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### HARVEST ASSESSMENT FOR TAIGA BEAN GEESE IN THE CENTRAL MANAGEMENT UNIT: 2020

Report prepared by the AEWA European Goose Management Platform Data Centre

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### **Summary**

This report focuses on the Central Management Unit of Taiga Bean Goose (Anser fabalis fabalis), encompassing breeding areas in northernmost Sweden, Northern and Central Finland, Northeast Norway, and in Russian Karelia, the Kola Peninsula and Arkhangelsk district. Birds from this Management Unit mostly winter in Sweden, Denmark and Germany, but all stage in Sweden. In this report, we briefly describe an integrated population model (IPM), the sources of data used to fit the IPM, and some preliminary results regarding Taiga Bean Goose demography. This report also uses the IPM to explore several harvest scenarios for consideration for the upcoming 2020/2021 hunting season. We caution the reader that the population size and harvest data currently used in the IPM contain varying levels of Tundra Bean Geese (Anser fabalis rossicus), although monitoring protocols have recently included efforts to better identify the two subspecies. Median estimates of the intrinsic rates of natural survival and reproduction (i.e., biological maxima) were 0.91 and 0.46, respectively. Median carrying capacity in spring was estimated to be 84,000 birds, with the strongest density dependence operative in populations close to carrying capacity. The estimate of the slope of the relationship between the January count and January temperature in southern Sweden was positive, implying that January counts are more biased in colder winters; January counts appear to be an average of 44% lower than true population sizes. Estimates of population size increased over the last decade in all three months in which Taiga Bean Geese were counted, especially so after the Finnish harvest moratorium in 2014. Estimated population size was 80,700 in October 2019, 77,000 in January 2020, and 75,200 in March 2020. Estimated harvest rates declined dramatically following the Finnish harvest moratorium in 2014, and this decrease in harvest pressure coincides with strong growth in the population. Harvest rates during 2014-2018 (i.e., the period of the Finnish moratorium, and for years in which harvest estimates are available from all Range States) averaged 0.046, which is higher than the agreed upon harvest rate of 0.03 in the interim harvest strategy. A continued harvest of the mean levels observed during 2014–2018 (about 3,300 birds) would be expected to result in a March population stabilizing around its current level of about 75,000. If the Finnish moratorium were lifted and harvest levels returned to those observed during 2009-2013 (about 8,900 birds), we would expect a harvest rate of about 0.12 and a mean population size of about 64,000 after five years. A total harvest of 6,500, of which 3,770 is allocated to Finland, 1,950 to Sweden, and 780 to Denmark, could be expected to maintain the population near the median goal of 70,000 (at least in the short term). For comparison, the mean

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harvest during 2014–2018 was 45, 2,199, and 1,103 Bean Geese harvested in Finland, Sweden, and Denmark, respectively.

## Introduction

The International Single Species Action Plan for the Conservation of Taiga Bean Goose (Marjakangas et al. 2015) recognized a dramatic and range-wide decline in population size and thus mandated a variety of corrective measures. Chief among these was the development and implementation of an international Adaptive Harvest Management (AHM) framework to adjust harvest levels to reflect the status of the population, based on agreed upon objectives, management alternatives, predictive models, effective monitoring programs, and iterative learning. This harvest assessment report is only concerned with the Central Management Unit of Taiga Bean Goose, encompassing breeding areas in northernmost Sweden, Northern and Central Finland, Northeast Norway, and in Russian Karelia, the Kola Peninsula and Arkhangelsk district. Birds from this Management Unit mostly winter in Sweden, Denmark and Germany, but all stage in Sweden. Annual censuses are conducted in Sweden during October and March, and in Sweden, Denmark and adjacent countries in mid-January. Abundance of Taiga Bean Geese in the Western Management Unit is currently considered too low to support recreational harvest, and estimates of population size and harvest are largely unavailable for the Eastern Management Unit.

