ADAPTIVE HARVEST MANAGEMENT FOR THE SVALBARD POPULATION OF PINK-FOOTED GEESE

2015 Progress Summary

Technical Report from DCE – Danish Centre for Environment and Energy No. 64 2015

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Abstract: This document describes progress to date on the development of an adaptive harvest management strategy for maintaining the Svalbard population of pink-footed geese (*Anser brachyrhynchus*) near their agreed target level (60,000) by providing for sustainable harvests in Norway and Denmark. This report provides an assessment of the most recent monitoring information (1991-2014) and its implications for the harvest management strategy, and it is an update of an initial assessment for 2013-2015 (see http://pinkfootedgoose.aewa.info/). By combining varying hypotheses about survival and reproduction, a suite of nine models have been developed that represent a wide range of possibilities concerning the extent to which demographic rates are density dependent or independent. Current updated model weights suggest little evidence for density-dependent survival and reproduction, suggesting that the population may have recently experienced a release from density-dependent mechanisms, corresponding to the period of most rapid growth in population size. The optimal harvest strategy for the 2013–2015 hunting seasons prescribed a harvest quota of 15,000 per year. The harvest in the 2014 hunting season was 14,991, compared to 11,081 in 2013, mostly due to an increase in harvest in Denmark during January 2015. The percentage of young in the fall of 2014 was 10.3%, which is lower than average. The observed population size of 59,000 in May 2015 was much lower than expected. For the 2015 hunting season, observed population size and temperature days suggest that an emergency closure should be considered. In the event a harvest of 15,000 is maintained, predicted population size in May 2016 is 51,700 (95% CL: 41,600-64,300), based on observed TempDays = 9 in May 2015 and the most recent model weights. On the other hand, if the season were closed this year, we would expect a population size of 66,700 (95% CL: 53,600-82,900) in May 2016. A total harvest of 6,700 would be expected to result in a 2016 population size at goal (i.e., 60,000).

Keywords: Adaptive management, density-dependence, harvest, population modelling

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Executive Summary

This document describes progress to date on the development of an adaptive harvest-management strategy for maintaining the Svalbard population of pink-footed geese (*Anser brachyrhynchus*) near their agreed target level (60,000) by providing for sustainable harvests in Norway and Denmark. Specifically, this report provides an assessment of the most recent monitoring information and its implications for the harvest management strategy.

The development of a passively adaptive harvest management strategy requires specification of four elements: (a) a set of alternative population models, describing the effects of harvest and other relevant environmental factors; (b) a set of probabilities describing the relative credibility of the alternative models, which are updated each year based on a comparison of model predictions and monitoring information; (c) a set of alternative harvest quotas, from which a 3-year quota is chosen; and (d) an objective function, by which alternative harvest strategies can be evaluated and an optimal strategy chosen.

By combining varying hypotheses about survival and reproduction, a suite of nine models have been developed that represent a wide range of possibilities concerning the extent to which demographic rates are density dependent, and the extent to which spring temperatures influence survival and reproduction. Five of the models incorporate density-dependent mechanisms that would maintain the population near a carrying capacity (i.e., in the absence of harvest) of 65k – 129k depending on the specific model. The remaining four models are density independent and predict an exponentially growing population even with moderate levels of harvest.

The most current set of monitoring information was used to update model weights for the period 1991 – 2014. Current model weights suggest little evidence for density-dependent survival and reproduction. These results suggest that the pink-footed goose population may have recently experienced a release from density-dependent mechanisms, corresponding to the period of most rapid growth in population size. There is equivocal evidence for the effect of May temperature days (number of days with temperatures above freezing: TempDays) on survival and on reproduction.

The optimal harvest strategy for the 2013–2015 hunting seasons prescribed a harvest quota of 15,000 per year. The harvest in the 2014 hunting season was 14,991, compared to 11,081 in 2013, mostly due to an increase in harvest in Denmark during January 2015. The percentage of young in the fall of 2014 was 10.3%, which is lower than average. The observed population size of 59,000 in May 2015 was much lower than expected. For the 2015 hunting season, observed population size and temperature days suggest that an emergency closure should be considered. In the event a harvest of 15,000 is maintained, predicted population size in May 2016 is 51,700 (95% CL: 41,600-64,300), based on observed TempDays = 9 in May 2015 and the most recent model weights. On the other hand, if the season were closed this year, we would expect a population size of 66,700 (95% CL: 53,600-82,900) in May 2016. A total harvest of 6,700 would be expected to result in a 2016 population size at goal (i.e., 60,000).

1 Introduction

The Svalbard population of pink-footed geese has increased from about 10 thousand individuals in the early 1960's to roughly 80 thousand today. Although these geese are a highly valued resource, the growing numbers of geese are causing agricultural conflicts in wintering and staging areas, as well as tundra degradation in Svalbard. The African-Eurasian Waterbird Agreement (AEWA; http://www.unep-aewa.org/) calls for means to manage populations which cause conflicts with certain human economic activities. This document describes progress to date on the development of an adaptive harvest-management strategy for maintaining pink-footed goose (*Anser brachyrhynchus*) abundance near their target level (60 thousand) by providing for sustainable harvests in Norway and Denmark. Specifically, this report provides an update of relevant information for the second year following the harvest quota prescribed for the 2013-2015 hunting seasons.

Previous progress reports (http://pinkfootedgoose.aewa.info/) described the compilation of relevant demographic and weather data and specified an annual-cycle model for pink-footed geese. Dynamic models for survival and reproductive processes were parameterized using available data. By combining varying hypotheses about survival and reproduction, a suite of nine models were developed that represent a wide range of possibilities concerning the extent to which demographic rates are density dependent or independent, and the extent to which spring temperatures are important. These nine models vary significantly in their predictions of the harvest required to stabilize current population size, ranging from a low of about 500 to a high of about 17 thousand. For comparison, the harvest in Norway and Denmark has averaged 11.3 thousand per year during the last four years.

The passive form of adaptive management is being employed to formulate an optimal harvest strategy. In passive adaptive management, alternative population models and their associated probabilities are explicitly considered in the development of an optimal harvest strategy. Model-specific probabilities (or weights) represent the relative credibility of the alternative models, and are based on a comparison of predicted and observed population size. Models that are better predictors of observed population size gain probability mass according to Bayes' theorem. Models with higher probabilities have more influence on the optimal harvest strategy.

This report focuses on updates of population status and alternative model weights, given the prescription for an annual harvest quota of 15 thousand for the 3-year decision-making cycle starting with the 2013 hunting season. This annual update is part of the process agreed to by the AEWA Svalbard Pink-Footed Goose International Working Group in Copenhagen in April 2013. It uses the most recent data on harvest (autumn 2014), population size (autumn 2014/spring 2015), and weather conditions on the breeding ground (May 2015). This report also describes the status of ongoing developments in pink-footed goose adaptive harvest management, as well as emerging technical issues.

