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

Assessment for the 2013-2015 hunting seasons

Technical Report from DCE – Danish Centre for Environment and Energy No. 28 2013

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Data sheet

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Abstract: This report describes progress on the development of an adaptive harvest-management strategy for maintaining the Svalbard population of pink-footed geese near their agreed target level (60,000) by providing for sustainable harvests in Norway and Denmark. Specifically, this report provides an optimal harvest quota for the 2013-2015 hunting seasons and describes a process for evaluating whether emergency hunting closures would be needed during that period. 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, and the extent to which spring temperatures are important. The most current set of monitoring information was used to update model weights for the 1991 – 2012 period. Current model weights suggest no evidence for density-dependent survival. 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 was equivocal evidence for the effect of May temperature days (number of days with temperatures above freezing) on survival and on reproduction. The optimal harvest strategy suggests that the appropriate annual harvest quota for the 2013-2015 period is 15,000; hence there is no need to take emergency measures to close the upcoming hunting season. For comparison, the estimated harvest in 2012 was 11,000. If the harvest quota of 15,000 were met, the autumn 2013 population count is expected to be 76,000. If only the most recent 3-year mean harvest were realized (11,500), an autumn population size of 80,000 thousand is expected. Thus, it may be that harvest is approaching the magnitude needed to stabilize the population

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 thousand) by providing for sustainable harvests in Norway and Denmark. Specifically, this report provides an optimal harvest quota for the 2013-2015 hunting seasons and describes a process for evaluating whether emergency hunting closures would be needed during that period.

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 or independent, and the extent to which spring temperatures are important. 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 1991 – 2012 period. Current model weights suggest no evidence for density-dependent survival and only slightly more evidence for the three models incorporating density-dependent 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 was equivocal evidence for the effect of May temperature days (number of days with temperatures above freezing: TempDays) on survival and on reproduction.

Based on the most recent model weights, an optimal harvest strategy was computed for the 3-year period 2013-2015. The strategy suggests that the appropriate annual harvest quota for the 2013-2015 period is 15 thousand; hence there is no need to take emergency measures to close the upcoming hunting season. For comparison, the estimated harvest in 2012 was 11 thousand. If the harvest quota of 15 thousand were met, the autumn 2013 population count is expected to be 76 thousand. If only the most recent 3-year mean harvest were realized (11.5 thousand), an autumn population size of 80 thousand is expected. Thus, it may be that harvest is approaching the magnitude needed to stabilize the population.

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 increasing 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 optimal harvest quota for the 2013-2015 hunting seasons and describes a process for evaluating whether emergency hunting closures would be needed during that period.

Previous progress report (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 was about 11 thousand in 2011 and the population increased from 70 to 80 thousand.

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 the development of a strategy that prescribes harvest quotas for a 3-year decision-making cycle starting with the 2013 hunting season (i.e., once chosen, the quota would remain in effect for three hunting seasons). It relies on a process agreed to at the last meeting of the AEWA Svalbard Pink-Footed Goose International Working Group in Copenhagen in April 2013. It uses the most available data on harvest (autumn 2012), population size (autumn 2012 / spring 2013), and weather conditions on the breeding ground (May 2013) (http://pinkfootedgoose.aewa.info/). It also describes a process for evaluating the need for season closures.

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 1991-2012, 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^2 is a prediction variance common to all models. This variance was estimated by averaging the mean squared errors (MSE) from all nine models:

$$MSE = {\sum_i \frac{\left(log(N_*(t+1)) - log(N_i(t+1))\right)^2}{n}}\Big/ 9$$

where sample size for yearly comparisons was $n = 12$. The final estimate of variance was $\sigma^2 = (0.1115)^2$.

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 12k 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 ≈ 2 is the differential vulnerability of young to adults. 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 value 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). 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.

Using the elements described above, we calculated a "quasi-optimal" harvest strategy based on an assumption of updated model weights and a completely deterministic system using dynamic programming. With a 3-year decision-making cycle, environmental variation is compounded annually between quota decisions and a truly optimal solution was computationally intractable with available software. However, software that can compute an optimal, fully stochastic solution is currently being developed.