An initial assessment of harvest potential for the Central Management Unit was completed in 2016. In 2017, the European Goose Management Platform adopted a strategy consisting of a constant harvest rate of 3% to assist recovery of the population while providing limited hunting opportunities. In 2018, significant advances were made in harvest-assessment methods for species with sparse data, using Taiga Bean Geese as a case study (Johnson et al. 2018). In 2019, Finland (Finnish Wildlife Agency and Natural Resources Institute) funded the development of an integrated population model (IPM) for the purpose of further improving harvest management. A progress report concerning development of the IPM was produced in March 2020 (Johnson et al. 2020).

Integrated population models represent an advanced approach to modeling, in which all available demographic data are incorporated into a single analysis. IPMs have many advantages over traditional approaches to modeling, including the proper propagation of demographic uncertainty, better precision of demographic rates and population size, the ability to handle missing data and estimate latent (i.e., unobserved) variables, and the capacity to guide the development of effective monitoring programs. Moreover, use of a Bayesian estimation framework for IPMs provides a natural framework for adaptation, in which model parameters can be updated over time based on observations from operational monitoring programs.

In this report, we briefly describe the IPM, the sources of data used to fit the model, and some preliminary results regarding Taiga Bean Goose demography. This report also uses the IPM to explore several harvest scenarios for consideration for the upcoming 2020/2021 hunting season. We note that there are some differences in the results between the IPM progress report and this report as a consequence of updating the IPM with an additional year of monitoring data.

## Methods

## **1. Population Dynamics**

Due to a paucity of data for this population, we relied heavily on previous work to specify model structure and for parameterizing prior distributions of model parameters (Johnson et al. 2018). Most notably, we used a discrete theta-logistic model rather than an age-specific matrix model. The theta-logistic model requires less

monitoring data to parameterize and appears capable of providing reasonable management performance even if the population is age structured (Johnson et al. 2018).

A key consideration in constructing an IPM is how to account for abundance that is observed at multiple times during the annual cycle. Counts of Taiga Bean Geese are available in January, March, and October (albeit with some level of contamination from Tundra Bean Geese). We consider March abundance as the start of the breeding season and the annual cycle. The challenge is to reframe the theta-logistic model, which only predicts annual changes in abundance, to one that will predict population size at other times during the year. In the following, we show how this can be done, initially assuming no density dependence in survival or production, and then accounting for density dependence. In this approach we make a limited number of assumptions: (1) all production occurs between March and October; (2) natural mortality is evenly distributed throughout the year; (3) density-dependence acts on both production and annual survival, and is based on abundance in March; and (4) the Finnish harvest represents the number of birds taken prior to the October count (Mikko Alhainen, personal communication).

To accommodate multiple counts during the year, we begin with the theta-logistic model with density dependence:

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

where N is population size, r is the *intrinsic* (or biological maximum) rate of growth, K is carrying capacity,  $\theta$  is a parameter describing the type of density dependence (i.e., concave, linear, or convex), H is total harvest, and t is year. Now we omit harvest and density dependence:

(2) 
$$N_{t+1} = N_t + N_t r$$
$$= N_t (1+r)$$

The expression (1+r) is the intrinsic finite rate of population growth, which can also be expressed in terms of intrinsic survival from natural causes,  $\psi$ , and production,  $\gamma$ :

(3) 
$$N_{t+1} = N_t \psi + N_t \psi \gamma$$
$$= N_t (\psi + \psi \gamma)$$

Therefore:

(4) 
$$1 + r = \psi + \psi \gamma$$
$$r = \psi + \psi \gamma - 1$$

In the theta-logistic model, the *realized* rate of population growth results from a reduction in the intrinsic rate of growth based on the size of the population relative to carrying capacity:

(5) 
$$r' = r \left( 1 - \left( \frac{N_t}{K} \right)^{\theta} \right)$$

Thus, to incorporate density dependence into a model with explicit survival and production rates, we simply

multiply both sides of Equation 4 by 
$$\left(1 - \left(\frac{N_t}{K}\right)^{\theta}\right)$$
:  
(6)  $r\left(1 - \left(\frac{N_t}{K}\right)^{\theta}\right) = (\psi + \psi\gamma - 1)\left(1 - \left(\frac{N_t}{K}\right)^{\theta}\right)$ 

