilation of data too late to be used in this report, and a lack of reporting. Because of problems with both the population and harvest monitoring programs it is difficult to estimate a harvest quota for 2018 with any degree of confidence.

## Introduction

Harvest levels appropriate for first rebuilding the population of the Central Management Unit and then maintaining it near the goal of 60,000 – 80,000 individuals in winter were assessed by Johnson et al. (2016). Based on a more recent assessment (Johnson 2017), the EGM IWG adopted a constant harvest rate (on adults) of 3% as an interim strategy, intended to provide limited hunting opportunity while rebuilding the population toward the goal. This assessment report provides harvest quotas for the 2018 hunting season based on this interim harvest strategy, as well as describing development of a dynamic harvest strategy. A dynamic strategy

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is one in which the harvest rate can vary each year with changes in population size. Development of a dynamic harvest strategy is described in more detail by Johnson et al. (2018).

We first describe a general model of population dynamics. Then we describe derivation of a dynamic harvest strategies and compare them with the constant harvest-rate strategy. Notably, we also show how the dynamic harvest strategy can explicitly account for two or more management objectives. In the examples provided, we incorporate both a desire to maintain the population near the goal and a desire to provide sustainable hunting opportunity, and show how these objectives can be traded off against each other.

## Methods

### *Models of population dynamics*

The age-structured model for Taiga Bean Geese developed by Johnson et al. (2016) provides the foundation for exploring harvest effects (Figure 1). In addition to accounting for age at first breeding, this model allows for age-specific survival rates and for young-of-the-year that may be more vulnerable to harvest than older birds (Baldassarre 2014). Detailed descriptions of population models for Taiga Bean Geese are provided in Appendix A.

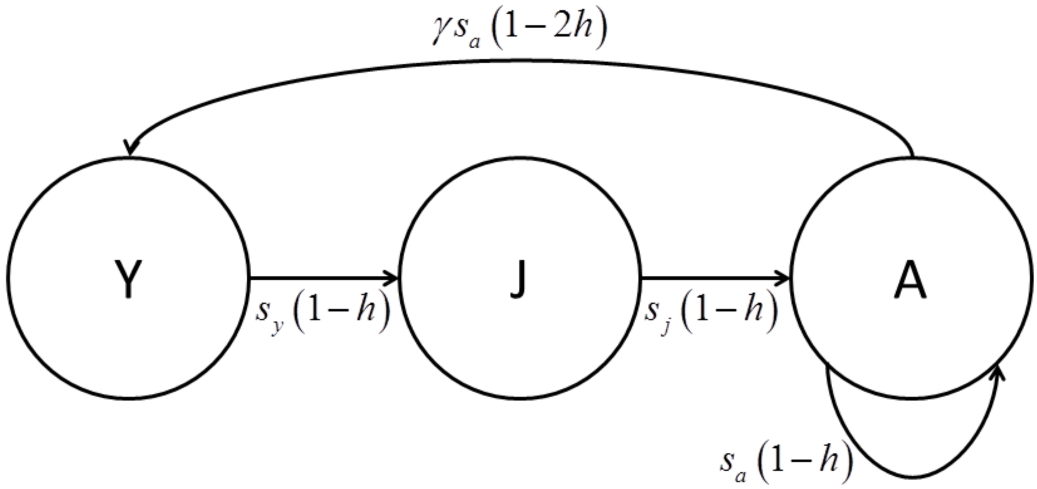


***Figure 1****. Life cycle of taiga bean geese based on a January anniversary date*. The three age classes represented are young (Y, birds aged 0.5 years), juvenile (J, birds aged 1.5 years), and adults (A, birds aged ≥2.5 years). Vital rates are survival in the absence of harvest, *s*, the harvest rate of birds that have survived at least one hunting season, $h$, and the reproductive rate, $\gamma$.

***Management objectives***

The International Single Species Action Plan (ISSAP) calls for restoring and then maintaining the population of taiga bean geese in the Central Management Unit at a level of 60,000 – 80,000 individuals in winter. Based on this goal, a possible objective function for calculating dynamic harvest strategies as a solution to a MDP is:

$$V^*\left(harvest_t \mid \vec{N}_t, \underline{M}, \vec{K}\right) = \underset{\left(harvest \mid \vec{N}_t, \underline{M}, \vec{K}\right)}{\arg\max} \sum_{t=1}^{\infty} U_t\left(\sum \vec{N}_{t+1} \mid harvest_t, \vec{N}_t\right),$$

where the optimum value $V$ of a harvest strategy maximizes population utility, *U*, where utility is defined as:

$$U_t\left(\sum \vec{N}_{t+1} \mid harvest_t, \vec{N}_t\right) = \left(1 + \mathrm{e}^{\left(\left|\sum\left(\vec{N}_{t+1} \mid harvest_t, \vec{N}_t\right) - \alpha\right| - \beta\right)}\right)^{-1}.$$

We considered a January population goal of $\alpha = 70,000$ Taiga Bean Geese, and inflection points of $[\alpha - \beta, \alpha + \beta]$, where $\beta = 15,000$. This utility function expresses near-complete satisfaction with population sizes in the range 60,000-80,000, with satisfaction declining for population sizes outside this range (Figure 2). The form of this utility curve is similar to that used for adaptive harvest management of Pink-footed Geese (Johnson and Madsen 2016).