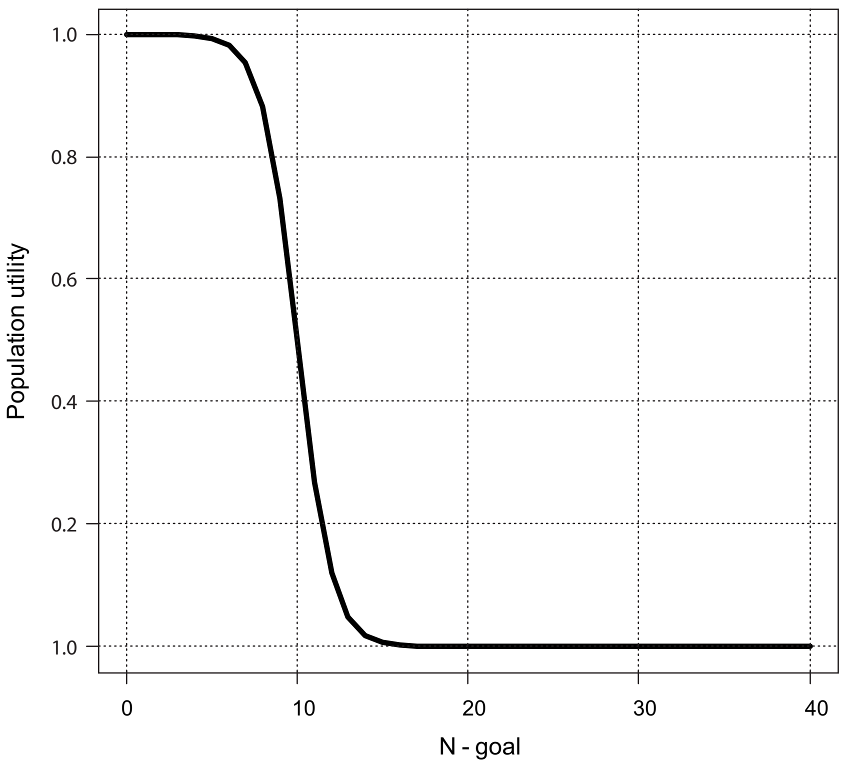

Figure 1. Population utility expressed as a function of the absolute difference between expected population size and the population goal of 60 thousand. Population sizes between about 50 and 70 thousand are acceptable (and thus have high utility), while those outside that range are very undesirable (and thus have low utility).

3 Results and Discussion

We used the most up-to-date set of monitoring information (http://pinkfootedgoose.aewa.info/; Appendix B) to update model weights for the 1991 – 2012 period. Discrimination among the nine alternative models became most pronounced after 2005 (Appendix C, Fig. 3). Current model weights (i.e., those based on population size after the 2012 harvest) suggest no evidence for density-dependent survival ($p_{DD-S} = 0.00$) and only slightly more evidence for the three models incorporating density-dependent reproduction ($p_{DD-R} = 0.42$) (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). Taken at face value, 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 was equivocal evidence for the effect of TempDays on survival ($p_{DAYS-S} = 0.52$) and on reproduction ($p_{DAYS-R} = 0.49$).