2 Methods

The development of a passively adaptive harvest management strategy requires specification of four elements: (a) a set of alternative population models, describing the effects of harvest and other relevant environmental factors; (b) a set of probabilities describing the relative credibility of the alternative models, which are updated each year based on a comparison of model predictions and monitoring information; (c) a set of alternative harvest quotas, from which a 3-year quota is chosen; and (d) an objective function, by which alternative harvest strategies can be evaluated and an optimal strategy chosen. An optimal management strategy prescribes a 3-year harvest quota for each and every level of abundance (and environmental conditions) that may be observed at the time the decision is made. To allow for the possibility of unforeseen changes in population status, we also require criteria for 1-year emergency closure of the hunting season.

Alternative Models. – The nine alternative models of population dynamics suggest how reproductive and survival rates of pink-footed geese vary over time (Table 1, Appendix A). Five of the models incorporate density-dependent mechanisms that would maintain the population near a carrying capacity (i.e., in the absence of harvest) of 65k – 129k depending on the specific model. The remaining four models are density independent and predict an exponentially growing population even with moderate levels of harvest. Consideration of these density-independent models is not intended to suggest that population size is truly unregulated, but that density dependence may only manifest itself at abundances far exceeding those experienced thus far. All nine models fit the available data and at the time of their development it was not possible to say with any confidence which was more appropriate to describe the contemporary dynamics of pink-footed geese.

Table 1. Nine alternative models of pink-footed goose population dynamics and their associated carrying capacities (*K*, in thousands) for randomly varying days above freezing in May in Svalbard (TempDays). N and A are total population size and the number of sub-adults plus adults (in thousands), respectively, on November 1. The sub-models represented by (.) denote randomly varying demographic rates (i.e., no covariates). Models M3, M4, M6, and M7 are density-independent growth models and thus have no defined carrying capacity.

Model	Survival sub-model	Reproduction sub-model	*K* (sd)
M0	(.)	(TempDays, A)	120 (8)
M1	(TempDays)	(TempDays, A)	129 (8)
M2	(TempDays, N)	(TempDays, A)	59 (4)
M3	(.)	(TempDays)	
M4	(TempDays)	(TempDays)	
M5	(TempDays, N)	(TempDays)	66 (3)
M6	(.)	(.)	
M7	(TempDays)	(.)	
M8	(TempDays, N)	(.)	65 (5)

Model Weights

Bayesian posterior probabilities (or weights) can be used to express the relative ability of each model to accurately predict the changes in population size that actually occurred. We calculated posterior probabilities for each of the nine models for each of the years 1991-2013, assuming equal prior probabilities in 1991 (i.e., $p_i = 1/9$). Posterior model probabilities were calculated as:

$$p_i(t+1) = \frac{p_i(t)\mathcal{L}_i(t+1)}{\sum_i p_i(t)\mathcal{L}_i(t+1)}$$

where t denotes the year, and $\mathcal{L}_i$ denotes the likelihood of the observed population size, given model i. The likelihoods, in turn, were calculated from the normal density function:

$$\mathcal{L}_i(t+1) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{log(N_*(t+1)) - log(N_i(t+1))}{\sigma}\right)^2}$$

where N_* is the observed population size, N_i is a model-specific prediction of population size, and σ is a prediction error common to all models. This error was estimated by averaging the mean squared errors from all nine models:

$$\sigma = \sqrt{\sum_i^m \frac{\sum_t \left(log(N_*(t+1)) - log(N_i(t+1))\right)^2}{mn}} = 0.11116$$

where $m = 9$ models and sample size for yearly comparisons was $n = 12$. This error reflects so-called process error, which is the variation in population size not explained by the models.

Alternative Harvest Quotas

We considered a set of annual harvest quotas of 0 to 30 thousand in increments of 2.5 thousand. This set seemed reasonable given the current harvest in Norway and Denmark of approximately 11k and only coarse control over harvests. As explained in previous reports, calculation of an optimal strategy of absolute harvest (rather than harvest *rates*) requires that we first specify the number of young and adults in the total harvest. But this cannot be known a priori because it depends on the age composition of the pre-harvest population. Yet, the age composition of the pre-harvest population cannot be predicted from our models without knowing the age composition of the harvest. To resolve this dilemma requires the ability to specify the ratio:

$$z = \frac{1 - h_t}{1 - d \cdot h_t}$$

where h is the harvest rate of adults and $d \approx 2$ is the differential vulnerability of young to adults (Appendix B). The problem is that z is not constant, but depends on the value of h (which is not known a priori). Therefore, we examined values of z for a range of realistic harvest rates (0.00 – 0.15) and chose a "typical" $z \approx 1.1$. We assumed this constant value for the purpose of calculating an optimal harvest strategy.

Objective Function

Based on input from the International Working Group, the management objective is to maximize sustainable harvest, subject to maintaining the population size within acceptable limits. For computational purposes, the optimal value (V*) of a harvest-management strategy (A) conditional on resource status (x) at time t is a product of both harvest and a population utility:

$$V^*(A_t|x_t) = \max_{(A_t|x_t)} E\left[\sum_{\tau=t}^{T} H(a_\tau|x_\tau)u(a_\tau|x_\tau)|x_t\right]$$

where $H(a_\tau|x_\tau)$ and utility $u(a_\tau|x_\tau)$ are action (a = harvest quota) and state-dependent harvest and population utility, respectively. Population utility is defined as:

$$u(a_\tau|x_\tau) = \frac{1}{1 + exp(|N_{t+1} - 60k| - 10k)}.$$

where N_{t+1} is the population size expected as a result of the current harvest quota and the population goal is 60 thousand (Fig. 1). The 10 (thousand) in the equation for population utility represents the difference from the population goal when utility is reduced by approximately one half. Thus, the objective function devalues harvest-quota decisions that are expected to result in a subsequent population size different than the population goal, with the degree of devaluation increasing as the difference between population size and the goal increases.

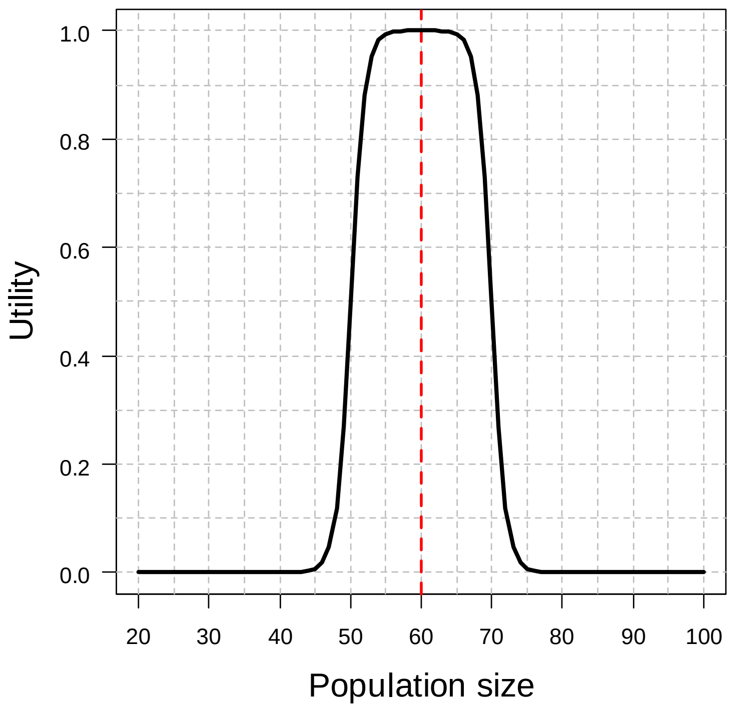

Figure 1. Utility (i.e., stakeholder satisfaction) expressed as a function of population size in pink-footed geese. Population sizes between about 50,000 and 70,000 are acceptable (and thus have high utility), while those outside that range are very undesirable (and thus have low utility).