Note that this approach does *not* explicitly account for the value of harvest, but rather assumes harvest is merely a tool to maintain population abundance within acceptable limits. Yet we know that hunters value the hunting opportunity afforded by sustainable populations of waterbirds (Buij et al. 2017). Thus, we can specify (at least) two, potentially competing objectives. One is to maintain population size within a range that satisfies conservation, agricultural, and public health and safety concerns. Another is to maximize sustainable hunting opportunity. Therefore, we can consider a utility function that accounts for both the desire to maintain a population near its goal and the desire to provide sustainable hunting opportunities:

$$U_t\left(\sum \vec{N}_{t+1}, harvest_t \mid \vec{N}_t\right) = w_p\left(1 + \mathrm{e}^{\left(\left|\sum\left(\vec{N}_{t+1}, \mid harvest_t, \vec{N}_t\right) - \alpha\right| - \beta\right)}\right)^{-1} + \left(1 - w_p\right)\frac{harvest_t}{\max harvest},$$

where $0 \le w_p \le 1$ is the relative degree of emphasis on maintaining the population near its goal. The second term then is the relative value of harvest, scaled by the maximum harvest under consideration. Thus, $p_w = 1$ represents a sole objective related to population size and $p_w = 0$ represents a sole objective of maximizing sustainable harvest. Values of $p_w$ intermediate between 0 and 1 represent a mix of both objectives. The assignment of weights is not the purview of scientists, but of decision makers who must judge how best to balance the desires of different stakeholder interests.

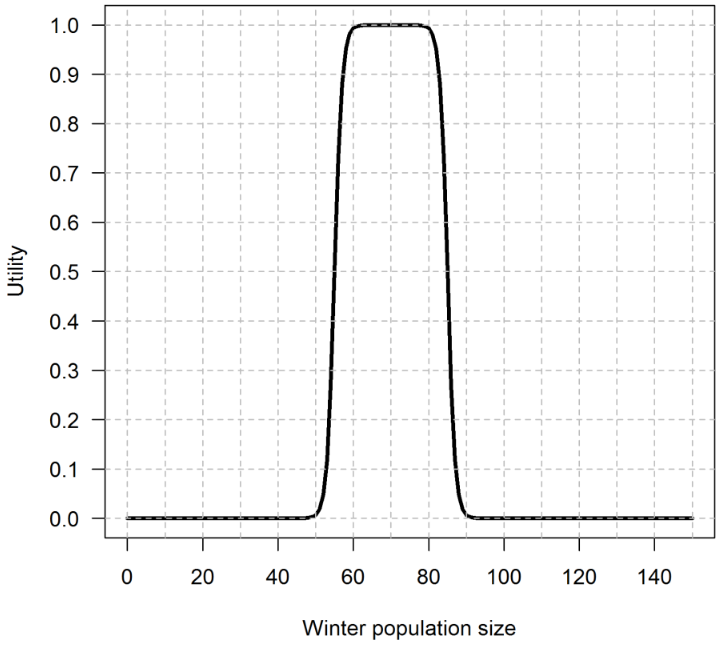


***Figure 2.*** *Possible utility of mid-winter population sizes of taiga bean geese in the Central Management Unit*

### *Alternative harvest quotas*

The ability of countries within the range of taiga bean geese to regulate their harvests is largely unknown. Therefore, for derivation of a dynamic harvest strategy we assumed annual, population-level harvest quotas in increments of 1,000 from 0 to 20,000, with the assumption that harvest could be regulated with this degree of precision. These alternative harvest levels could be adjusted as needed when more information about harvest levels and the ability to manipulate them become available. Although no data specific to Taiga Bean Geese are available, we assumed that young-of-the-year are twice as vulnerable to harvest as older birds based on studies of other goose species (Frederiksen et al. 2004, Madsen 2010, Alisauskas et al. 2011, Clausen et al. 2017).

### *Optimization and simulation*

The temporally constant harvest rate that is optimal is highly dependent on the desired time horizon for rebuilding the population. Yet the choice of a time horizon is highly subjective, and depends on objectives that may not be explicitly stated (e.g., the desire to provide some recreational harvest in the short term). Rather than prescribe a constant harvest rate, prescriptions for an annual (absolute) harvest could be calculated as optimal solutions to a Markov decision problem (MDP) (e.g., as with Pink-footed Geese). MDPs involve a temporal sequence of decisions, with strategies that identify actions at each decision point depending on the state of the managed system (Possingham 1997). The goal of the manager is to develop a decision rule that prescribes management actions for each possible system state that maximizes a temporal sum of utilities or values, which in turn are defined by the managers' objectives. A key advantage when optimizing MDPs is the ability to produce a feedback (or closed-loop) policy specifying optimal decisions for *possible* future system states rather than *expected* future states (Walters and Hilborn 1978). This makes optimization of MDPs appropriate for systems that behave stochastically, without any assumptions about the system remaining in a desired equilibrium or about the production of a constant stream of utilities. Moreover, specification of harvest management as a MDP would greatly facilitate development of a fully adaptive management program, in which reducing uncertainty about population dynamics is recognized as a goal of management.