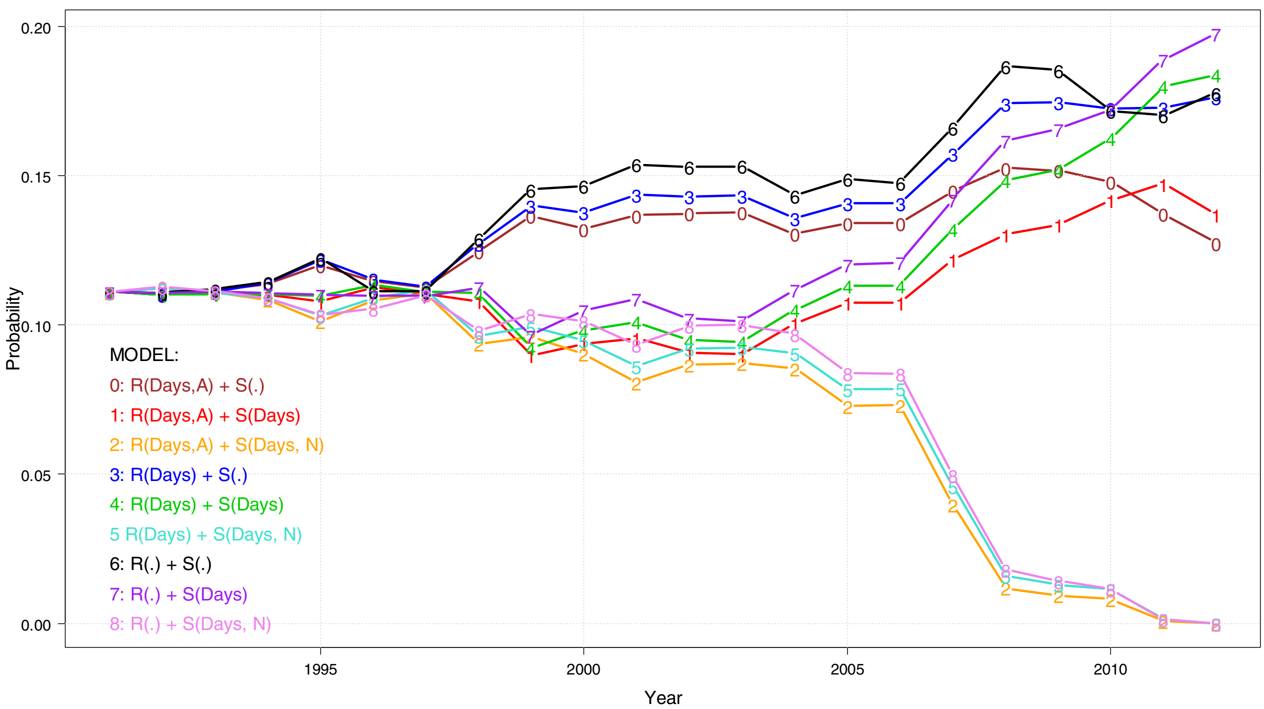

Figure 2. Posterior model weights for nine alternative models describing the annual dynamics of the pink-footed goose population, assuming equal prior model weights in 1991. See Table 1 and Appendix A for a description of the models.

