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Using re-sighting data to estimate population size of Pink-footed Geese (*Anser brachyrhynchus*)

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In wildlife management, the ability to reliably assess population sizes is a basic prerequisite. When populations are managed specifically to maintain a population target this is even more vital. In this study we apply a mark-resight approach using neck-collared geese to develop and present an alternative method to total counts when estimating the population size of Pink-footed Geese (*Anser brachyrhynchus*). Estimates of population size from the mark-resight approach showed an increasing trend from 31,000 birds in 1991/1992 to 100,700 birds in 2011/2012, and fluctuating numbers around 80,000 in recent years. By exploring the relationship between uncertainty of the population estimate and the monitoring effort, we showed that a minimum of approximately 120 independent flocks greater than 100 birds should be surveyed to derive a ratio estimate of marked to unmarked birds minimizing uncertainty of the overall population estimate. This threshold was only met in the last 6 years of our data series, and there was therefore a high degree of uncertainty concerning estimates from earlier years. Our analysis revealed that recent mark-resight estimates were in good agreement with the total counts derived from traditional methods, although generally slightly higher. By deriving an independent population estimate, the approach can be used to quality assure the traditional total counts, which may (due to overlooked birds and changing site use) be prone to underestimation of true population size, especially in spatially expanding and widespread populations.

1. Introduction

In most of wildlife management, one of the most fundamental prerequisites is to reliably assess the size of free-ranging populations. In order to evaluate both the state of these populations, as well as potential effects of environmental changes or management actions on population change, managers rely on consecutive assessments of population estimates, derived from systematically robust methods allowing for direct comparisons between individual years. In waterbird monitoring, several methods have been developed to assess population sizes (Delany 2005, Delany & Scott 2005). Each of these is associated with a range of benefits and drawbacks in relation to underlying assumptions, data collection and accuracy of the estimates. Choosing the most optimal method relies on the species' visibility in the landscape, delineation of population flyways, available data sources and available resources (Robertson *et al.* 1995, Ganter & Madsen 2001, Alldredge *et al.* 2007, Grimm *et al.* 2014).

When populations are managed to maintain a population size around a set population target, or increase a population towards an agreed goal, the ability to accurately estimate population size is vital. This approach has gained growing acceptance in the management of North American species (NAWMP 2004, Rosenberg & Blancher 2005), and numerical population targets are increasingly used in wildlife conservation (Sanderson 2006), and in the management of conflict species with potential negative effects on natural habitats, human interests or endangered species (Williams & Madsen 2013).

One such example is the Svalbard breeding population of Pink-footed Geese (*Anser brachyrhynchus*). The combined effects of recent exponential growth of this population, increasing damage to agricultural crops and impacts on vulnerable tundra vegetation, have led to the implementation of an International Single Species Management Plan (ISSMP) for this population, under the auspices of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) (Madsen & Williams 2012). A main objective of this plan is to maintain a stable population size of approximately 60,000 birds (Madsen *et al.* 2017), using the principles of adaptive harvest management (Nichols *et al.* 2007).

For most European species of waterfowl, population size has traditionally been estimated by "total counts" (Delany 2005). Geese, swans and ducks are rather conspicuous birds in the landscape, and given their flocking behavior and the generally limited range of potential habitats they occupy, surveying by ground-based, internationally synchronized total counts is probably much more feasible for these species than for any other avian group. For geese and swans in particular, their nature of communal overnight roosting further enables observers to survey birds from a large geographical area in a very limited time by counting birds as they leave or depart from the roosts.

In the case of the Pink-footed Goose, population size has been assessed annually since 1980 by coordinated counts throughout the entire flyway of this population, including all known areas with significant numbers of birds (Madsen 1982, Madsen *et al.* 2018). In recent years however, the population has increasingly expanded its distribution in Northwest Europe. In the mid-1990s spring-staging Pink-footed Geese were restricted to a few important staging areas in Denmark and Norway (Madsen *et al.* 1999). Since the mid-2000s, the population has spread over most of the Danish west coast and northern Jutland (Madsen *et al.* 2015, Clausen & Madsen 2016), expanded their range in mid-Norway (Madsen *et al.* 2015) and flocks of > 1,000 birds have been observed in both Sweden, western Finland and Germany (Kruckenberg & Penkert 2010, Madsen *et al.* 2018). This development might have been driven by the effects of increasing population size (Madsen *et al.* 2018), changes in land use (Clausen *et al.* 2018) and changes in traditional staging sites (Clausen & Madsen 2016).