A solution algorithm for a Markov decision process is dynamic programming (Puterman 1994), which we used to derive harvest strategies for the Central Management Unit of taiga bean geese. We used the open-source software MDPSolve© (https://sites.google.com/site/mdpsolve/) for Matlab (https://www.mathworks.com/) to compute optimal solutions for a theta-logistic population model based on demographic parameters provided in Table A1. See Appendix A for more details.

To predict management performance, we simulated both a constant-harvest-rate strategy

($h_a = 0.03$) and the optimal, dynamic strategy for the theta-logistic model with the fully specified age structured (matrix) model. We performed 100,000 simulations, each with a different parameterization of the matrix model as derived from random draws of the empirical distributions of demographic rates. Every simulation was run for a period of 10 years. We initialized population sizes as $N = 38,717$, which was the January 2018 count from Sweden, Denmark, and the Netherlands.

We also used the 100,000 realizations of the matrix model to estimate absolute harvest associated with constant adult harvest rates and varying population sizes, which might be observed in the monitoring program. We made the assumption that the age structure associated with a specified population size was equivalent to the stable age distribution associated with the transition matrices, $\underline{M}^i$; therefore, harvest quotas represent approximations.

## Results & Discussion

Using the constant harvest-rate strategy, harvest quotas increase non-linearly with population size (Figure 3). We note that this strategy was *not* derived based on an explicit formulation of objectives, and thus is not designed to maintain the population near the goal of 70,000. Rather, it is viewed as an interim harvest strategy, intended to allow some limited hunting opportunities while the population recovers. Thus, this strategy might be discontinued if the population exceeded the goal.

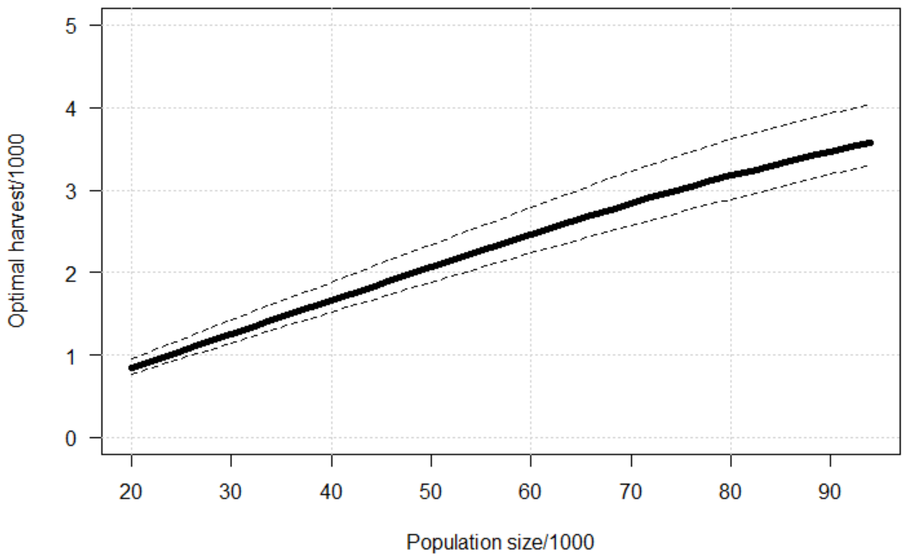


***Figure 3.*** *Median harvest quotas and 95% confidence limits for a range of taiga bean goose population sizes in the Central Management Unit in January based on a target adult harvest rate* $h_a = 0.03$

We simulated application of this constant harvest-rate strategy for a period of 10 years, beginning with the observed population size of 38,717 observed in January 2018. We contrasted these simulated population sizes with those arising from application of a dynamic strategy solely designed to maintain population size near its goal (Figure 4). Simulated population sizes for the constant harvest-rate strategy were highly variable, but the median approached the goal after about 8 years (Figure 5). We note that the large confidence limits on population size are attributable to model uncertainty, a moderate level of environmental variation, and imprecision in achieving the harvest quotas. With the dynamic strategy, the median population size in this case approached the goal after about 6 years (Figure 6).

The reason why the dynamic strategy more quickly achieves the goal can be seen in Figures 7 and 8. The constant harvest-rate strategy allows some harvest in the beginning of the time frame, whereas the dynamic strategy does not. This period of closed hunting seasons enables the population to recover more quickly than the constant harvest-rate strategy. With the constant harvest-rate strategy, the median change in harvest quota was 0 over the time frame, but simulations were variable, often with extreme changes in quotas (Figure 9). With the dynamic strategy, the median change in harvest quota between years was <200 birds over the entire time frame, although the amount of change was highly variable in the latter portion of the time period (Fig. 10).