Using the elements described above, we calculated a passively adaptive harvest strategy using dynamic programming. This year we took advantage of new software (MDPSolve©; https://sites.google.com/site/mdpsolve/), which can be used to compute an optimal, fully stochastic solution (past solutions have been based on an assumption of deterministic system dynamics). We calculated the optimal harvest strategy for both 3-year and 1-year decision making cycles. This latter strategy is used to determine whether an emergency closure of the hunting season is required in the midst of the 3-year quota.

3 Results and Discussion

Discrimination among the nine alternative models became most pronounced after 2006 (Fig. 2, Appendix D). Current model weights (i.e., those based on population size after the 2014 harvest) continue to suggest little evidence for density-dependent survival ($p_{DD-S} = 0.0005$, Fig. 3) (recall that probability or model weight is on a scale of 0.0 – 1.0, with 0.0 indicating no evidence and 1.0 indicating certainty). This year saw a significant increase in the evidence for density-dependent reproduction, however, reflecting reproductive success in 2014 that was lower than average ($p_{DD-R} = 0.3369$, Fig. 3). Model weights thus far suggest that the pink-footed goose population may have recently experienced a release from density-dependent mechanisms, corresponding to the period of most rapid growth in population size (Fig. 4). There was also equivocal evidence for the effect of TempDays on survival ($p_{DAYS-S} = 0.4057$, 2 of 3 survival models) and on reproduction ($p_{DAYS-R} = 0.3319$, 2 of 3 reproductive models) (Fig. 3). We also calculated predictions of population size for each year based on each model, and then compared them with observed population sizes (Fig. 5). The predictive ability of most models has been relatively poor for population sizes exceeding 60 thousand, with a tendency towards predictions of population size that are less than those observed.

The prescribed, 3-year harvest quota for the 2013 – 2015 period is 15,000, based on the observed numbers of young (8,064) and adults (73,536) in autumn 2012, temperature days (8) in May 2013, and the model weights at that time. We note, however, that the harvest strategy is extremely knife-edged, meaning that only small changes in population size (particularly around the goal of 60 thousand) are required to produce extreme changes in the harvest quota. This result can be primarily attributed to the lack of evidence for density dependence, such that the weighted or "average" model is essentially an exponential growth model. Exponential growth models can produce wide swings in population size with only small changes in harvest because there are no self-regulating mechanisms that would dampen changes in population size.

Population status.— The 2014 Progress Summary (http://pinkfootedgoose.aewa.info/node/174) provided a model-averaged prediction of population size in spring of 2015 of 71,000. That prediction was based on the previous year's population size of 76,000, 9 days above freezing (TempDays) in Svalbard in May 2014, and a harvest quota during the 2014 hunting season of 15,000. The actual harvest of 14,991 (1,791 in Norway and 13,200 in Denmark) was very close to the quota, principally due to an increased harvest on land in Denmark during January Open for the first time). The percentage of young in the fall of 2014 was 10.3%. Using the observed harvest and percentage of young rather than their predictions, the nine alternative models of population dynamics predict population sizes in May 2015 ranging from 54,500 to 67,400. The model-averaged (using last year's model weights) prediction for May 2015 was 66,900. The observed population size in May 2015 of 59,000 was thus much lower than expected (Fig. 4). Indeed, weighted population models suggest that there was less than a 7% chance that population size would be less than 60,000 in May 2015.

Given the slightly above-average number of days above freezing in Svalbard in May 2014, the percentage of young in the fall of 2014 was expected to be near the long-term average of 14.7%. The observed percentage of 10.3% appears to be a key reason that the observed population size fell short of the prediction, but the observed percentage of young cannot completely account for the discrepancy between predicted and observed population size. In fact, during the last several years of high population levels the nine alternative population models have tended to under-predict population size (Fig. 5), suggesting the possibility that some geese were missed during the May 2015 census. However, this is mere speculation on our part as other explanations are possible (e.g., an unexpected increase in natural mortality).

Harvest strategy.—In 2013 the Svalbard Pink-Footed Goose International Working Group prescribed an annual harvest of 15,000 for three hunting seasons, reflecting a goal to reduce population size to 60,000 in a few years. The 2015 hunting season will be the third year of that plan and, thus, the currently prescribed harvest for 2015 is 15,000. However, managers have agreed to consider an emergency closure of the hunting season should the population fall short of the goal of 60,000 due to unforeseeable environmental conditions; e.g. extreme weather or high harvest levels. To address this need, monitoring information and model weights are updated each year, followed by calculation of an optimal *one*-year harvest strategy. Each year, this harvest strategy prescribes the resource conditions (population size and temperature days) for which a closed season (i.e., harvest quota = 0) would be appropriate (Fig. 6). Based on guidance from the International Working Group, hunting season closures would be enacted for one year only, with a re-evaluation of resource conditions the following year. For the 2015 hunting season, observed population size and temperature days suggest that an emergency closure should be considered. We recognize, however, that Norway and Denmark may not yet have the administrative procedures in place to close the season this year. In the event a harvest of 15,000 is maintained, predicted population size in May 2016 would be 51,700 (95% CL: 41,600-64,300), based on observed TempDays = 9 in May 2015 and the most recent model weights. On the other hand, if the season were closed this year, we would expect a population size in May 2016 of 66,700 (95% CL: 53,600-82,900). To assist decision makers in planning for the 2015 hunting season, we also examined intermediate levels of harvest. A harvest equivalent to the 2010-2013 average of 11,300 (i.e., the average prior to the extension of the hunting season through January in Denmark) would result in a predicted population size in May 2016 of 55,400 (95% CL: 44,500-68,900). A harvest of 6,700 would be expected to result in a 2016 population size near the goal of 60,000 (95% CL: 48,200-74,600).

For purely illustrative purposes, we also calculated a new 3-year harvest strategy based on the most current model weights (Fig. 7). The strategy is slightly more liberal than that calculated in 2013 as a result of increases in the weights for exponential-growth models (i.e., those lacking density dependence). Thus, the strategy "evolves" over time to reflect what is learned in the process (i.e., the updating of model weights). However, we emphasize that the harvest quota for the 2013 – 2015 period remains 15,000. A new 3-year strategy will be calculated next year in preparation for the next 3-year decision cycle, which begins with the 2016 hunting season.

