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AN INTERIM HARVEST STRATEGY FOR TAIGA BEAN GEESE

Produced by the AEWA European Goose Management Platform Data Centre

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An Interim Harvest Strategy for Taiga Bean Geese*

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Abstract

In 2016 the AEWA European Goose Management International Working Group (EGM IWG) adopted document AEWA/EGM IWG 1.8 (Johnson et al. 2016), which contained initial elements of an Adaptive Harvest Management programme for Taiga Bean Geese. This report addresses a number of limitations with the population model presented in that document, and provides up-to-date population projections for the Central Management Unit under a range of constant harvest rates. Based on simulations for the 2017-2025 timeframe, median population size was near the median goal of 70,000 in 2019, 2020, and 2021 for harvest rates of birds aged one year or more of 0.00, 0.02, and 0.04, respectively. Simulated population sizes generally increased over the timeframe, albeit with a lot of variation and with the degree of uncertainty increasing over time. With a harvest rate of 0.02, harvests averaged 1,848 (95% CI: 1,403 – 2,492) over the timeframe; a harvest rate of 0.04 produced an average harvest of 3,484 (95% CI: 2,617 – 4,884). Future work for the Central Management Unit will involve development of a dynamic harvest strategy by employing a Markov decision process, in which multiple, possibly competing, management objectives can be addressed.

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

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Johnson et al. (2016). Optimal harvest *rates* (i.e., the proportion of the population that is harvested) for 5, 10, 15, and 20-year time horizons were h = 0.00, 0.02, 0.05, and 0.06, respectively. These optima represent a tradeoff between the harvest rate and the time required to achieve and maintain a population size within desired bounds. Johnson et al. (2016) also reported the length of time it would take under ideal conditions (no density dependence and no harvest) to rebuild depleted populations in the Western and Eastern Management Units. Populations of Taiga Bean Geese in the Western and Eastern Units would require at least 10 and 13 years, respectively, to reach their minimum goals under the most optimistic of scenarios. The presence of harvest, density dependence, or environmental variation could extend these timeframes considerably. Finally, Johnson et al. (2016) stressed that development and implementation of internationally coordinated monitoring programs will be essential to further development and implementation of adaptive harvest management programs for Taiga Bean Geese.

During their meeting in December 2016, the EGM IWG adopted the following positions in response to the report of Johnson et al. (2016):

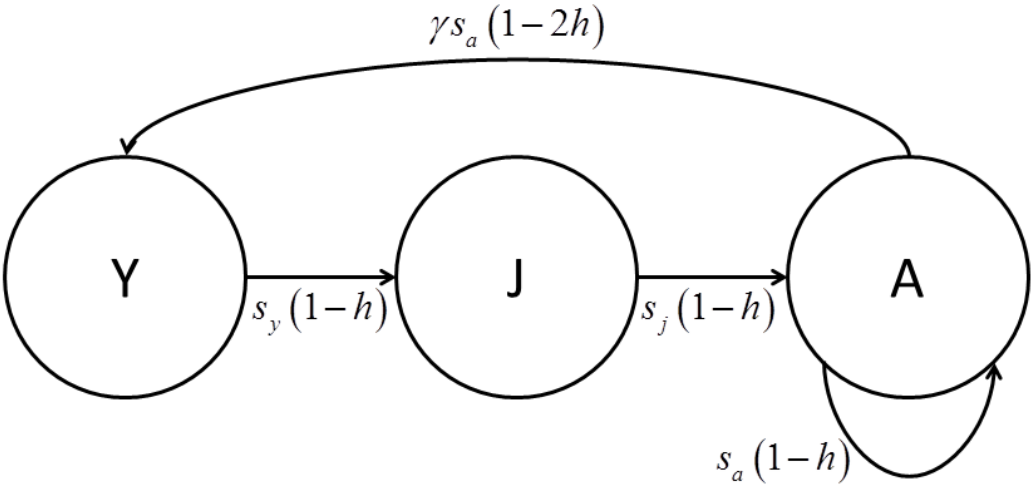
- The EGM IWG adopted document AEWA/EGM IWG 1.8 (i.e., Johnson et al. 2016) containing initial elements of an Adaptive Harvest Management programme for Taiga Bean Geese developed on the basis of predictive models.
- The EGM IWG adopted the continuation of the closed hunting season for the Western and closure of hunting for the Eastern 1 & 2 Management Units (MU) until such time as further management alternatives could be possibly outlined for consideration on the basis of strengthened datasets
- For the Central MU the EGM IWG decided to defer the decision on one of the management alternatives until the next EGM IWG Meeting in June 2017, subject to the availability of a better information basis following the mid-January counts.