And now by substitution in our original theta-logistic model:

(7) 
$$N_{t+1} = N_t \left\{ 1 + \left[ \left( \psi \left( 1 + \gamma \right) - 1 \right) \left( 1 - \left( \frac{N_t}{K} \right)^{\theta} \right) \right] \right\} - H_t$$

Having survival and production as explicit parameters allows us to implement our assumptions concerning timing of annual events. Thus, we predict abundance in October as a function of March abundance,  $N^M$ :

(8) 
$$N_t^O = N_t^M + N_t^M \left[ \left( \psi^{7/12} \left( 1 + \gamma^1 \right) - 1 \right) \left( 1 - \left( \frac{N_t^M}{K} \right)^{\theta} \right) \right] - H_t^F$$

in which we assume seven months of natural mortality, all of the reproduction, and a portion of the total harvest occurring prior to October, where  $H_t^F$  represents the harvest in Finland.

Abundance in January is conditional on October abundance:

(9) 
$$N_t^J = \left(N_t^O - H_t^D - \alpha H_t^S\right) \psi^{\frac{3}{12}}$$

where  $H_t^D$  and  $H_t^S$  represent harvests in Denmark and Sweden, respectively, and where  $\alpha$  represents the proportion of the Swedish harvest occurring prior to January (i.e., the regular hunting season).

Abundance in the following March is thus:

(10) 
$$N_{t+1}^{M} = \left(N_{t}^{J} - (1 - \alpha)H_{t}^{S}\right)\psi^{\frac{2}{12}}$$

where  $(1-\alpha)$  represents the proportion of the Swedish harvest that is taken after the regular season to help prevent crop damage (i.e., conditional hunting).

#### 2. Data and Model Fitting

Abundance and harvest statistics are compiled annually by the EGMP Data Centre and provided in a population status report (Henning et al. 2020)<sup>1</sup>. We caution the reader that the data currently used in the IPM for population size and harvest contain varying and largely unknown levels of Tundra Bean Geese, although monitoring protocols now include efforts to better identify the two subspecies.

<sup>&</sup>lt;sup>1</sup> There may be minor differences in the data reported in this harvest assessment and that in the population status report depending on when final data were received and the time remaining for analysis.

March counts of Taiga Bean Geese in Fennoscandia (Skyllberg 2015) were compiled for the years 2007-2020, with the exception of 2010 and 2013 when no March counts were conducted. It is believed that about 4,000 of the birds in the March count are of the tundra subspecies.

Bean Geese have also been counted in Sweden in October since 1977. Only since 2016 has an attempt been made to differentiate the subspecies, with an average of 11% (about 7,000 birds) likely being of the tundra subspecies. However, October is considered among the best months to count Taiga Bean Geese of the Central Management Unit (Leif Nilsson, personal communication). At this time of the year, the breeding birds from northern Fennoscandia and neighboring parts of Russia have reached southern Sweden and according to neck-banding studies have only rarely left the country.

Finally, Bean Geese have been counted in January in Sweden since 1978 and in Denmark since 1980. Attempts to differentiate the subspecies in both countries have been made since 2014. Since then, about 11% (about 4,000 birds) of the Bean Geese in Sweden have been identified as being of the tundra subspecies. In Denmark, a mean of about 5,000 Taiga Bean Geese have been counted since 2014. Therefore, we used only January counts from Sweden, reasoning that the number of Tundra Bean Geese included in those counts was similar to the excluded count of Taiga Bean Geese in Denmark.

From a biological perspective, we would expect October abundance to be the highest, followed by January and then by March (i.e., reproduction and a limited harvest occurs between March and October; only mortality occurs between October and March). Generally, October counts are highest, but January counts in Sweden (which has the most complete data and harbors most of the geese in January) are lower than the counts in March, which is not biologically plausible (i.e., the January counts may be biased low). It is well known that Taiga Bean Geese winter in Germany and Poland, where they are not counted. Managers suspect that harsh winters drive more birds into Germany and Poland, a conclusion apparently supported by the positive relationship between the January count January temperature in southern Sweden and (https://www.tutiempo.net/clima/ws-26360.html; accessed February 19, 2020) (Figure 1).