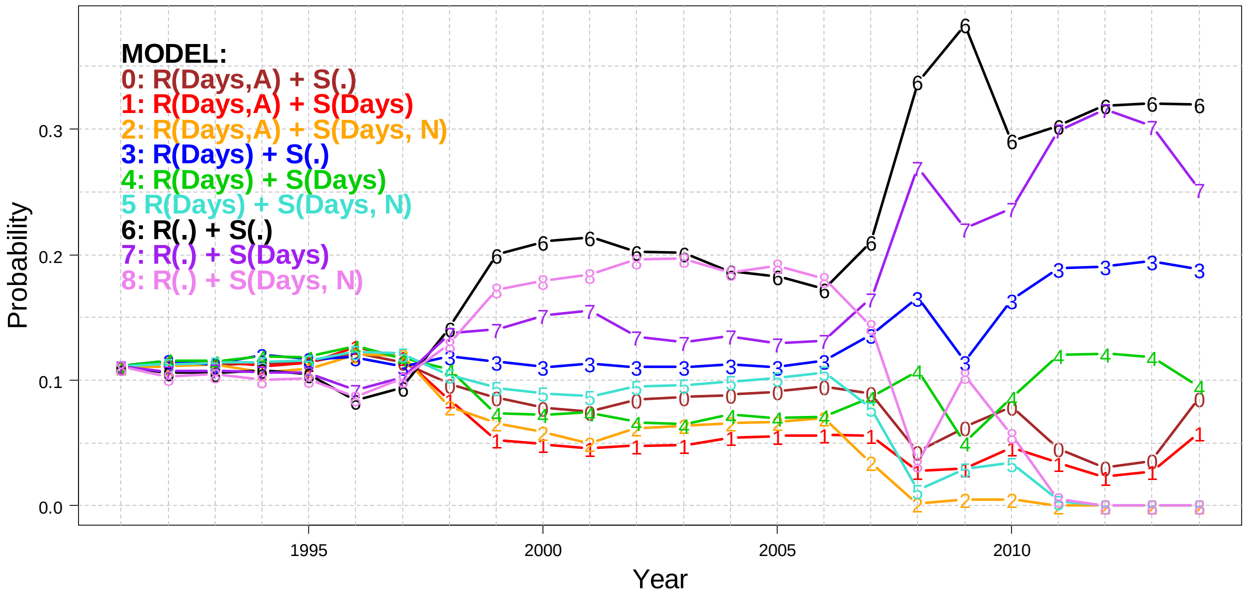

Figure 2. Posterior model weights for nine alternative models describing the annual dynamics of the pink-footed goose population, assuming equal prior model weights in 1991. See Table 1 and Appendix A for a description of the models.

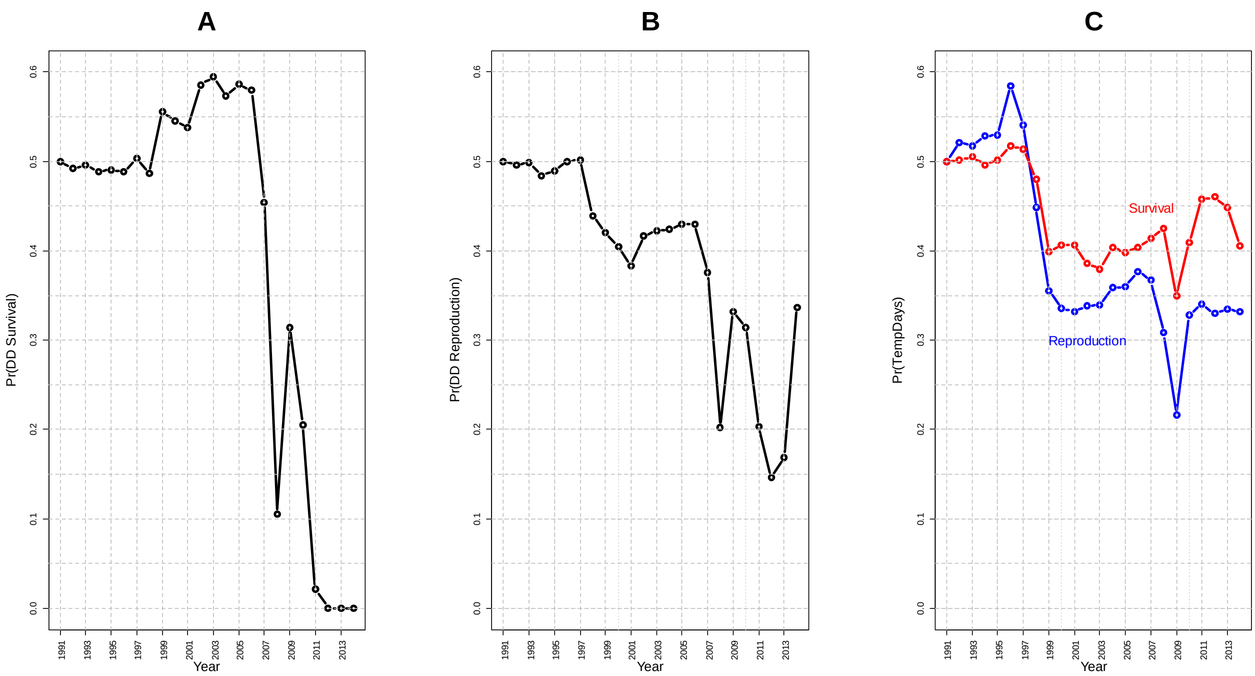

Figure 3. Aggregate weight on pink-footed goose population models that incorporate (A) density-dependent survival; (B) density-dependent reproduction; and (C) days above freezing in May in Svalbard in the reproductive and survival processes.