Especially relevant in the context of this progress summary is the decision to defer until June 2017 the choice of a constant harvest rate for the Central Management Unit. In hindsight, this was fortunate because there are a number of limitations with the population model used by Johnson et al. (2016):

- The theta-logistic population model can exhibit pathological (i.e., biologically unrealistic) behavior for populations that are far above carrying capacity, K. This was an unrecognized problem in the population simulations, where the sampled growth rate sometimes allowed the population to greatly over-shoot K. We have addressed this problem in what follows by setting K as an upper bound on population size.

- Johnson et al. (2016) used the density-dependent matrix model developed by Jensen (1995), but we discovered this model is valid only when there is a terminal age class (i.e., a fixed maximum lifespan). The life cycle formulation for Taiga Bean Geese does not have a terminal age class, and the result was that population projections in Johnson et al. (2016) were biased low. We herein generalize Jensen's (1995) model of population dynamics to account for the lack of a terminal age class.
- As a result of the problem concerning lack of a terminal age class, harvests associated with varying population sizes and harvest rates reported by Johnson et al. (2016) were also biased low. We rectified this problem by assuming that the January population experiences net growth prior to the following season's harvest. We believe this to be a reasonable assumption, given the relatively long period between January and harvest in the subsequent fall and winter.

Revised Models of Population Dynamics. – We retained the age-structured population model



described by Johnson et al. (2016), but now allow for age-specific survival rates (Fig. 1).

Fig. 1. Life cycle of Taiga Bean Geese based on a mid-winter 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, γ. In addition to accounting for age at first breeding, this model allows for age-specific survival rates and for the fact that young-of-the-year are twice as vulnerable to harvest as older birds.

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, 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:

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

Model Parameterization and Simulation. – We parameterized the population model using the methods of Johnson et al. (2016). 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. Demographic parameters used in this report are provided in Table 1.

Table 1. Model-based demographic parameters of Taiga Bean Geese in the Central Management Unit as estimated by the methods of Johnson et al. (2016). See the model description in text for an explanation of the parameters.

Parameter	2.5%	50%	97.5%
$s_{\{y,j,a\}}$	0.775	0.885	0.941
γ	0.285	0.511	1.040
θ	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

We performed i =100,000 simulations of population dynamics with constant harvest rates, each with a different parameterization of the matrix model as based on random draws of the empirical distributions of demographic parameters. Every simulation was run for a period of 9 years (i.e., until 2025). We examined adult harvest rates of 0.00, 0.02, and 0.04, as higher rates are not expected to allow the population to reach the goal of 70,000 within the timeframe. We initialized population size at 57,000, which was the count from January 2017 in Sweden and Denmark (no count for 2017 was available from Germany). 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 environment variation by taking the deterministic outcomes for age-specific population sizes and multiplying each by independent values of e^{σ}, where $\sigma \sim Normal(0, 0.1)$; this produces a coefficient of variation of approximately 10% in what otherwise would be deterministic population projections. From the simulations, we summarized population sizes and harvests.

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. Here 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, $\underline{M}^i$. All simulations were performed using the open-source computing language R (RCoreTeam 2016).

Results & Discussion

Simulated population sizes generally increased over the timeframe, albeit with a lot of variation and with the degree of uncertainty increasing over time (Fig. 2). Median population size was near the median goal of 70,000 in 2019, 2020, and 2021 for harvest rates of birds aged one year or more of 0.00, 0.02, and 0.04, respectively. A decline in population size over the timeframe was possible with a harvest rate of 0.04. With a harvest rate of 0.02, harvests averaged 1,848 (95% CI: 1,403 – 2,492) over the timeframe; with a harvest rate of 0.04 harvest averaged 3,484 (95% CI: 2,617 – 4,884).