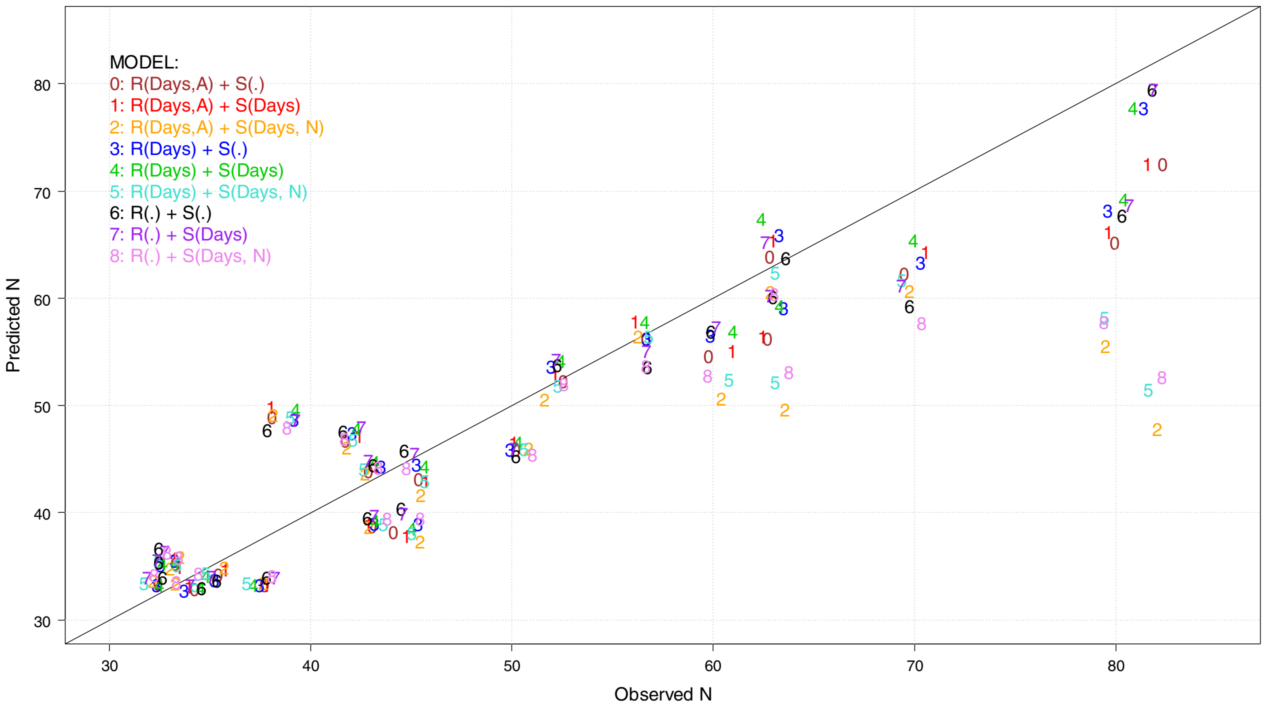

Figure 3. Comparison of observed population sizes and those predicted by nine alternative models describing the annual dynamics of the pink-footed goose population. See Table 1 and Appendix A for a description of the models. The diagonal line represents perfect correspondence between observations and predictions. Predictive ability declined as the population entered a rapid growth phase (i.e., observed population sizes in excess of 60 thousand).

Based on the most recent model weights, we computed a quasi-optimal harvest strategy for the 3-year period 2013-2015. Because it is not practical to provide the full strategy here (it is a 5808 × 4 table), we used a linear model and least-squares regression to calculate an *approximate* decision rule for population sizes containing ≤90 thousand adults and ≤16 thousand young:

$$Q = -20.671 + 0.445Y + 0.435A + 0.137D,$$

where Q is harvest quota in thousands, Y and A are the number of young and adults in thousands in November, respectively, and D = temperature days in May. Thus, the decision rule implies adding 445 to the harvest quota for every thousand young, adding 435 to the quota for every thousand adults, and adding 137 to the quota for every temperature day. Graphs of optimal harvest quotas for TempDays = {0, 8, 16} are provided in Figs. 4 – 5. The strategy suggests that the appropriate harvest quota for the 2013-2015 period is 15k (based on Y = 8.1k, A = 73.5k, and D = 4). For comparison, the estimated harvest in 2012 was 11.0k.

We can also use the alternative models and their associated weights to predict the population size expected after the harvest in autumn 2013. If the harvest quota of 15 thousand were met, we would expect the autumn 2013 population count to be 76 thousand. On the other hand, if only the most recent 3-year mean harvest were realized (11.5 thousand), we would expect an autumn population size of 80 thousand. Thus, it may be that harvest is approaching the magnitude needed to stabilize the population. We emphasize that all harvest estimates and harvest quotas expressed in this report do *not* include mortality resulting from crippling.