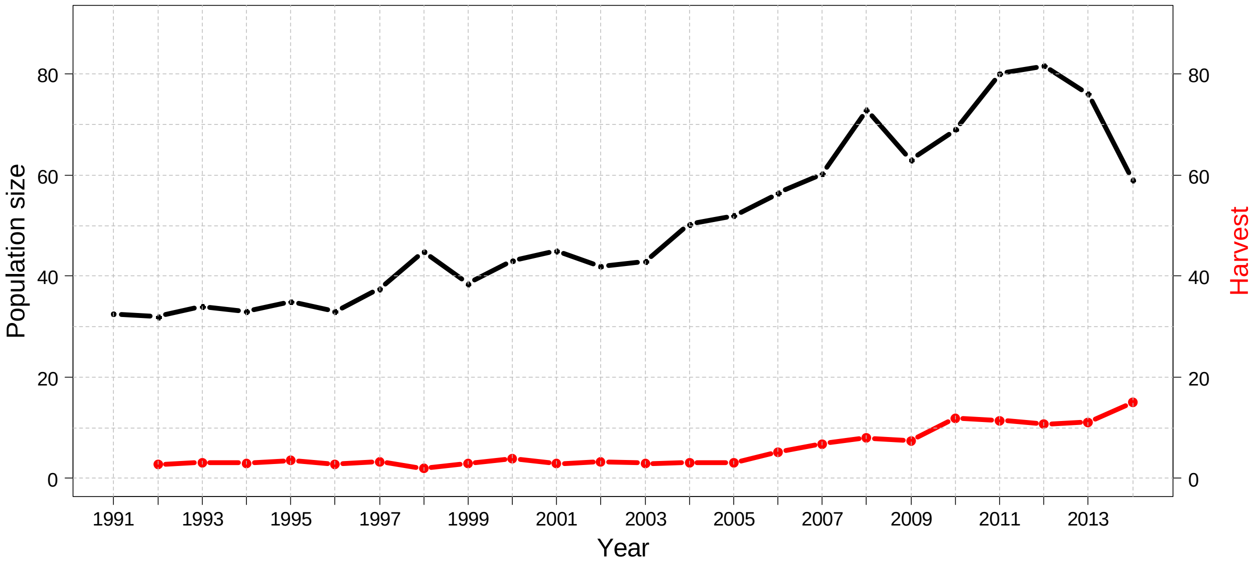

Figure 4. Counts of pink-footed geese during autumn/spring and total harvest (both in thousands) in Norway and Denmark.

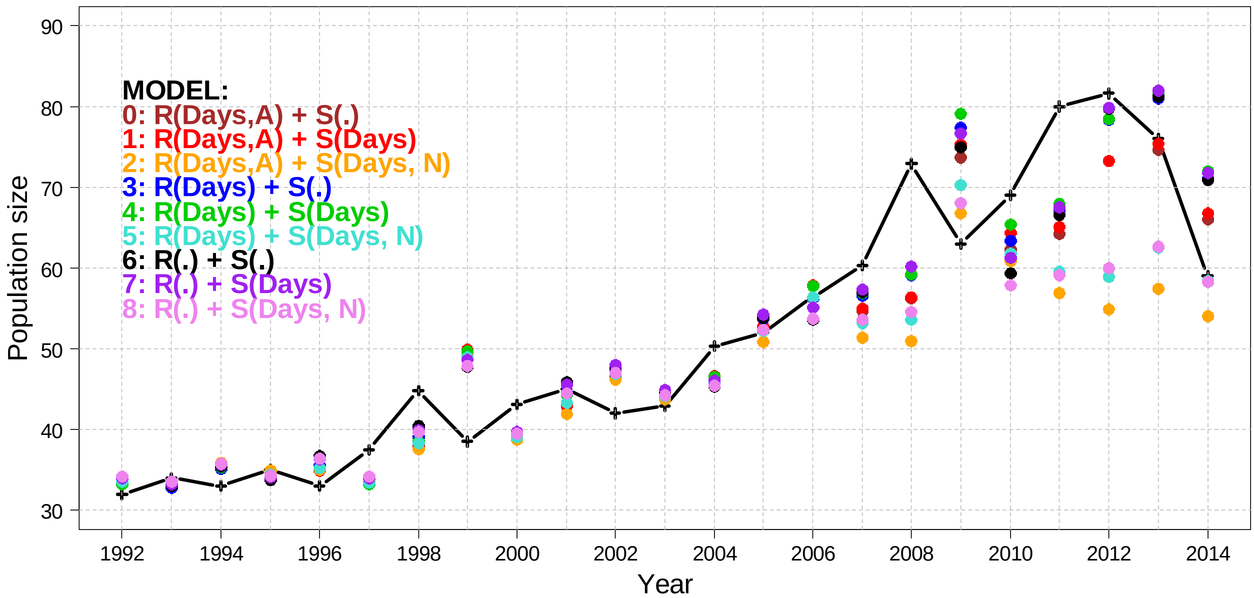

Figure 5. Comparison of observed population sizes (line) and those predicted by nine alternative models (circles) describing the annual dynamics of the pink-footed goose population. See Table 1 and Appendix A for a description of the models. Predictive ability declined as the population entered a rapid growth phase (i.e., observed population sizes in excess of 60 thousand).

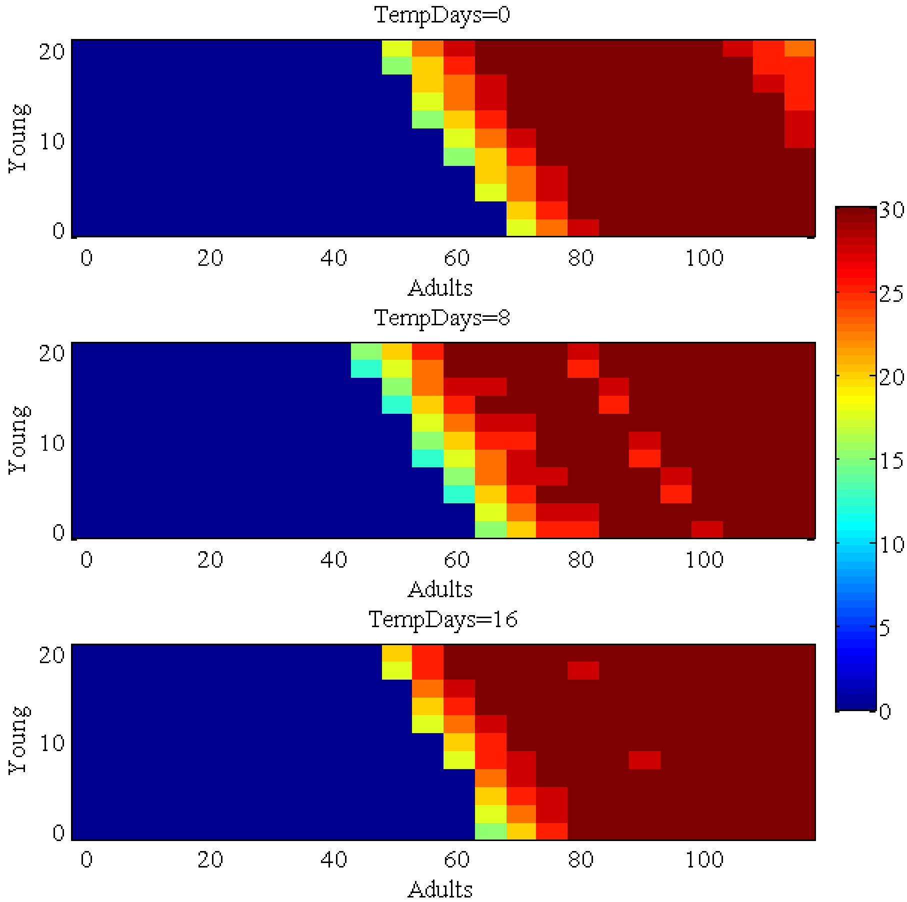

Figure 6. One-year harvest quotas for the Svalbard population of pink-footed geese, for a range of days above freezing in Svalbard in May (TempDays = 8 is near the average). Harvest quotas and the number of young and adults are in thousands. The strategy is very knife-edged, meaning that extreme changes in harvest quota can accompany small changes in population size.