The expanding distribution and exploitation of hitherto unknown areas complicate a reliable assessment of population size from total counts, and recently the completion of repeated counts indicated that approximately 15% of the population had been missed in 2015 (Madsen 2015). In order to sustainably harvest this population, and ensure that population numbers remain relatively stable, an accurate assessment of annual population size is of utmost importance. Consequently, the international working group for the Svalbard Pink-footed Goose ISSMP recommended the development of an additional assessment of population size to complement and cross-check with the annual counts.

In this study, we applied a mark-resight approach to develop and present an additional method of estimating population size of Pink-footed Geese, and provided an estimate of the uncertainty of the estimate. This uncertainty mainly pertained to the variance of the ratio of marked to unmarked birds, which was used to derive an assessment of how many ratios are necessary to produce a reliable estimate of population size. Our method relies solely on observations of marked geese and is thus completely independent of total counts. A similar approach was applied in the 1990s by Ganter & Madsen (2001), but in that analysis, the methodology was not evaluated statistically, detection probability of birds was not accounted for, and uncertainty not fully quantified. Hence, with the present paper, we provide a statistically based framework for using the mark-resight approach, and assess the efforts and resources needed to apply this method. We also discuss transferability to other species, and the potential challenges and future possibilities in relation to monitoring of Pink-footed Geese.

2. Methods

2.1. Focal population

The Svalbard-breeding population of Pink-footed Geese migrates via Norway to overwintering areas in Denmark, the Netherlands and Belgium (Madsen *et al.* 1999). During the last decade, increasing numbers have prolonged their stopover in Denmark before migrating further south, and increasing proportions stay in Denmark throughout the winter (Clausen *et al.* 2018). In spring, the geese make stopovers in mid and northern Norway before migrating to the Svalbard breeding grounds.

Total counts of the population indicate that the population size has increased from well over 30,000 birds in the early 1990s, to reach a peak of 81,600 birds in 2012, with numbers in 2018 around 70,000 birds (Madsen *et al.* 2018). The current population target is 60,000 geese, and the population is subject to a considerable amount of harvest with the aim to regulate the population size around the agreed target (Madsen *et al.* 2017, Clausen *et al.* 2017).

2.2. Marking and re-sighting data

Svalbard-breeding Pink-footed Geese have been subject to a long-term ringing scheme using plastic neck-collars. The first birds were caught and ringed in 1990 and, since then, a total of approximately 5,000 geese have been marked, with individual capture events ranging between 12 and 500 birds. Most birds have been captured by cannon-netting in spring in Denmark (two sites) and mid Norway (three sites), but a small number (< 600) have been caught in northwest Finland (one site) and by rounding up geese during wing moult in Svalbard (seven sites). All geese were ringed with metal rings and plastic neck-collars with unique inscriptions, sexed by cloacal examination and aged by feather characteristics. A detailed description of the captures can be found in Madsen *et al.* (2002) and Clausen and Madsen (2014).

Reporting of neck-collared Pink-footed Geese are done continuously by both professional observers and volunteer observers throughout the wintering range of this population. All sightings are reported to a common database using the online entry platform www.geese.org. Due to systematic re-sighting campaigns in autumn and spring, the database contains approximately 400,000 re-sightings throughout the period 1990–2018, with the majority of records from professional observers in the period from late September to mid-November and late March to late May. In addition to reporting marked birds, the professional observers also carry out assessments of the ratio of marked to unmarked birds in individual flocks.

Observers are instructed to collect ratios by scanning through a flock of geese one by one, assigning each observed individual as either collared or not, and only for individuals for which the neck is clearly visible. This procedure is followed for a random sample of the flock or until all birds are assigned to one of the two groups. In the 1990s and early 2000s, the effort to collect ratio data was rather limited, but since the 2012/2013 winter efforts have been improved by means of systematic campaigns similar to the reporting of neck collars.

Observation efforts have also been adjusted to ongoing changes in the birds' wintering site use. This means that until 2011, almost all observations were made in Friesland, and as the geese in growing proportions started to winter in Jutland, the majority of the observations were made in Denmark (Clausen *et al.* 2018). Until 2011, all ratio observations were made in autumn, but thereafter the efforts were expanded to include both autumn and spring. Occasional neck-collar loss does occur in this population (Clausen *et al.* 2015), but because ringed individuals are used to estimate both terms of equation (1) in this study, neck-collar loss will not lead to biases in the population estimate.