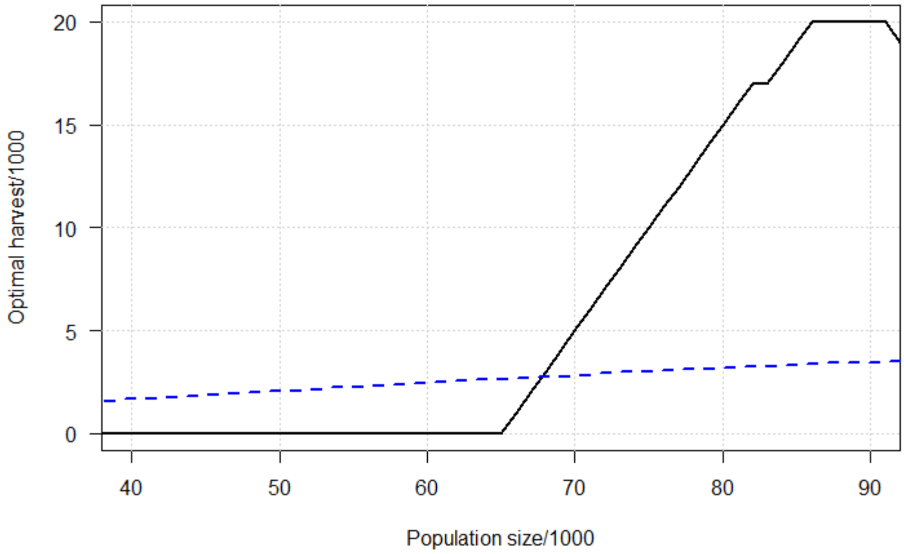


***Figure 4.*** *A dynamic harvest strategy (black solid line) design to maintain the population near its goal compared to the constant harvest-rate strategy with a target adult harvest rate* $h_a = 0.03$ *(blue dashed line) for the Central Management Unit of Taiga Bean Geese*

According to the constant harvest-rate strategy, the harvest quota for the 2018 season is 1,610 (95% CI: 1,472 – 1,825), based on the January 2018 count of 38,717 Taiga Bean Geese (Jensen et al. 2018. Taiga Bean Goose: Population status report 2017-2018. AEWA European Goose Management Platform) (Table 1). This contrasts with the 2017 quota of 2,335 (95% CI: 2,123 – 2,645) based on the January 2017 count of 56,792. Table 1 provides the allocation of the 2018 harvest quota among range states based on the agreed upon proportions of 15% for Russia, 49% for Finland, 26% for Sweden, and 10% for Denmark. We emphasize that these quotas include both harvest during the regular season and derogation shooting.

We acknowledge that the January 2018 count of taiga bean geese in the Central Management Unit was likely biased low. Counts in the autumn and spring in Sweden were higher than the January count, and the number of taiga bean geese wintering in Germany is unknown. However, the population model described in this report is based on an anniversary date of January, so it is not possible to use counts from other times of the year to estimate a harvest quota. Efforts are underway to address the deficiencies in monitoring population size, and this may ultimately require a revision of the population model used to inform harvest management. Additionally, the size of the harvest during the fall and winter of 2017-18 remains unknown, due to an inability to differentiate taiga and tundra bean geese in the harvest (Denmark), compilation of data too late to be used in this report (Sweden), and a lack of reporting (Germany). Efforts are underway to address these deficiencies as well, but it is unclear whether the 2017 quota of 2,335 (95% CI: 2,123 – 2,645) was exceeded, especially as this quota must include both recreational harvest and derogation shooting. Because of problems with both the population and harvest monitoring programs it is difficult to estimate a harvest quota for 2018 with any degree of confidence.

***Table 1.*** *State-specific harvest quotas (median and 95% confidence limits) of taiga bean geese in the Central Management Unit for the 2017 and 2018 hunting seasons, given a target adult harvest rate* $h_a = 0.03$ *and agreed-upon harvest allocation*

| | **2017** | | | **2018** | | |
|---|---|---|---|---|---|---|
| **State** | 2.5% | 50% | 97.5% | 2.5% | 50% | 97.5% |
| **Russia** | 319 | 350 | 397 | 221 | 241 | 274 |
| **Finland** | 1040 | 1144 | 1296 | 721 | 789 | 894 |
| **Sweden** | 552 | 607 | 688 | 383 | 419 | 475 |
| **Denmark** | 212 | 233 | 264 | 147 | 161 | 183 |
| **Total** | 2123 | 2335 | 2645 | 1472 | 1610 | 1825 |

Finally, we investigated how the dynamic strategy might vary with different weights on the objectives to maintain the population near its goal and to provide sustainable hunting opportunities. We examined weights on the population objective of 0.0, 0.5, and 1.0. The weight on the harvest objective is the compliment of the weight on the population objective (i.e., 1 – population weight). As expected, the harvest strategy becomes increasingly liberal with increasing emphasis on providing harvest opportunity (Figure 11). For a sole objective to maintain the population near its goal, simulated population size after 10 years was about 71,000, whereas it was about 61,000 with a strategy designed to maximize sustainable harvests (Table 2). For equal weights on the two objectives, the dynamic strategy produced intermediate values of simulated population size and harvest.