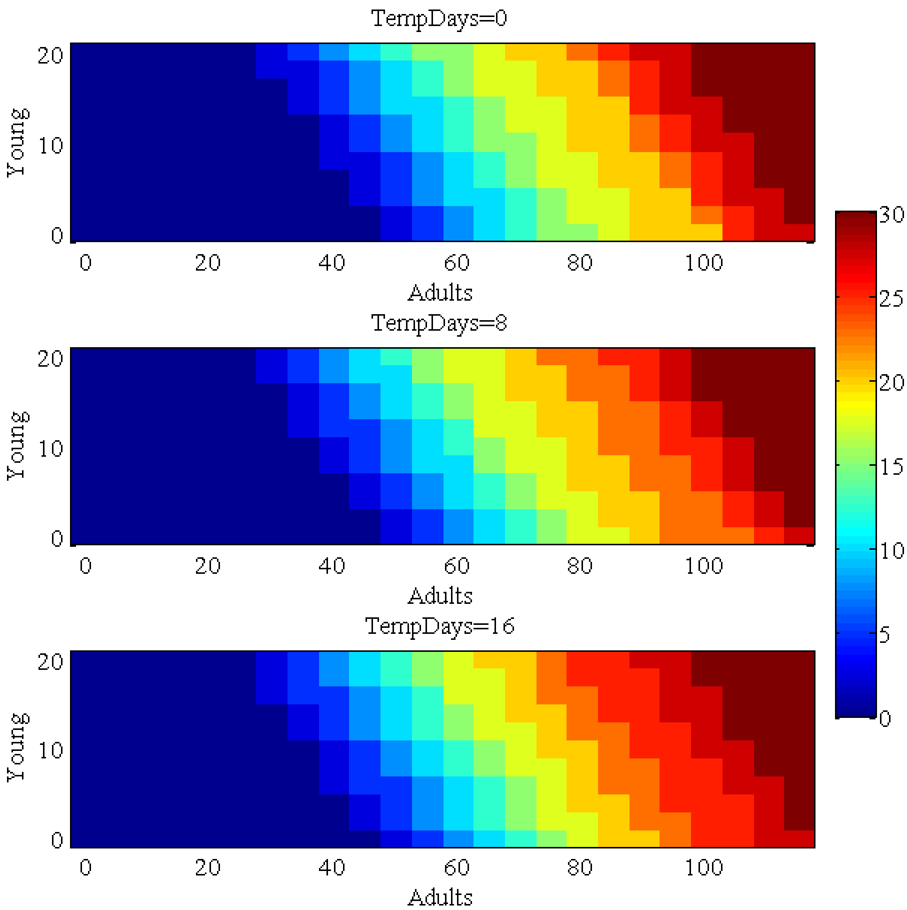

Figure 7. Three-year harvest quotas for the Svalbard population of pink-footed geese, for a range of days above freezing in Svalbard in May (TempDays = 8 is near the average). Harvest quotas and the number of young and adults are in thousands. The strategy is less knife-edged than the 1-year strategy and tends to be more liberal at low population sizes and more conservative at high population sizes.

4 Ongoing Development of the Adaptive Harvest Management Process

Monitoring needs.—There are a number of improvements being made in monitoring programs for pink-footed geese and we here report on recent progress.

1. Regarding age composition of the harvest, Denmark has decided to move from wing surveys to direct reporting of pink-footed goose harvest; however, wing survey data will be retained to keep track of the age composition of the harvest. The sample size in Denmark has increased slightly due to better local organization of wing collection. For Norway we have six years of data on age composition of the harvest based on collaboration with a group of hunters; hence, we do not yet have a full-reporting system but a voluntary contribution.
2. Annual harvest estimates do not include the crippled, non-retrieved geese which are likely to die due to their injuries before the end of the hunting season. At present we have no data concerning the level of non-retrieved geese available. This should be addressed by field surveys and reporting by hunters in Norway and Denmark in order to derive an estimate of the total numbers shot annually. Field assistants observing neckbanded geese and performing population monitoring in Norway, Denmark and The Netherlands record the number of crippled pink-footed geese observed in the field during autumn; however, the observed numbers have been very low.
3. Until recently, population estimates were based on internationally coordinated counts in early November, which is in the middle of the hunting season. We note that these counts are assumed to constitute a complete census and thus there is no accounting for sampling error. For modeling purposes, it would be advantageous to postpone the count to the spring, i.e., after the closure of hunting and as close to the migration to the breeding grounds as possible. During the last five seasons, spring counts in early May have been conducted with good results. Furthermore, autumn counts have become increasingly biased because the geese have been short-stopping in Norway, Denmark, and Sweden and are using new areas which are not fully covered. A special effort has been made to increase the spatial coverage of the November count, which has led to the discovery of roosts sites outside the normal range. Therefore, we have found it necessary to use spring counts rather than those from autumn in recent years.
4. The most recent survival rate estimates are from 2002 and it is a high priority to update these estimates. Furthermore, effects of neckbands on survival and neckband loss rates should be estimated. Aarhus University has been conducting these analyses and has recently generated an up-to-date time series of survival rate estimates. Also, two papers have been published on the rate of loss of neckbands (Clausen, K.K., Frederiksen, M. & Madsen, J. 2015. Measuring neckband loss of Pink-footed Geese Anser brachyrhynchus. Bird Study (online first)) and on the effects of neckbands on body condition of pink-footed geese (Clausen, K.K. & Madsen, J. 2014. Effects of neckbands on body condition of migratory geese. Journal of Ornithology 155: 951-958.). The survival estimates have not yet been published.

5. Finally, we suggest that independent population estimates should be derived based on capture-resightings of marked individuals. This has been done in the past, but the estimates need to be updated. Throughout the years, the proportion of marked individuals in goose flocks has been recorded in the field during autumn and spring. For precise estimates, however, it will be necessary to increase the proportion of marked individuals in the population, which has fallen in recent years due to difficulties catching a sufficiently large sample in Denmark. In May 2015, however, 377 pink-footed geese were caught by cannon-netting and neck-banded in Nord-Trøndelag, Norway, and it is planned to continue this effort in the coming years.