2.3. Data analyses

An estimation of total population size (N) can be derived by dividing the number of marked geese in the population (M) with the ratio between number of screened geese and marked geese (R, Sheaffer & Jarvis 1995, Clausen *et al.* 2013):

$$N = M / R \quad (1)$$

R was estimated from observations of marked individuals in screened flocks. In recent years, with ratio data from both autumn and spring, ratios from the entire wintering period were treated as one sampling period, as they did not differ statistically between the two seasons (general linear model with season and year as independent variables and a log transformed (ratio + 1) ratio as dependent variable: $F_{1,1387} = 0.41, p = 0.521$). The estimate of R was calculated as the mean of the ratios from screened flocks with marked birds during autumn and spring:

$$R = \sum \frac{m_i}{g_i} \quad (2)$$

where *mi* specifies the number of marked individuals in flock i, and g_i the number of birds screened for collars in the ith flock. The distribution of the ratios deviated from normal, so we log transformed the ratios before calculating the mean and then back transformed the estimate to get an estimate of R.

Since the annual ratio estimate was based on flocks with marked birds, the ratio overestimates the proportion of marked individuals in the population. The overestimation of the ratio for each year corresponds to the ratio between total numbers of scanned birds in marked flocks divided by the total number of birds observed, and the estimate was therefore corrected by this magnitude.

We estimated the ratio for flocks where more than 100 individuals were scanned. This minimum number of birds scanned was chosen due to higher probability of finding marked birds in large flocks, which resulted in fewer $R = 0$. In addition, small flocks with just a few marked birds gave high ratios relative to the large flocks and hence resulted in a larger variance of R.

Consequently, the distribution of the log transformed ratios for flocks > 100 were better to work with as they did not violate assumptions regarding normality. Pink-footed Geese are often most found in large flocks, and on average, the number of birds reported in flocks > 100 made up 98% of all individuals reported annually. Therefore, the > 100 cut-off were unlikely to lead to sub-sampling of the population.

The variance of R (V_R) was calculated as:

$$V_R = \sum \frac{(g_i - R \times m_i)^2}{f(f - 1 \times \hat{a}^2)} \quad (3)$$

where f specifies the total number of flocks and $\hat{a}$ the mean number of marked geese per flock (Clausen *et al.* 2013). The estimate of the variance was based on the corrected ratio estimate. For the estimates of ratios only years where > 10 flocks had been screened were included, which led to the exclusion of two years with very limited data. Observations to estimate ratios were available from autumn 1991, meaning that our earliest population estimate was for the 1991/1992 winter.

M was estimated from the number of birds seen alive in any given year (A) corrected for annual variation in detection probability (dp):

$$M = \frac{A}{dp} \quad (4)$$

The number of birds seen alive (A) was defined as the sum of all neck-collared birds reported at least 2 times within a window of 2 months (March 23rd–May 22nd), corresponding to the period with intensive surveying by professional observers.

Neck-collared Pink-footed Geese were generally seen several times during this period, and to minimize the influence of re-sighting errors, we only included a bird as observed if it was seen at least two times in the observation window.

Annual detection probability (dp) was estimated using the program MARK (White & Burnham 1999), based on dead recoveries and encounter histories of all individuals ringed (Joint Live and Dead Encounters). Encounter histories were based on the same annual observation window (March 23rd–May 22nd) as mentioned above, and again, only birds with at least 2 sightings within the observation window were included as positive observations. Using MARK we fitted a number of models with various constraints on survival, re-sighting probability and recovery probability. These models were evaluated using the Akaike information criterion (AIC, Burnham & Anderson 2002), and estimates of annual detection probability from the best performing model used in equation (4).

The total variance of N (VN) can be approximated using the delta method (Rice 1988), assuming no covariance between *R* and *M*:

$$V_N = R^2 \times V_m + M^2 \times V_R \quad (5)$$

The variance of *M* (V_M) was far from trivial to estimate as it is a ratio (van Kempen & van Vliet 2000), but in this study V_M had miniscule importance compared to the contribution of $M^2 \times V_R$, as the R^2 had a maximum of 0.00023 and an average of 0.000087. Consequently, in this study V_n was approximated as $M^2 \times V_R$, and we used this variance to estimate the confidence limits for the annual population estimates.