Approximate harvests for varying population sizes and harvest rates are provided in Table 1. It is important to remember that these harvests must account for all shooting mortality, including recreational harvest, derogation shooting, and crippling loss. The confidence interval accounts for uncertainty about demographic rates, and might be viewed as the range of acceptable harvests for a given population size and harvest rate.

We made a concerted effort to account for uncertainty about population dynamics, as well as for a moderate level of environmental variation, in simulating harvest strategies for the Central Management Unit of Taiga Bean Geese. Harvesting in the face of such uncertainty involves an element of risk that cannot be avoided, and the attitude toward that risk is the purview of policy makers rather than scientists.

Finally, we note that the management process described in this report for the Central Management Unit still does not yet represent a fully adaptive strategy. Adaptation based on what is learned depends on the ability to make predictions about changes in population size that are model-specific, as well as an ability to measure, at a minimum, actual harvest and population size each year. The comparison of monitoring observations and model predictions then permits models to be improved so that better decisions can be made in the future. We continue to emphasize the need to develop and implement annual monitoring protocols for all management units of Taiga Bean Geese, in which common standards for data collection, reporting, and summarization are rigorously applied.

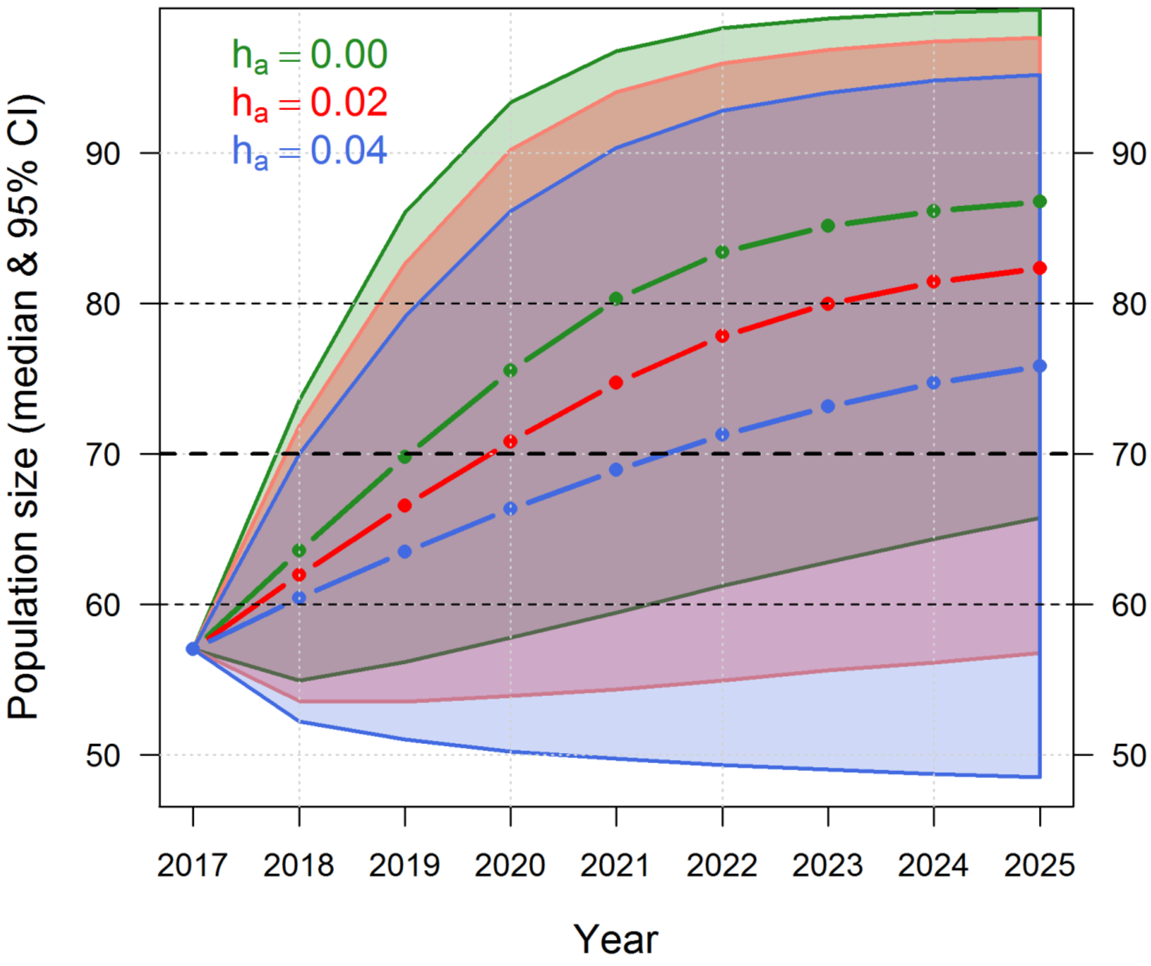


Fig. 2. Simulated population sizes of Taiga Bean Geese in the Central Management, given varying harvest rates of birds aged one year or more, h_a. The dashed, horizontal lines indicate the population goal of 60,000 - 80,000 birds in January.