January temperature

*Figure 1*. January counts of Bean Geese in Sweden as a function of the average January temperature (Celsius) at the Malmo airport in southern Sweden. The dashed line represents the best-fitting linear model.

Estimates of total Bean Goose harvest are available from 1996 onward for Finland, Sweden, and Denmark. However, the 2019/2020 estimate of harvest in Sweden will not be available until October 2020. Thus, we have used the average of harvest during 2014-2018 as a placeholder for this datum. In recent years, efforts have been made to distinguish the two subspecies in the harvest. In Sweden in 2017, 10-24% of the Bean Goose harvest was judged to be of the tundra subspecies. In Finland since 2017, a mean of 80% of the harvest was judged to be of the tundra subspecies, but sample sizes and total harvests there have been extremely low. Comparable data are not yet available for Denmark, but the proportion of the taiga subspecies in the total Bean Goose harvest is believed to be very low because of regional hunting restrictions where Taiga Bean Geese concentrate.

For purposes of fitting the IPM, we assembled a complete set of population and harvest data for Finland, Sweden, and Denmark for the calendar years 1996-2020 (Appendix). To fit the IPM we used JAGS 4.3.0 (Plummer 2003), run in the R computing environment (R Core Team 2018) using runjags (Denwood 2016). For each model we used three chains of 550,000 iterations and retained the last 50,000 samples from each chain for analysis. We assessed parameter convergence using the potential scale reduction factor, psrf (Gelman and Rubin 1992), and assumed values of psrf < 1.1 indicated parameter convergence (Gelman and Hill 2006). Unless otherwise noted, we report the medians and 95% credible intervals of posterior estimates.

## 3. Harvest Scenarios

We used the fitted IPM to project mean population size (Kéry and Schaub 2012) for five future years under three harvest scenarios: (a) using mean harvests in Finland, Sweden, and Denmark from 2014–2018 when Finland had a Taiga Bean Goose moratorium (total = 3,346); (b) using mean harvests of the five years prior to the moratorium in Finland (2009-2013) (total = 8,898); and (c) using a mean harvest expected to keep the spring population near the median goal of 70,000, assuming the agreed upon allocation among Range States. For (c), we used an equilibrium analysis (Conroy and Carroll 2009), along with the posterior estimates of demographic parameters from the theta-logistic population model, to approximate the allowable harvest. We note that the Russian harvest is unknown, and in the IPM it is implicitly included as natural mortality. We thus re-normalized the remaining Range States' desired harvest allocation as 58%, 30%, and 12% for Finland, Sweden, and Denmark, respectively. All prior distributions for hypothetical future harvests for each Range State and for each year were specified as Poisson distributions with means based on the three harvest scenarios.

# Results

Among the four key demographic parameters in the deterministic model  $(\psi, \gamma, K, \theta)$  (Table 1), only the posterior distribution for reproductive rate,  $\gamma$ , differed markedly from its prior distribution. This was not unexpected due to extrinsic identifiability problems (Kéry and Schaub 2012) arising from the limited nature of the available data (i.e., only abundance and harvests). Median estimates of intrinsic survival and reproductive rates (i.e., biological maxima) were 0.91 and 0.46, respectively. Median carrying capacity in spring was 84,000, with the strongest density dependence operative in populations close to carrying capacity ( $\theta > 1$ ). The posterior estimate of the slope of the relationship between the January count and January temperature in southern Sweden was positive, implying that January counts are more biased in colder winters. The IPM suggested the January count was 44% less on average than the true abundance (range: 27-63%).

Parameter	Prior median	Prior 95% CI	Posterior median	Posterior 95% CI	
Natural survival ( $\psi$ )	0.884	0.793-0.947	0.909	0.849-0.958	
Reproductive rate $(\gamma)$	0.298	0.179-0.496	0.465	0.343-0.601	
Carrying capacity (K)	87,553	80,951–94,693	84,134	77,870–90,659	
Form of density	2.340	1.300-4.212	2.227	1.330-3.442	
dependence $(\theta)$					

*Table 1*. Prior and posterior estimates of demographic parameters for Taiga Bean Geese in the Central Management Unit based on an IPM. Natural survival and reproductive rates are intrinsic values (i.e., biological maxima).