The annual re-sighting estimates were compared to the total counts by regressing the two sets of independent estimates and look for annual deviations as well as consistent biases from the expected linear Y = X relationship.

2.4. Uncertainty of the population estimate in relation to monitoring effort

Because uncertainty of the population estimate pertained primarily to the variance of the ratio of marked to unmarked birds, we used the ratio effort to evaluate when the applied method was accurate enough to be useful (how many ratios were needed to produce a reliable estimate). To quantify the uncertainty of the annual population size estimates we used the difference between upper and lower confidence limits.

The relation between the uncertainty and sample size of the ratios seemed to approach an asymptote. An asymptotic function can estimate the number of flocks where only small reductions of the uncertainty of the population estimate would be achieved by further increasing the number of flocks screened. The applied Gaussian functions could only fit to an increasing exponential function, so instead of a declining exponential function we modelled 1/difference. This function estimates the same tipping point of the asymptote. To model the relationship we used the Gaussian function in equation 6 (below).

Difference indicates the difference between upper and lower confidence limits, nugget represents the intercept with the y axis, sill + nugget estimate the asymptote. For a Gaussian function 95% of the asymptote is reached at $\sqrt{3}$ × range, which can be considered an estimate of the number of flocks where the asymptote has been reached (https://support.sas.com/documentation/cdl/en/statug/63347/HTML/default/viewer.htm#statug_variogram_a0000000579.htm).

In addition, the estimate of the population size showed a positive relation to the uncertainty. To account for the linear effects of population size we included the estimate of the population size in the model. The Gaussian function and the relation to the population estimate was modelled together using the formula in equation 7 (below), where α is the slope for the relation between 1/difference and the population estimate. We estimated the Gaussian model using proc model in SAS 9.3 (SAS Institute, Cary, NC).

3. Results

3.1. Population size of Pink-footed Geese

Through most of the study period (1991/1992–2011/2012) the number of flocks screened for ratio estimates varied between 1 and 49 flocks per year. Due to the increase in monitoring effort over the last six years, the number of flocks screened from 2012/2013 onwards was more than five-fold relative to earlier years (Table 1). After initiation of the ringing scheme in the early 1990s, the ratio of marked to unmarked geese increased steadily from 0.007 to reach a peak of 0.015 in 2007/2008. From then onwards the ratio declined to reach a level similar as the early period (Table 1).

Numbers of neck-collared birds observed an-

$$\frac{1}{difference} = nugget + sill \times (1 - \exp(\frac{-number\ of\ flocks^2}{range^2})) \quad (6)$$

$$\frac{1}{difference} = nugget + sill \times (1 - \exp(\frac{-number\ of\ flocks^2}{range^2})) + \alpha \times estimate \quad (7)$$

Table 1. Corrected ratios (*R*) and sample sizes for flocks > 100 of Pink-footed Geese (*Anser brachyrhynchus*).

Winter	Ratio	No. of flocks with marked birds	Total no. of flocks
1991/1992	0.0074	25	28
1992/1993	0.0076	15	15
1993/1994	0.0067	25	25
1994/1995	0.0094	13	13
1995/1996	0.0088	26	26
1996/1997	0.0060	38	44
1997/1998	0.0041	44	49
1998/1999	0.0088	1	1
1999/2000	0.0096	33	34
2000/2001	0.0103	27	27
2001/2002	0.0107	21	21
2002/2003	0.0112	22	23
2003/2004	0.0126	13	14
2004/2005	0.0124	18	20
2005/2006	0.0143	13	14
2006/2007	0.0091	14	16
2007/2008	0.0153	14	15
2008/2009	0.0112	13	15
2009/2010	0.0127	23	24
2010/2011	0.0086	6	6
2011/2012	0.0052	10	16
2012/2013	0.0065	183	274
2013/2014	0.0052	204	295
2014/2015	0.0041	226	383
2015/2016	0.0062	291	373
2016/2017	0.0060	192	264
2017/2018	0.0087	217	246

Table 2. Number of birds ringed, number of birds observed at least twice in the observation window, detection probability and estimated number alive of Pink-footed Geese (*Anser brachyrhynchus*) in the period 1991/1992–2017/2018. Note that birds ringed in any given year (towards the end of the observation period) does not form part of the numbers observed and does not affect detection probability before the following year.