Further development of a dynamic harvest strategy, including elements required for adaptation based on what is learned from implementation of the strategy, depends on the development of better monitoring protocols, which at a minimum provide reliable estimates of population size and harvest at a flyway level. It will also require further discussions among stakeholders regarding the objectives of harvest management and what makes for acceptable tradeoffs among them.

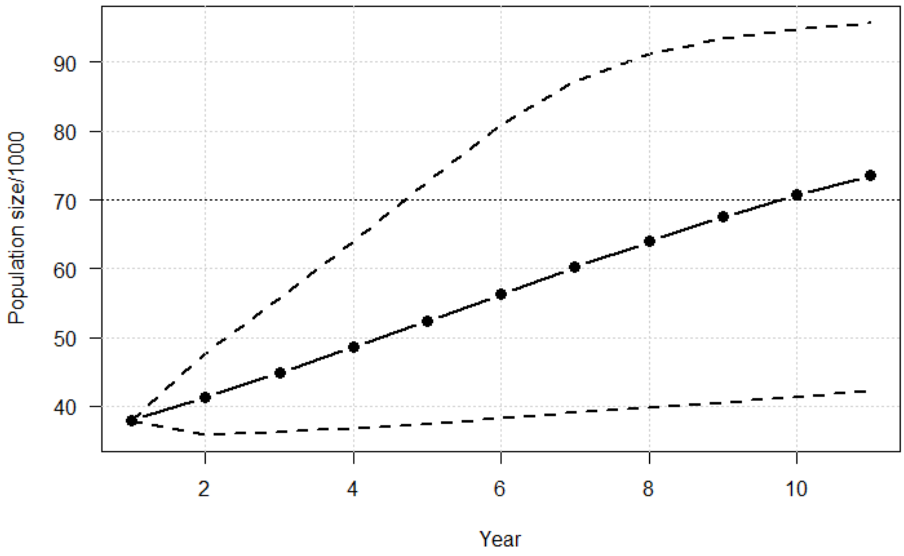


***Figure 5.*** *Simulated population sizes (median and 95% confidence limits) of taiga bean geese in the Central Management, given a target adult harvest rate* $h_a = 0.03$. The dotted horizontal line indicates the population goal of 70,000 birds in January.

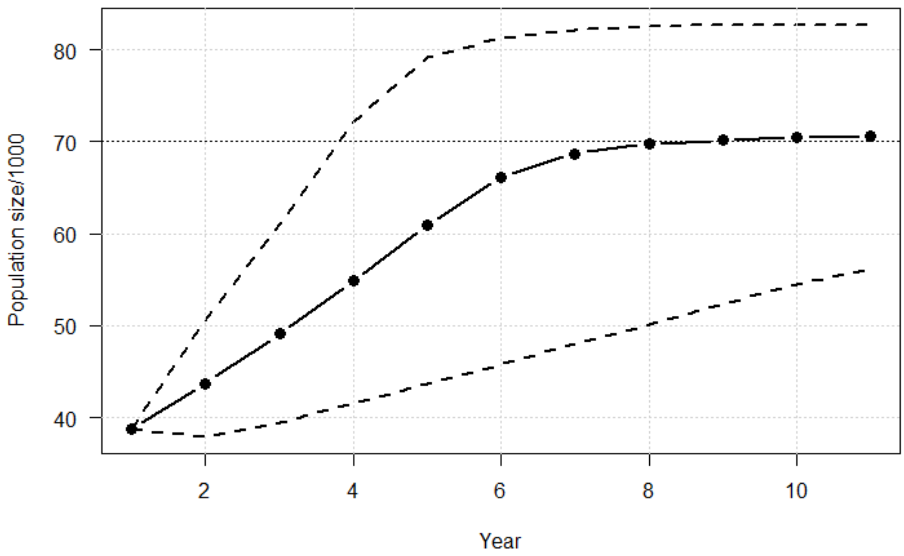


***Figure 6.*** *Simulated population sizes (median and 95% confidence limits) of taiga bean geese in the Central Management using a dynamic harvesting strategy with a sole objective of maintaining the population near the goal of 70,000 birds in January*