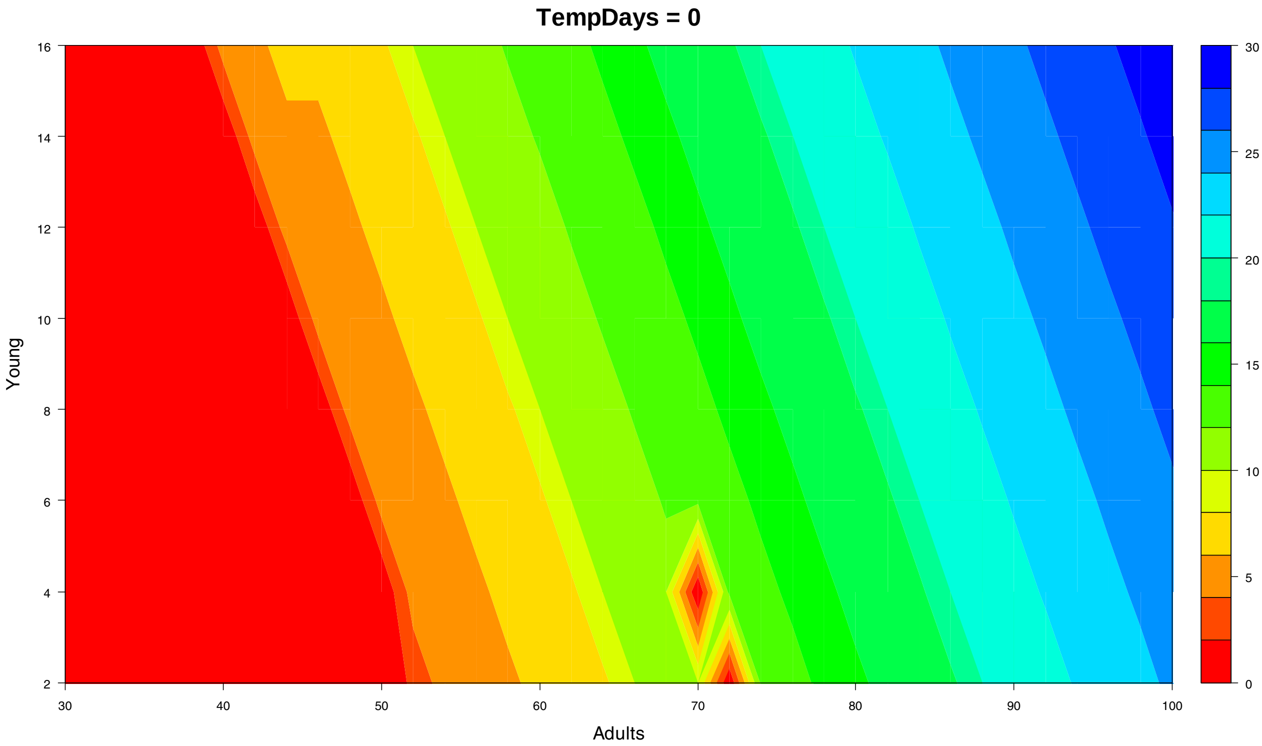

Figure 4. Three-year harvest quotas (color key) for the Svalbard population of pink-footed geese based on model weights in 2013, under the condition of zero days above freezing in Svalbard in May. Harvest quotas and the number of young and adults are in thousands.