Table 1. Approximate, median harvests and 95% confidence limits for a range of Taiga Bean Goose population sizes (N) and two constant, harvest rates of birds aged one year or more, h_a.

	Harvest/1000					
	$h_a = 0.02$			$h_a = 0.04$		
N/1000	2.50%	50%	97.50%	2.50%	50%	97.50%
45	1.135	**1.243**	1.407	2.270	**2.486**	2.815
50	1.255	**1.377**	1.559	2.511	**2.753**	3.118
55	1.374	**1.510**	1.710	2.748	**3.020**	3.421
60	1.490	**1.640**	1.858	2.981	**3.281**	3.715
65	1.604	**1.768**	2.005	3.207	**3.536**	4.011
70	1.714	**1.891**	2.151	3.429	**3.782**	4.297

Future Work

Dynamic harvest strategies. – 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 (or minimizes) a temporal sum of utilities, 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 the need to rely on assumptions about the system remaining in a desired equilibrium or 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.

Management objectives. – The 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 suggest a mid-winter population goal of $\alpha = 70,000$ Taiga Bean Geese, and inflection points of $\left[\alpha - \beta, \alpha + \beta\right]$, where $\beta = 15,000$. This utility function thus expresses near-complete satisfaction with population sizes in the range 60,000-80,000, with satisfaction declining for population sizes outside this range (Fig. 3). The form of this utility curve is similar to the one used for adaptive harvest management of pink-footed geese.

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. 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 provide 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.

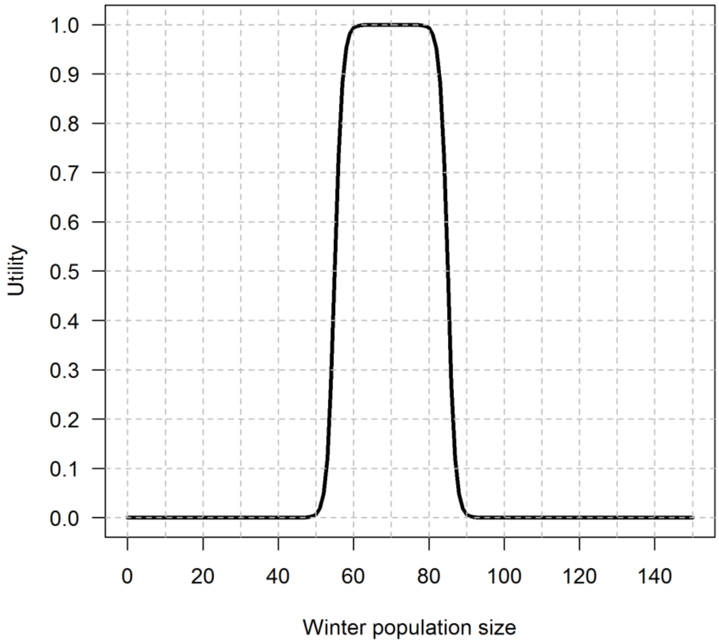


Fig. 3. Possible utility of mid-winter population sizes of Taiga Bean Geese in the Central Management Unit.

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