Optimization.—The optimization of harvest strategies involves the interaction between models of population dynamics, decision alternatives (i.e., varying levels of harvest), and management objectives. As discussed, current model weights largely suggest density-independent population growth. In the absence of harvest, the model-averaged finite population growth rate is $\lambda = 1.17$ (or 17% per year); thus, the overall rate of hunting mortality needed to stabilize population size is $(\lambda - 1)/\lambda = 0.15$. Notably, small departures from this harvest rate will result in either rapid increases or declines in population size; yet the management objective tolerates only small departures from the goal of 60,000 pink-footed geese. Combining exponential growth with this management objective, and accounting for the lagged effects of a 3-year harvest decision, produces a harvest strategy that is extremely knife-edged. As a consequence, the optimal harvest quota may be quite high for populations only slightly higher than the goal of 60,000, and quite low or even zero for populations only slightly lower than the goal. We believe this form of management would be seen as unacceptable to most stakeholders, especially hunters and farmers. Thus, we believe it might be necessary to consider ways in which the variability in harvest quotas might be dampened. We note, however, that moderating the variability in harvest quotas will mean increased variation in population size and this may be equally undesirable to some stakeholders. Because such tradeoffs are inevitable, we will endeavor to provide sufficient analyses to the International Working Group so that they can make an informed decision about modification to the harvest-management framework to dampen variability in the harvest quota.

Regulating harvests.—Until the most recent hunting season, it has not been necessary to determine how harvests could be regulated in Norway and Denmark in order to not exceed the quota. The focus has been on increasing harvest to stabilize the population, and until the last hunting season the observed harvest had been well below the current quota of 15,000. Now that population size has apparently decreased to the goal of 60,000, it will be necessary to reduce harvests to the level necessary to maintain the population near the goal. We note, however, that northern Europe does not have a strong tradition of regulating the level of waterbird harvest, such as is the case in North America. Possibilities for regulating the harvest include shortening the hunting season and/or imposing daily bag limits. Co-management agreements with hunters may also be a possibility if hunters are willing to voluntarily limit their take. In any case, extensive communication with stakeholders will be necessary to develop an efficient and acceptable approach.

Revision of population models.—Another principal need concerns the form of the model set. We believe a Bayesian state-space model may be a more useful approach than that originally used, as the Dutch review of previous work suggested (http://pinkfootedgoose.aewa.info/node/149). The advantage of a Bayesian state-space model is that it can directly incorporate the harvest data in the model development, as well as update all of the parameters of the model each year. With the current approach, a discrete set of models assumes that the parameters (e.g., regression coefficients) are fixed and the model weights are updated each year. With the state-space approach, the joint posterior distribution for all the parameters can be updated each year to account for uncertainty. It's a much more elegant way to use the available data, and we can discretize the joint posterior as finely as necessary to account for a wide range of parameter values. We hope to make progress on the Bayesian state-space model by the time the International Working Group meets in December 2015.

5 Acknowledgements

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Appendix A.

Models of survival and reproduction for the Svalbard population of pink-footed geese

Survival. – We considered three alternative models to describe the dynamics of survival from non-hunting sources of mortality, θ_t: (1) survival varies randomly from year to year; (2) survival varies depending on weather conditions and population size at the start of the year (November 1); and (3) survival varies depending only on weather conditions.

The first model assumes that $\hat{\theta}_t$ has a mean of 0.951 and a standard deviation of 0.019. We used the method of moments to parameterize a beta distribution as $\hat{\theta}_t \sim Beta(125.16, 6.46)$.

For the other two models of survival, we used the logit of $\hat{\theta}_t$, total population size N on November 1, various weather variables X in the interval November 1 – October 31, and used least-squares regression to fit the model. The model including temperature days (days above freezing in Svalbard in May) and population size had the lowest AIC of all models examined:

$$ln\left(\frac{\hat{\theta}_t}{(1-\hat{\theta}_t)}\right) = 4.293 + 0.053X_t - 0.044N_t$$

where X is temperature days and population size N is in thousands. The regression coefficients for both covariates were of the expected sign and different from zero ($P < 0.05$).

Due to uncertainty about contemporary rates of survival and the degree of density dependence (especially given the recent growth in population size), we also considered a third model that included temperature days but not population size. This density-independent model had the form:

$$ln\left(\frac{\hat{\theta}_t}{(1-\hat{\theta}_t)}\right) = 2.738 + 0.049X_t$$

Annual survival is then the product of survival from natural causes $\hat{\theta}$ and hunting:

$$\hat{S}_t = \hat{\theta}_t(1-\hat{h}_t)$$

where $\hat{h}$ = estimated harvest rate (including retrieved and un-retrieved harvest) of birds that have survived at least one hunting season.

Reproduction. – We considered the counts of young during the autumn census, 1980-2011, as arising from binomial (or beta-binomial) trials of size N_t, and used a generalized linear model with a logit link to explain annual variability in the proportion of young (p_t). The best fitting models were based on a beta-binomial distribution of counts, which permits over-dispersion of the data relative to the binomial. The best model, as based on AIC, included population size and temperature days:

$$ln\left(\frac{\hat{p}_t}{(1-\hat{p}_t)}\right) = -1.687 + 0.048X_t + 0.014A_t$$

where X is May temperature days and A is the number of sub-adults and adults on November 1. The regression coefficients for both covariates were of the expected sign, but only the coefficient for temperature days was highly significant ($P = 0.01$). The coefficient for adult population size was only marginally significant ($P = 0.06$), and this appears to be because of a lack of evidence for density dependence post-2000.

To allow for the possibility that reproduction is not (or no longer is) density-dependent, we considered a model with only temperature days:

$$ln\left(\frac{\hat{p}_t}{(1-\hat{p}_t)}\right) = -1.989 + 0.027X_t$$

Finally, we considered a second density-independent reproduction model in which the number of young in autumn was described as rising from a beta-binomial distribution with no covariates. The parameters of this distribution were estimated by fitting an intercept-only model ($\bar{p} = 0.14, \theta = a/\bar{p} = b/(1-\bar{p}) = 43.77$).

See Johnson et al. (2014) for more details.

Appendix B.

The difficulties of specifying a harvest quota when population size is measure post-harvest

To optimize a total harvest quota (or target), we must first be able to specify (for varying harvest quotas) the portion of the harvest that is expected to be young and the portion that is expected to be adults (actually sub-adults + adults). The expected age composition of the harvest, in turn, depends on the *pre-harvest age composition* of the population (i.e., prior to both the census and harvesting) and the *differential vulnerability of young*.

1. We can easily calculate the pre-harvest population of adults as:

   $$A_t = (Y_{t-1} + A_{t-1})\,\theta_{t-1}$$

   The pre-harvest population of young is:

   $$Y_t = (Y_{t-1} + A_{t-1})\,\theta_{t-1}\left(\frac{1-h_t}{1-d \cdot h_t}\right)R_t$$

   where both h and R are post-harvest and post-census. But h is not known (or specified) when total harvest is the control variable. However, this equation could provide the pre-harvest population of young (and therefore resolve our problem), if we could assume $\left(\frac{1-h_t}{1-d \cdot h_t}\right)$ is constant. But even if d is constant (which we do assume), $\left(\frac{1-h_t}{1-d \cdot h_t}\right)$ is not (it depends on the value of h).

2. Another possibility we explored was to assume that

   $$\theta_{t-1}\left(\frac{1-h_t}{1-d \cdot h_t}\right) \approx 1.$$

   This was found to be a reasonable assumption, but only based on the assumptions used to partition survival into non-hunting and hunting components for the period in which we had survival rate estimates. If harvest rate varies from the approximately 4% assumed during the period of survival estimates, then the above equation is no longer a valid assumption. Of course, we are explicitly investigating the impacts of varying harvest rates.