Posterior population estimates aligned reasonably well with the counts in March and October, with the exception of March counts at the beginning and end of the time series. We note that the IPM progress report suggests these data are better fit using a fixed-year or random-year effect for the intrinsic reproductive rate. Posterior estimates of population size exhibited less variability than the counts due to observation errors of the latter (i.e., under and over counting) and the autoregressive nature of the population model (Figure 2). Posterior estimates of abundance were reasonably precise, but it is important to note that these estimates are from a deterministic model that omits any environmental variation (which would lead to less precision). Posterior estimates of population size increased over the last decade for all three months, especially so after the Finnish harvest moratorium in 2014. Estimated population size was 80,700 (75,900–86,100) in October 2019, 77,000 (72,100–82,200) in January 2020, and 75,200 (70,200–80,500) in March 2020.



*Figure 2*. Posterior estimates of the abundance of Taiga Bean Geese in the Central Management Unit (in thousands, in black, with 95% credible intervals in grey). Raw counts are in red. The vertical, dashed lines represent the last year of empirical data. Future (mean) abundances were projected based on the 2014–2018 average harvests from Finland, Sweden, and Denmark.

We also derived estimates of annual harvest and apparent survival rates of the population (Figure 3). Estimated harvest rates declined dramatically following the Finnish harvest moratorium in 2014, and this decrease in

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harvest pressure coincides with strong growth in the population. Harvest rates during 2014–2018 (i.e., the period of the Finnish moratorium, and for years in which harvest estimates are available from all Range States) averaged 0.046 (0.034–0.058), which is higher than the agreed upon harvest rate of 0.03 in the interim harvest strategy. Estimates of apparent survival increased markedly with implementation of the Finnish harvest moratorium, and have averaged 0.867 (0.856–0.878) in recent years. We refer to these estimates as "apparent" survival because actual survival rates may have been less if density dependence operated on survival in a significant way.



*Figure 3*. Posterior estimates of harvest and apparent survival rates of Taiga Bean Geese in the Central Management Unit, with 95% credible intervals in grey. The vertical, dashed lines represent the last year of empirical data. Future (mean) rates were projected based on the 2014–2018 average harvests from Finland, Sweden, and Denmark (about 3,300 birds).

With regard to future harvest scenarios, a continued harvest of the mean levels observed during 2014–2018 (about 3,300 birds) would be expected to result in a March population stabilizing around its current level of about 75,000 (Figure 2). If the Finnish moratorium were lifted and harvest levels returned to those observed during 2009–2013 (about 8,900 birds), we would expect a harvest rate of about 0.12 and a mean population size of about 64,000 after five years (Figure 4). Finally, to produce a March population size of about 70,000 after five years, we would require a harvest rate of about 0.09, or a total harvest of about 6,500 birds (Figure 5).



*Figure 4*. Posterior estimates of annual harvest rate and March population size (in thousands) of Taiga Bean Geese in the Central Management Unit, with 95% credible intervals in grey. The vertical, dashed lines represent the last year of empirical data. Future means were projected based on the 2009–2013 average harvests from Finland, Sweden, and Denmark (about 8,900 birds).



*Figure 5*. Posterior estimates of annual harvest rate and March population size (in thousands) of Taiga Bean Geese in the Central Management Unit, with 95% credible intervals in grey. The vertical, dashed lines represent the last year of empirical data. Future means were projected based on attaining a population level of 70,000, dependent upon a total harvest of 6,500, with proportions allocated among Finland (58%), Sweden (30%), and Denmark (12%) per agreement among the Range States.

#### Discussion

Results suggest strong population growth coincident with a sharp decrease in harvest pressure in 2014. For the last five years, the January and March populations appear to have been within the management target of 60,000-80,000 at the end of winter, with the most recent estimates of abundance approaching the upper bound.