Winter	No. ringed	No. observ-ved (*A*)	Detection proba-bility (*dp*)	Esti-mated alive (*M*)
1991/1992	151	366	0.933	230
1992/1993	3	298	0.896	329
1993/1994	100	354	0.851	298
1994/1995	130	421	0.841	345
1995/1996		316	0.828	381
1996/1997		217	0.718	302
1997/1998	339	516	0.747	236
1998/1999		405	0.853	474
1999/2000	151	491	0.826	411
2000/2001	192	522	0.800	412
2001/2002	274	657	0.782	490
2002/2003	205	646	0.734	600
2003/2004	289	847	0.849	656
2004/2005	395	1,043	0.878	738
2005/2006		846	0.933	907
2006/2007	528	1,175	0.872	741
2007/2008	104	531	0.416	1,026
2008/2009	189	703	0.583	881
2009/2010		531	0.662	802
2010/2011	168	582	0.705	587
2011/2012	227	664	0.828	527
2012/2013		400	0.696	574
2013/2014	37	284	0.618	399
2014/2015	377	547	0.590	288
2015/2016	350	782	0.856	504
2016/2017	460	984	0.881	594
2017/2018	12	623	0.881	693

nually varied as a result of fluctuations in ringing activity and observation effort (Table 2). The best performing MARK model included annual variation in survival rate and detection probability, and a constant recovery probability and fidelity (*S*(t) *p*(t) *r*(.) *F*(.)). However, detection probabilities were very consistent across the different models, and the choice of final model was unlikely to influence *M* significantly. The estimated numbers of marked birds alive (*M*) varied between 230 geese in the first year of the study (1991/1992) and 1,026 geese in 2007/2008 (Table 2).

Mark-resight estimates of population size of Pink-footed Geese showed an overall increasing trend from around 31,000 birds in 1991/1992 to approximately 100,700 birds in 2011/2012 (Fig. 1). From 2011/2012 to 2017/2018 the population has fluctuated around 80,000 birds. Due to the small sample size of collected ratios in early years, only estimates from the 2012/2013 season onwards were accurate enough to have management value. When compared to the estimated population size from total counts (Fig. 2), the linear relationship between the two was very good ($Y = 8.626 + 1.002X$, $R^2 = 0.85$). However, the mark-resight estimate was generally higher (18% across all years, 7% in years with high ratio monitoring effort), and therefore suggested a slightly higher