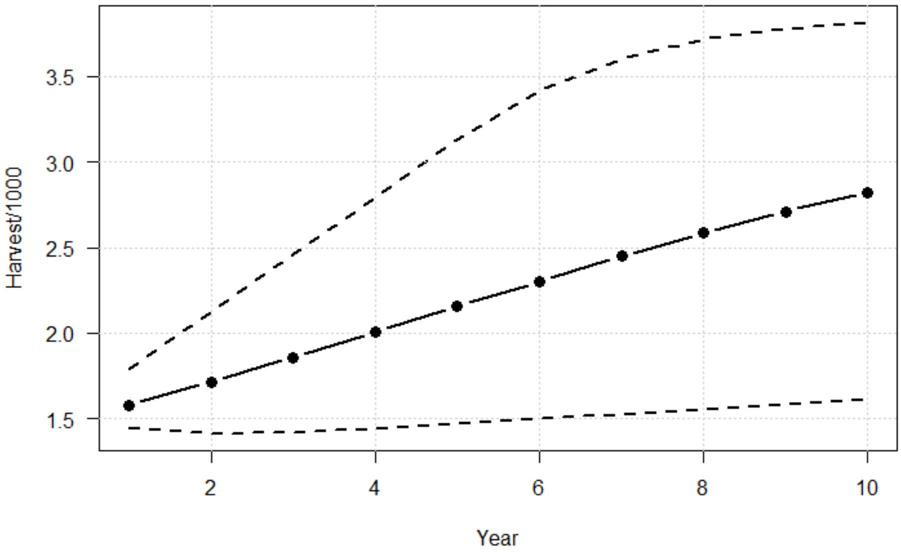


***Figure 7.*** *Simulated harvest quotas (median and 95% confidence limits) of taiga bean geese in the Central Management, given a target adult harvest rate* $h_a = 0.03$

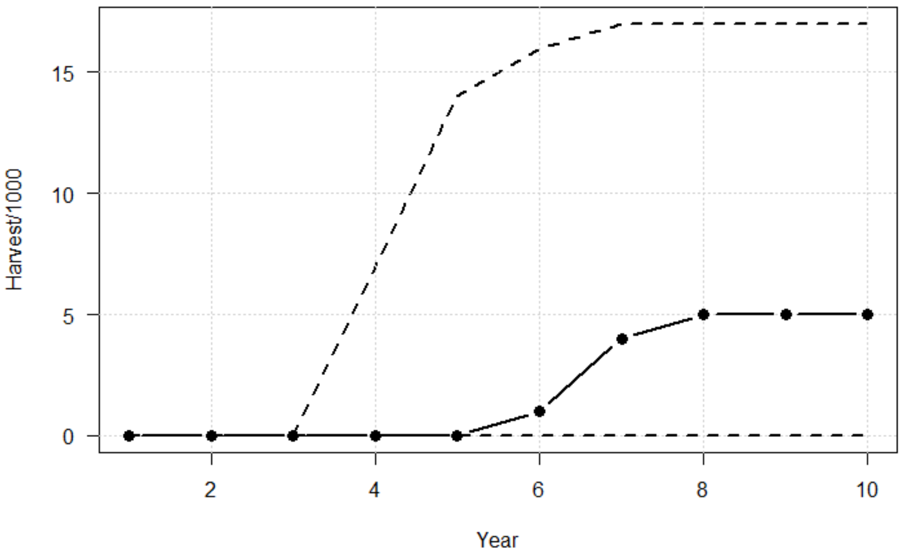


***Figure 8.*** *Simulated harvests (median and 95% confidence limits) of taiga bean geese in the Central Management using a dynamic harvesting strategy with a sole objective of maintaining the population near the goal of 70,000 birds in January*

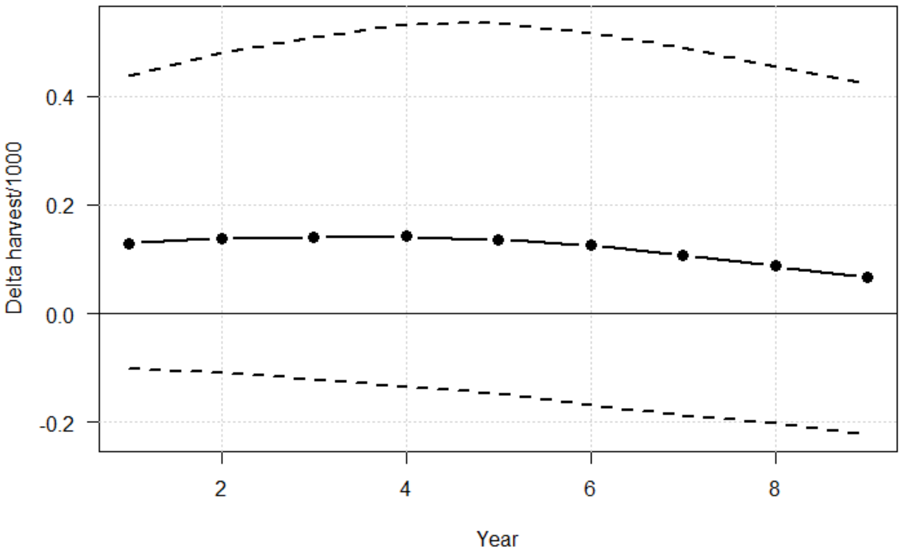


***Figure 9.*** *Simulated annual differences in harvest quotas (median and 95% confidence limits) of taiga bean geese in the Central Management, given a target adult harvest rate* $h_a = 0.03$