If the desire is to keep the population near the median target of 70,000, some harvest liberalization may be permissible. A total harvest of 6,500, in which 3,770 is allocated to Finland, 1,950 to Sweden, and 780 to Denmark, could be expected to maintain the population near the median goal of 70,000. For comparison, the mean total harvest in the last five years was 3,347, with an average of 45, 2,199, and 1,103 Bean Geese harvested in Finland, Sweden, and Denmark, respectively.

Not unexpectedly, we found it challenging to estimate key demographic parameters using a time series of only counts and harvests, especially when those estimates include the tundra subspecies to unknown and varying degrees. Additional data on survival and/or reproduction from a capture-mark-recapture program and observations of the ratio of young to adults in the autumn would be immensely helpful in deriving more robust estimates of key demographic parameters. With respect to population counts, we agree with the recommendation of the Taiga Bean Goose Task Force to maintain all three seasonal counts at least through 2021, when a more informed decision about monitoring efforts can be made. We also strongly recommend that recent efforts to better identify subspecies in both the counts and harvests be continued. As a longer time series of these data accumulate, we should be able to exclude any differential effects of Tundra Bean Goose demography in the IPM. Finally, we have treated the portion of harvest occurring before and after the January count in Sweden as fixed, based on expert opinion. If an estimate of January population size remains an objective of an IPM, then we will need observational data to apportion the Swedish harvest, preferably on an annual basis.

Ultimately, we seek development of an adaptive management framework to guide the annual setting of harvest quotas. Using the IPM and agreed upon management objectives, we can derive optimal, abundance-dependent harvest strategies using stochastic dynamic programming (SDP) (Marescot et al. 2013). A key advantage of SDP is its ability to produce a dynamic, feedback policy specifying optimal harvest decisions for all possible population sizes rather than relying on expected, future abundances. In practice, this makes SDP appropriate for systems that behave stochastically, absent any assumptions about the system remaining in a desired equilibrium or about the production of a constant stream of resource benefits. Moreover, use of a Bayesian estimation framework for IPMs provides a natural framework for adaptation, in which model parameters can be updated over time based on observations from operational monitoring programs or external studies.

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### Appendix

The following table provides the complete set of data used to fit the IPM. Note that January data are aligned with the annual cycle of the model (i.e., the January count and temperature in calendar year t+1 is aligned with the March and October counts in calendar year t).<sup>2</sup>

		0.1.1					
Voar	warch	Count	Harvest:	Harvest:	Harvest:	January	January
1006	count	60000	EEOO	1700	600	0025	2.7
1996		60090	5500	1700	600	8925	-2.7
1997		48651	4000	934	400	22648	1.5
1998		48467	10900	1620	2703	15186	1.2
1999		53900	8600	2409	2357	28923	1.5
2000		41657	3200	3088	992	24109	1.3
2001		68248	4700	4124	1203	14022	1.6
2002		42667	4000	3323	1074	15036	-1
2003		49446	8900	3457	1437	19326	-2
2004		52123	4800	2540	1428	34560	2.1
2005		44544	6400	6402	1329	19283	-1.7
2006		42998	11200	3950	352	40291	4
2007	56960	62602	6300	3140	364	40133	3.1
2008	55405	65969	5600	2910	405	32532	-0.1
2009	49280	53871	7900	1597	602	29085	-3.8
2010		47859	5100	4151	782	8734	-0.6
2011	46930	56497	3600	3093	563	34603	1.1
2012	47395	61201	3900	1619	3619	42103	-1
2013		50988	3300	2735	1927	41962	0.9
2014	53855	59444	0	1675	1296	41367	2.4
2015	60033	70975	0	1582	1440	42337	-0.9
2016	58386	75579	0	2212	1301	55434	0.2
2017	65418	76928	176	1977	822	36945	2.2
2018	65060	68297	49	3547	654	39170	1.1
2019	63518	80793	77		148	37926	4.8
2020	65509						

 $<sup>^{2}</sup>$  There may be minor differences in the data reported in this harvest assessment and that in the population status report depending on when final data were received and the time remaining for analysis.