3. Our conclusion is that a post-harvest assessment of population size and reproductive success imposes restrictions on the investigation of optimal harvest strategies that cannot be circumvented. This is part of the basis for recommending a pre-harvest population census and some measure of reproductive success prior to harvesting (which could be accomplished by assessing the age composition of the harvest). The problem could also be resolved if estimates of realized harvest rates of both young and adults were available.

Appendix C.

Monitoring information for the Svalbard population of pink-footed geese

N and Y represent total population size and the number of young, respectively, TempDays is the number of days above freezing in May in Svalbard, and HarvDen and HarvNor are the reported harvests from Denmark and Norway, respectively. We note that the harvest in Norway in 2014 has been revised since publication of the monitoring report.

Year	N	Y	TempDays	HarvDen	HarvNor
1991	32500	7215	9	3000	NA
1992	32000	1984	4	2500	240
1993	34000	6154	7	2300	850
1994	33000	4092	7	2600	420
1995	35000	8260	9	2800	790
1996	33000	6072	1	2000	850
1997	37500	5400	4	2500	820
1998	44800	5466	0	1414	570
1999	38500	4736	13	1973	920
2000	43100	2112	6	2567	1400
2001	45000	4905	2	2353	548
2002	42000	4452	8	2611	655
2003	42900	5448	8	2299	684
2004	50300	5634	11	2056	1076
2005	52000	3796	8	1694	1347
2006	56400	9757	18	3518	1657
2007	60300	7658	7	4597	2221
2008	63000	8190	5	5416	2633
2009	63000	6867	15	4846	2600
2010	69000	15400	20	8841	3100
2011	80000	15600	10	8019	3410
2012	81600	8078	5	8580	2169
2013	76000	8968	8	9262	1819
2014	59000	6077	9	13200	1791

Appendix D.

Posterior model weights for nine alternative models describing the annual dynamics of the pink-footed goose population, assuming equal prior model weights in 1991. See Table 1 and Appendix A for a description of the models.

Year	M0	M1	M2	M3	M4	M5	M6	M7	M8
1991	0.11111	0.11111	0.11111	0.11111	0.11111	0.11111	0.11111	0.11111	0.11111
1992	0.11375	0.11438	0.11100	0.11554	0.11611	0.11300	0.10627	0.10706	0.10288
1993	0.11232	0.11453	0.11276	0.11275	0.11514	0.11400	0.10573	0.10785	0.10492
1994	0.11343	0.11146	0.10650	0.12010	0.11875	0.11451	0.10818	0.10646	0.10060
1995	0.11427	0.11367	0.10893	0.11693	0.11860	0.11561	0.10477	0.10594	0.10128
1996	0.12128	0.12691	0.12057	0.11855	0.12732	0.12288	0.08375	0.09203	0.08671
1997	0.11464	0.11820	0.11969	0.11119	0.11765	0.12109	0.09405	0.10209	0.10140
1998	0.09689	0.08423	0.07889	0.11906	0.10844	0.10417	0.14167	0.13731	0.12933
1999	0.08635	0.05249	0.06595	0.11474	0.07349	0.09427	0.19997	0.14039	0.17236
2000	0.07798	0.04887	0.05867	0.11061	0.07287	0.08962	0.21056	0.15151	0.17929
2001	0.07526	0.04600	0.04973	0.11371	0.07438	0.08712	0.21419	0.15544	0.18416
2002	0.08459	0.04805	0.06179	0.11058	0.06653	0.09509	0.20249	0.13493	0.19595
2003	0.08676	0.04836	0.06387	0.11079	0.06500	0.09634	0.20124	0.13052	0.19712
2004	0.08843	0.05427	0.06612	0.11211	0.07250	0.09902	0.18653	0.13508	0.18594
2005	0.09100	0.05544	0.06693	0.11085	0.07002	0.10205	0.18306	0.12925	0.19141
2006	0.09497	0.05639	0.06985	0.11568	0.07130	0.10650	0.17253	0.13178	0.18100
2007	0.08980	0.05591	0.03482	0.13602	0.08644	0.07810	0.21057	0.16520	0.14314
2008	0.04337	0.02766	0.00144	0.16605	0.10759	0.01229	0.33781	0.26979	0.03399
2009	0.06249	0.02967	0.00486	0.11480	0.05079	0.02941	0.38323	0.22091	0.10385
2010	0.07915	0.04667	0.00489	0.16396	0.08649	0.03445	0.29093	0.23712	0.05634
2011	0.04566	0.03399	0.00019	0.18892	0.11986	0.00405	0.30272	0.29905	0.00557
2012	0.03051	0.02295	0.00000	0.19058	0.12135	0.00006	0.31881	0.31561	0.00013
2013	0.03623	0.02750	0.00000	0.19480	0.11831	0.00002	0.32081	0.30229	0.00003
2014	0.08599	0.05831	0.00000	0.18844	0.09550	0.00006	0.31972	0.25185	0.00014

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ADAPTIVE HARVEST MANAGEMENT FOR THE SVALBARD POPULATION OF PINK-FOOTED GEESE

2015 Progress Summary

This document describes progress to date on the development of an adaptive harvest management strategy for maintaining the Svalbard population of pink-footed geese *(Anser brachyrhynchus)* near their agreed target level (60,000) by providing for sustainable harvests in Norway and Denmark. This report provides an assessment of the most recent monitoring information (1991-2014) and its implications for the harvest management strategy, and it is an update of an initial assessment for 2013-2015 (see http://pinkfootedgoose.aewa.info/). By combining varying hypotheses about survival and reproduction, a suite of nine models have been developed that represent a wide range of possibilities concerning the extent to which demographic rates are density dependent or independent. Current updated model weights suggest little evidence for density-dependent survival and reproduction, suggesting that the population may have recently experienced a release from density-dependent mechanisms, corresponding to the period of most rapid growth in population size. The optimal harvest strategy for the 2013–2015 hunting seasons prescribed a harvest quota of 15,000 per year. The harvest in the 2014 hunting season was 14,991, compared to 11,081 in 2013, mostly due to an increase in harvest in Denmark during January 2015. The percentage of young in the fall of 2014 was 10.3%, which is lower than average. The observed population size of 59,000 in May 2015 was much lower than expected. For the 2015 hunting season, observed population size and temperature days suggest that an emergency closure should be considered. In the event a harvest of 15,000 is maintained, predicted population size in May 2016 is 51,700 (95% CL: 41,600-64,300), based on observed TempDays = 9 in May 2015 and the most recent model weights. On the other hand, if the season were closed this year, we would expect a population size of 66,700 (95% CL: 53,600-82,900) in May 2016. A total harvest of 6,700 would be expected to result in a 2016 population size at goal (i.e., 60,000).

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