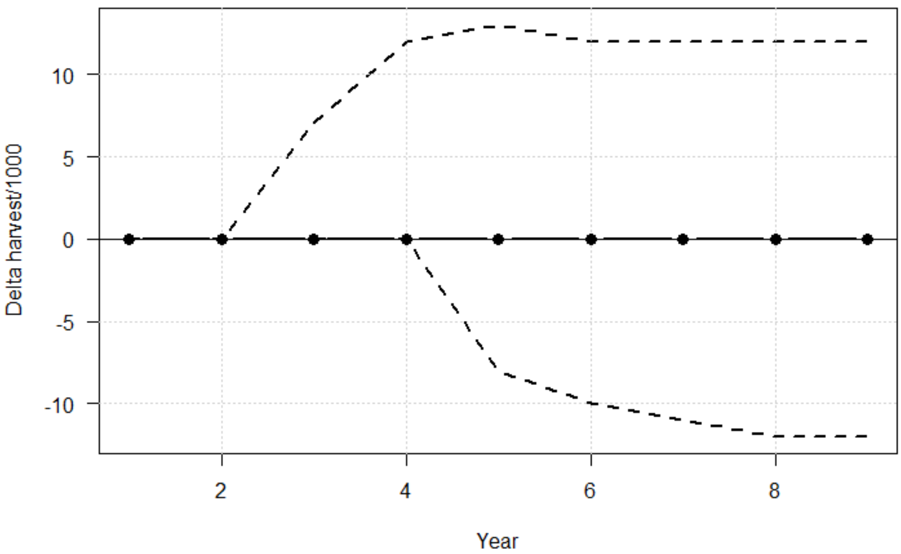


***Figure 10.*** *Simulated annual differences in harvest quotas (median and 95% confidence limits) of taiga bean geese in the Central Management using a dynamic harvesting strategy with a sole objective of maintaining the population near the goal of 70,000 birds in January.*

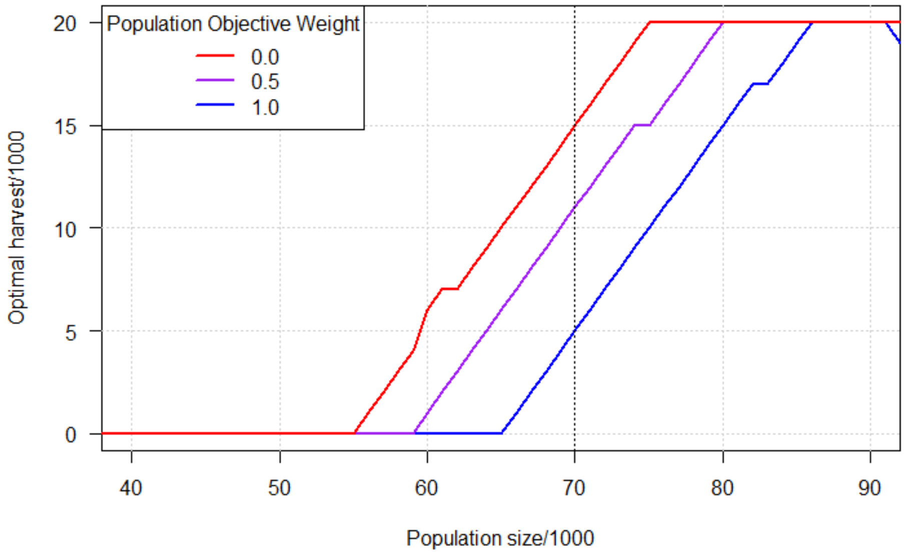


***Figure 11**. Dynamic harvest strategies for the Central Management Unit of taiga bean geese. The three strategies have different weights on the objective to maintain the population around 70,000 birds in January.* The weight on the objective of sustainable harvest is the compliment of the population objective weight.

***Table 2.** Medians and 95% confidence limits (in thousands) of simulated population sizes, harvest quotas, and annual changes in harvest quotas (Δ Harvest) for the Central Management Unit of taiga bean geese.* The three strategies have different weights on the objective to maintain the population around 70,000 birds in January. The weight on the objective of sustainable harvest is the compliment of the population objective weight. Note that for all three cases the median change in harvest quota from year to year was 0, although the confidence intervals on the magnitude of change varied slightly.

| Population objective weight | Population | Harvest | Δ Harvest |
|---|---|---|---|
| **1.0** | 70.6 (56.2 – 82.6) | 5 (0 – 17) | 0 (-12 - 12) |
| **0.5** | 65.2 (54.1 – 76.9) | 6 (0 – 17) | 0 (-11 – 11) |
| **0.0** | 61.2 (51.3 – 72.2) | 7 (0 – 17) | 0 (-10 – 10) |

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# Appendix A Models of population dynamics for taiga bean geese in the Central Management Unit

### *Model structure*

The matrix model representation of the life cycle is:

$$\begin{bmatrix} Y_{t+1} \\ J_{t+1} \\ A_{t+1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \gamma s_a (1-2h) \\ s_y (1-h) & 0 & 0 \\ 0 & s_j (1-h) & s_a (1-h) \end{bmatrix} \cdot \begin{bmatrix} Y_t \\ J_t \\ A_t \end{bmatrix},$$

where *t* represents year. After revising the model of Jensen (1995) to account for the lack of a terminal age class, the density-dependent matrix model with harvest is:

$$\vec{N}_{t+1} = \underline{H}_t \left( \vec{N}_t + \underline{D}_t \left( \underline{M} \vec{N}_t - \vec{N}_t \right) \right).$$