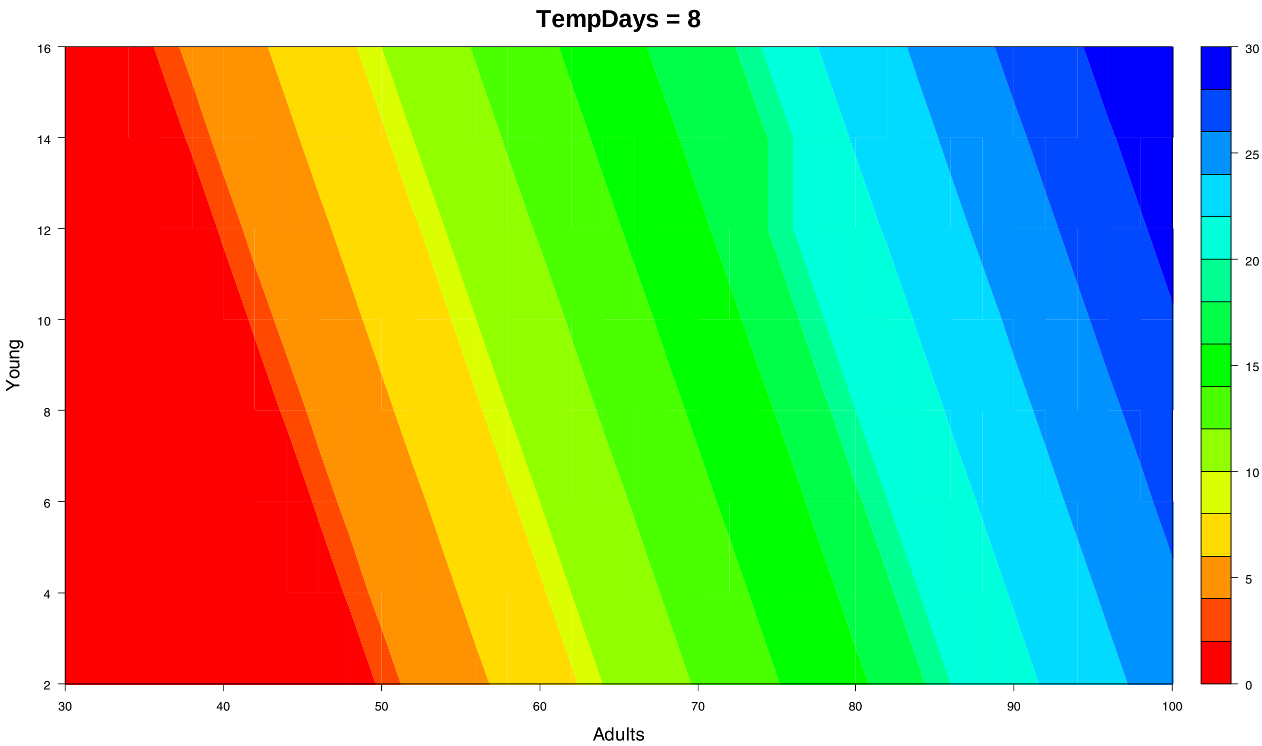

Figure 5. Three-year harvest quotas (color key) for the Svalbard population of pink-footed geese based on model weights in 2013, under the condition of eight days (near the average) above freezing in Svalbard in May. Harvest quotas and the number of young and adults are in thousands.