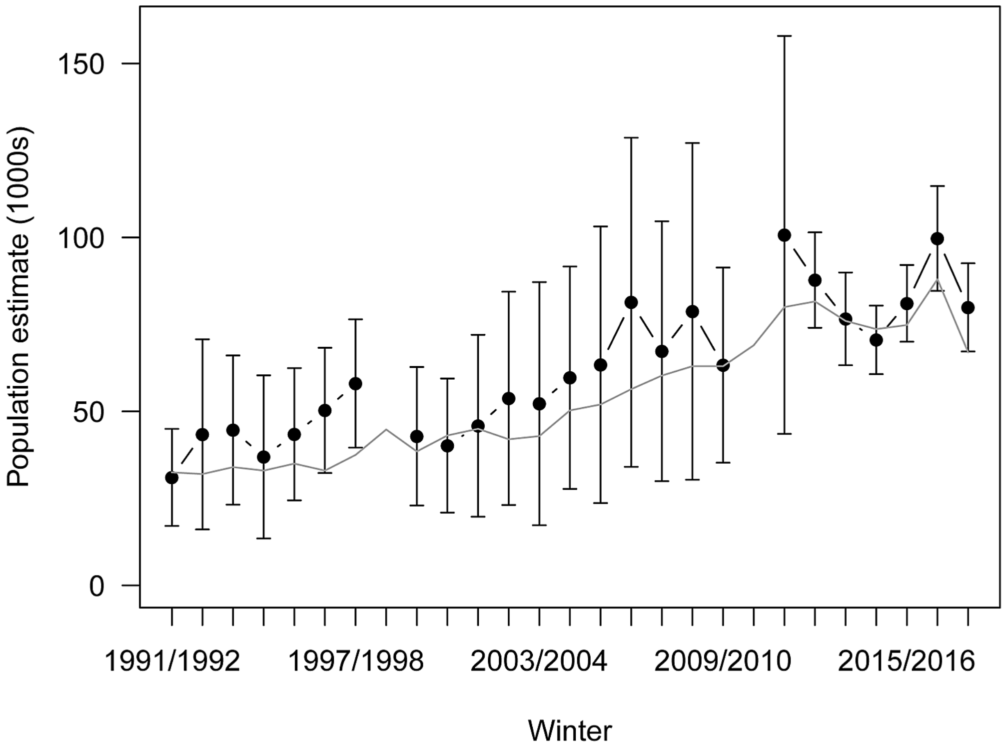

Fig. 1. Estimated population size of Pink-footed Geese (*Anser brachyrhynchus*) in the period 1991/1992–2017/2018 from the mark-resight analysis. Error bars indicate the 95% confidence limits, and grey solid line estimates from the total counts. Note the difference in uncertainty of the estimates between the periods with low (1991/1992–2011/2012) and high (2012/2013–2017/2018) ratio observation effort. For two years (1998/99 and 2010/11) sample size of the ratios of marked to unmarked geese was below 10 and hence these years have been omitted from the analysis.

population size than that derived from total counts. The slope close to one indicated that the difference between the two estimates was rather consistent across population sizes (Fig. 2).

3.2. Uncertainty of the population estimate in relation to monitoring effort

The exponential function to estimate onset of the asymptote (the lower threshold for appropriate monitoring effort) gave a good fit to the data (R^2 = 0.913). The range estimate suggested that the difference between the confidence limits stabilized at 113 flocks > 100 birds (65.5 × $\sqrt{3}$, Table 3), at a difference around 25,000 (Fig. 3). The lack of data in the region around our estimate of range initially made it rather uncertain, and to explore the robustness of the estimate we subsampled a random 50% of the data in all six years with high monitoring effort, to create sample sizes mimicking an intermediate monitoring effort close to the estimate of range.

Based on a data set including the original data for the winters 1991/1992–2011/2012 and 50% subsampled data for the years 2012/2013–2017/2018 we re-ran the analysis. This revealed a very similar estimate of range (69.8, Table 3), corresponding to 121 flocks. Jointly, these analyses suggest an onset of the asymptote in the region of 120 flocks, above which further effort will only lead to minor reductions in uncertainty of the population estimate. It is important to note that our estimate of 120 flocks was built on fully independent ratio samples, meaning that this number is only valid when individual flocks subject to ratio collection were separated in time or space. If we consider this effort suitable, the appropriate number of ratios was only achieved from the 2012/2013 winter onwards, when efforts were improved by means of systematic campaigns (see methods).

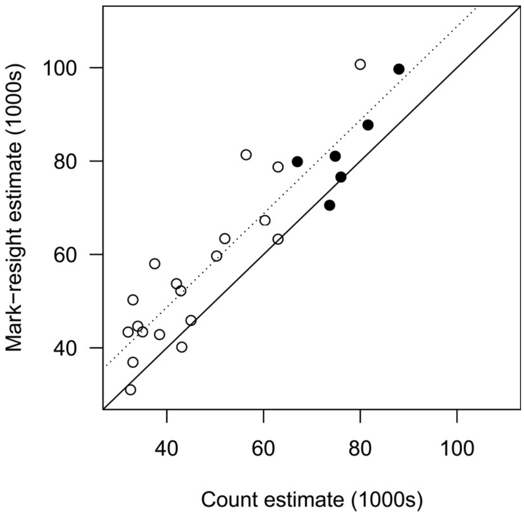

Fig. 2. Comparison of estimated population size of Pink-footed Geese (*Anser brachyrhynchus*) from the mark-resight approach presented in this study and total counts. Solid line indicates the perfect Y = X relationship of complete agreement between the two methods, and dashed line the actual relationship (Y = 8.626 + 1.002X). Filled circles indicate the six years with high ratio observation effort.

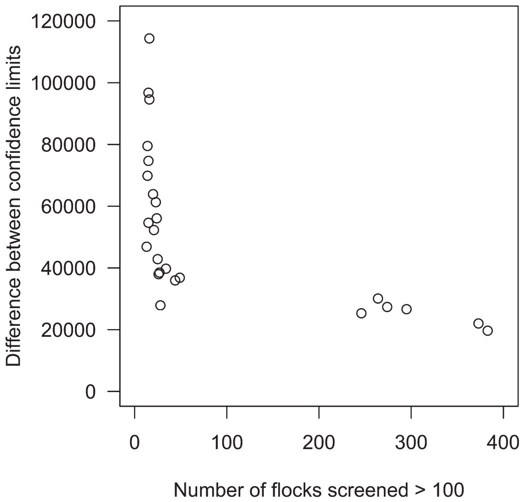

Fig. 3. Relationship between uncertainty of the population estimate (difference between confidence limits) and the number of flocks with > 100 individuals screened for ratios of marked to unmarked geese.