In this model, the transition matrix *without* harvest or density dependence is:

$$\underline{M} = \begin{bmatrix} 0 & 0 & \gamma s_a \\ s_y & 0 & 0 \\ 0 & s_j & s_a \end{bmatrix}.$$

Non-linear, age-specific density-dependence is:

$$\underline{D}_t = \begin{bmatrix} 1-\left(\frac{Y_t}{K_y}\right)^{\theta} & 0 & 0 \\ 0 & 1-\left(\frac{J_t}{K_j}\right)^{\theta} & 0 \\ 0 & 0 & 1-\left(\frac{A_t}{K_a}\right)^{\theta} \end{bmatrix},$$

where $K_i = p_i K$, with $p_i$ specified by the stable age distribution of $\underline{M}$, for $i \in \{Y, J, A\}$. The assumption of age-specific carrying capacities helps keeps the relative sizes of the age classes within biologically realistic bounds.

Following net growth in the population, we assume that young-of-the-year are twice as vulnerable to harvest as older birds; thus, the matrix of survival from harvest is:

$$\underline{H}_t = \begin{bmatrix} 1-2h_t & 0 & 0 \\ 0 & 1-h_t & 0 \\ 0 & 0 & 1-h_t \end{bmatrix}.$$

Absolute harvest is then a function of the harvest rate of adults and subadults, $h_t$, and the fall flight of each age class:

$$harvest_t = h_t \left( 2Y_t^F + J_t^F + A_t^F \right).$$

The fall flight in turn is calculated by assuming that net population growth precedes harvest:

$$\vec{N}_t^F = \vec{N}_t + \underline{D}_t \left( \underline{M} \vec{N}_t - \vec{N}_t \right).$$

This age-structured model is of limited utility in directing harvest management, however, because it requires the age structure of the population be observed prior to making a harvest decision (information which is not available). One of the most commonly used models without age structure to determine sustainable harvests is the discrete theta-logistic model (Gilpin and Ayala 1973):

$$N_{t+1} = N_t + N_t r \left[ 1 - \left( \frac{N_t}{K} \right)^{\theta} \right] - h_t N_t,$$

where $N$ is population size, $r$ is the intrinsic rate of growth, $K$ is carrying capacity, $\theta > 0$ is the form of density dependence, $h$ is harvest rate, and $t$ is time (assumed here to be in 1-year increments). Johnson et al. (2018) demonstrated that this model could be useful for guiding harvest management decisions even if the population is age structured. Importantly, this model only requires that total population size be observed in January.

***Model parameterization***

We parameterized the two population models using the methods described by Johnson et al. (2018). For the age-structured model, only a distribution of predicted survival rates for adults was available, but we assume that average survival from natural causes is the same among all age classes after birds survive their first winter. To allow for stochastic differences in age-specific survival, however, we drew survival rates of young and juveniles independently from the distribution of adult survival rates. Estimates of demographic parameters are provided in Table A1.

***Table A1.*** *Model-based demographic parameters of taiga bean geese in the Central Management Unit (medians and 95% confidence limits) as estimated by the methods of Johnson et al. (2018).* See model descriptions in text for an explanation of the parameters.

| Model | Parameter | 2.5% | 50% | 97.5% |
|---|---|---|---|---|
| **Age-structured** | $s_{\{y,j,a\}}$ | 0.775 | 0.885 | 0.941 |
| | $\gamma$ | 0.285 | 0.511 | 1.040 |
| | $\theta$ | 0.613 | 2.354 | 9.028 |
| | $K_y$ (in thousands) | 15.0 | 21.7 | 31.6 |
| | $K_j$ (in thousands) | 12.1 | 16.6 | 22.7 |
| | $K_a$ (in thousands) | 45.1 | 55.0 | 64.7 |
| **Theta-logistic** | $r$ | 0.115 | 0.149 | 0.190 |
| | $K$ | 85.5 | 93.6 | 103.6 |
| | $\theta$ | 0.613 | 2.354 | 9.028 |

***Derivation and simulation of dynamic harvest strategies***

Dynamic harvest strategies were calculated as passively adaptive strategies using stochastic dynamic programming. We used the open-source software MDPSolve© (https://sites.google.com/site/mdpsolve/) to compute optimal solutions. We also used MDPSolve to simulate the optimal policies to estimate their expected performance.

For simulation purposes, each initial population vector was parameterized using a random draw from a Dirichlet distribution with parameters equal to the stable age distribution of $\underline{M}_i$ (in percent). This allowed for uncertain, but plausible, values of the initial age distribution for simulation purposes. Finally, at each time step, we introduced random environmental variation by taking the deterministic outcomes for age-specific population sizes and multiplying each by independent values of $e^{\sigma}$, where $\sigma \sim Normal(0, 0.1)$; this produces a coefficient of variation of approximately 10% in annual predictions of population size in what otherwise would be deterministic projections. We also allowed for less than precise control over harvests in the same manner, but where $\sigma \sim Normal(0, 0.05)$. From the simulations, we summarized population sizes, harvests, and the magnitude of year-to-year changes in target harvests. All simulations and their analyses were performed using the open-source computing language R (RCoreTeam 2016).