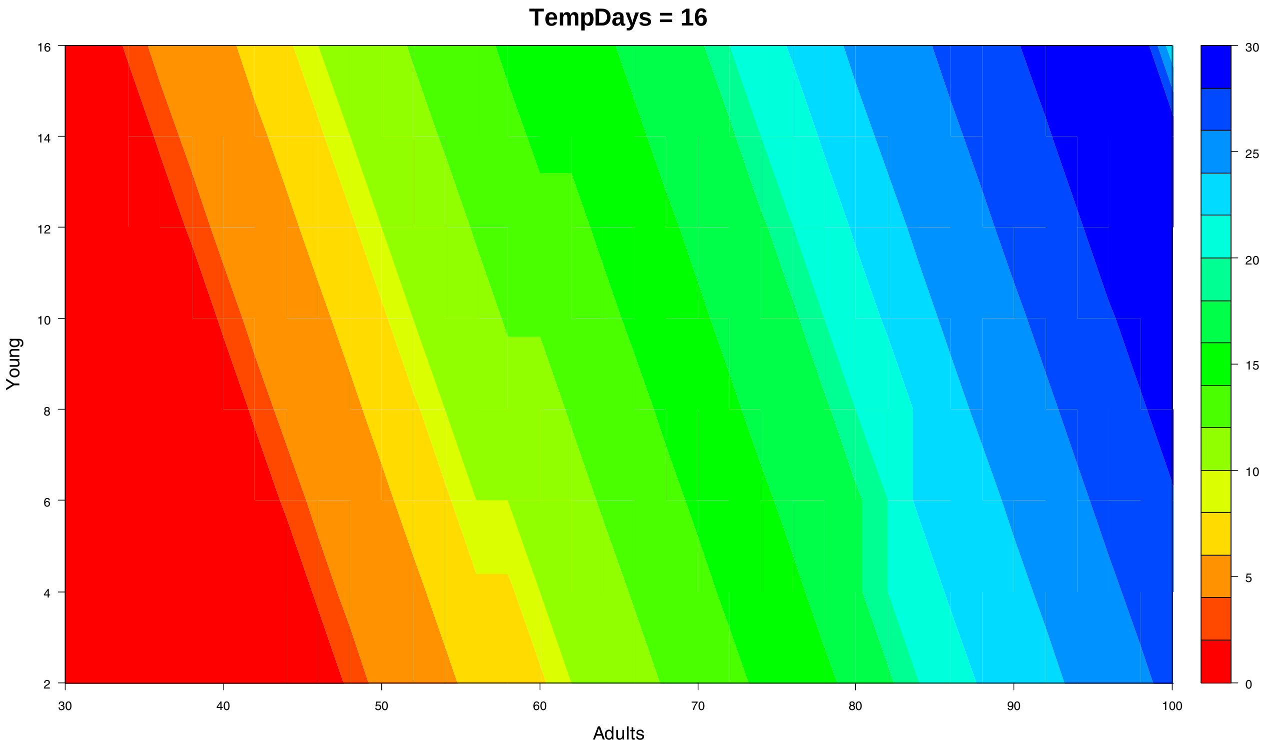

Figure 6. Three-year harvest quotas (color key) for the Svalbard population of pink-footed geese based on model weights in 2013, under the condition of 16 days above freezing in Svalbard in May. Harvest quotas and the number of young and adults are in thousands.

Finally, managers have expressed a desire to know under what conditions a closure of the hunting season might be considered, in the event that the population falls well below the target due to a combination of unforeseeable environmental conditions, e.g. extreme weather, and high harvest levels. To address this need, monitoring information and model weights should be updated each year, followed by calculation of an updated optimal harvest strategy. Each year, this harvest strategy will prescribe the resource conditions (population size and temperature days) for which a closed season would be optimal. 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 2013 autumn hunting season, population size is well above that which would call for an emergency closure.

4 Future Work

There are several needs related to the monitoring programs for pink-footed geese:

From the Danish wing surveys, annual data on the age composition (young vs older geese) is available; however, the sample size is relatively small (usually <200 per year). At present quantitative information is lacking about the age composition of the Norwegian harvest. In autumn 2013, an effort will be made to increase the numbers of wings from the Danish bag and a system is planned for collecting and aging wings in Nord-Trøndelag in mid-Norway.

Annual harvest estimates and predicted harvest 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 no data concerning the level of non-retrieved geese are 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.

Until recently, population estimates were based on internationally coordinated counts in early November, which is in the middle of the hunting season. 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 3 seasons, spring counts in early May have been conducted with good results. Furthermore, autumn counts have become increasingly difficult because the geese have been short-stopping in Norway, Denmark and Sweden and using new areas which are not fully covered. Therefore, it is recommended that the count in May be a priority, but the November count should be maintained in the coming years in order to provide data for calibration of counts.

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 plans to carry out these analyses in the course of autumn 2013, based on capture-resightings up to spring 2013.

The other two principal needs concern the optimization process and the form of the model set. Because of software limitations, we currently are unable to account for sources of stochasticity in calculating optimal harvest strategies. A new software program developed at North Carolina State University should allow us to overcome this limitation. Finally, a Bayesian state-space model may be a better modeling approach, as the Dutch review of previous work suggested (http://pinkfootedgoose.aewa.info/). The advantage of a Bayesian state-space model is that it can directly incorporate the harvest data in the modeling, as well as update all of the parameters of the model each year. With the current approach, a discrete set of models assume the parameters (e.g., regression coefficients) are fixed and the model weights are updated each year. With the Bayesian 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 wider array of parameter values.

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:

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

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. 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 ($\bar{p} = 0.14, \theta = a/\bar{p} = b/(1-\bar{p}) = 43.77$).

Appendix B.

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.

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	70000	15400	20	8841	3100
2011	80000	15600	10	8019	3410
2012	81600	8064	4	8853	2169

Appendix C.

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	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
1992	0.1103	0.1103	0.1123	0.1101	0.1102	0.1122	0.1109	0.1109	0.1128
1993	0.1114	0.1106	0.1110	0.1113	0.1105	0.1110	0.1119	0.1111	0.1113
1994	0.1138	0.1101	0.1085	0.1141	0.1104	0.1090	0.1144	0.1107	0.1090
1995	0.1201	0.1079	0.1013	0.1218	0.1097	0.1033	0.1224	0.1102	0.1034
1996	0.1149	0.1126	0.1081	0.1154	0.1135	0.1092	0.1114	0.1097	0.1054
1997	0.1125	0.1103	0.1106	0.1129	0.1111	0.1116	0.1114	0.1098	0.1100
1998	0.1246	0.1079	0.0936	0.1272	0.1107	0.0964	0.1290	0.1126	0.0981
1999	0.1366	0.0898	0.0961	0.1400	0.0925	0.0994	0.1454	0.0966	0.1036
2000	0.1322	0.0938	0.0902	0.1378	0.0982	0.0949	0.1466	0.1050	0.1014
2001	0.1368	0.0956	0.0807	0.1437	0.1010	0.0863	0.1538	0.1087	0.0935
2002	0.1373	0.0908	0.0868	0.1431	0.0950	0.0922	0.1530	0.1022	0.0997
2003	0.1377	0.0902	0.0872	0.1434	0.0943	0.0926	0.1532	0.1014	0.1001
2004	0.1305	0.1006	0.0855	0.1357	0.1051	0.0907	0.1434	0.1117	0.0970
2005	0.1342	0.1074	0.0730	0.1408	0.1130	0.0785	0.1489	0.1203	0.0841
2006	0.1342	0.1076	0.0731	0.1408	0.1133	0.0787	0.1477	0.1210	0.0837
2007	0.1449	0.1218	0.0398	0.1573	0.1322	0.0460	0.1662	0.1422	0.0496
2008	0.1527	0.1304	0.0119	0.1742	0.1484	0.0160	0.1867	0.1618	0.0181
2009	0.1517	0.1336	0.0094	0.1747	0.1522	0.0131	0.1854	0.1657	0.0143
2010	0.1479	0.1419	0.0081	0.1726	0.1625	0.0115	0.1718	0.1722	0.0114
2011	0.1372	0.1473	0.0008	0.1728	0.1800	0.0015	0.1701	0.1890	0.0014
2012	0.1274	0.1370	0.0000	0.1763	0.1838	0.0000	0.1778	0.1976	0.0000

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

Assessment for the 2013-2015 hunting seasons

This report describes progress on the development of an adaptive harvest-management strategy for maintaining the Svalbard population of pink-footed geese near their agreed target level (60,000) by providing for sustainable harvests in Norway and Denmark.

Specifically, this report provides an optimal harvest quota for the 2013-2015 hunting seasons and describes a process for evaluating whether emergency hunting closures would be needed during that period. 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, and the extent to which spring temperatures are important. The most current set of monitoring information was used to update model weights for the 1991 – 2012 period. Current model weights suggest no evidence for density-dependent survival. 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 was equivocal evidence for the effect of May temperature days (number of days with temperatures above freezing) on survival and on reproduction.

The optimal harvest strategy suggests that the appropriate annual harvest quota for the 2013-2015 period is 15,000; hence there is no need to take emergency measures to close the upcoming hunting season. For comparison, the estimated harvest in 2012 was 11,000. If the harvest quota of 15,000 were met, the autumn 2013 population count is expected to be 76,000. If only the most recent 3-year mean harvest were realized (11,500), an autumn population size of 80,000 thousand is expected. Thus, it may be that harvest is approaching the magnitude needed to stabilize the population.

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