4. Discussion

The mark-resight approach described in this study shows an additional way of estimating waterfowl population size, relying only on data on observations of marked birds. Accuracy of the estimates varied considerably between the early period with low sample sizes of *R* and the late period with high sample sizes of *R*.

By exploring the relationship between uncertainty of the population estimate and the monitoring effort, we were able to show that approximately 120 independent flocks > 100 birds should be included to derive a ratio estimate minimizing uncertainty, indicating that only in the last six winters (2012/2013 onwards) has the mark-resight effort been good enough to ensure reliable estimates. This underlines the high susceptibility of the population estimate to the precision of the ratio *R* (Sheaffer & Jarvis 1995).

Based on these findings, it can be concluded that current ratio efforts should be maintained in order to minimize uncertainty of the population estimates using this method, and that sample sizes of *R* below 50 (which was the case for most of our study period) will only produce very uncertain estimates with confidence limits spanning tens of thousands of birds.

Accuracy aside, the estimates from the mark-resight approach were generally in good agreement with traditional total counts, albeit on average slightly higher. While this could suggest that total counts could be interpreted as a "minimum population size", our re-sight method also has drawbacks that might affect or even bias the estimated population size. As such, the estimate of *R* is built on the assumptions that 1) ringed birds are randomly distributed in the population and 2) there is an equal probability of detection among marked and unmarked geese (Clausen *et al.* 2013).

Regarding 1), this assumption is often challenged when marking and re-sighting is not sufficiently separated in either time or space. In our data however, the collection of ratios was separated from marking events in both time (covering several seasons and birds marked in different years) and space (covering several sites across two countries). In addition, marked birds are reported across the entire wintering range and wintering period of the population. Overall, the potential violations of this assumption are therefore likely reduced to a minimum. Nonetheless, adult breeding Pink-footed Geese travel in family groups and ex-

Table 3. Output from the exponential models to estimate asymptotic relationship between the number of flocks screened and variance of the population estimate. Range × v3 indicate the number of flocks counted when the asymptote is reached. Sill + nugget indicate the asymptote for the exponential part of the model, but do not represent the overall asymptote for the model. α indicate the slope for the relation between the population estimate and the 1/(difference between confidence limits). Subsampled data indicate the analysis including an artificial 50% reduction in monitoring effort (halving the number of flocks counted) in the years 2012–2017.

	Original data				Subsampled data			
Parameter	Estimate	SE	*t*	*p*	Estimate	SE	*t*	*p*
Range	65.5	9.4	6.98	< 0.001	69.8	10.4	6.72	< 0.001
Sill	0.000033	0.000002	15.80	< 0.001	0.000033	0.000002	15.84	< 0.001
Nugget	0.000032	0.000003	9.87	< 0.001	0.000032	0.000003	11.12	< 0.001
α	–30 × 10–12	4.6 × 10–11	–6.40	< 0.001	–29 × 10–11	4.3 × 10–11	–6.83	< 0.001

hibit some level of site-fidelity (birds returning to previously used sites), which render complete random distribution of ringed birds practically impossible. However, when data are pooled at regional level as we have done here, these effects are smoothed.

Regarding 2), this assumption may easily be violated if observers conduct ratios by assessing the total number of birds in a flock, and subsequently judge the number of marked birds by identifying neck-collared individuals. Such an approach would assume a 100% detection efficiency of marked individuals, and failure to detect all collared birds would lead to underestimation of *R* and overestimation of *N*. Other waterfowl studies have found mark-resight estimates to be slightly higher than total counts (Hestbeck & Malecki 1989, Ganter & Madsen 2001, Clausen *et al.* 2013), and if detection failure of marked birds is a regular phenomenon when estimating *R* this may partly explain this bias. However, as mentioned in the methods, Pink-footed Goose observers are instructed to conduct ratios by scanning through a flock of geese one by one, assigning each observed individual as either collared or not. Consequently, steps have been taken not to violate this assumption as well, and the bias associated with survey method should be kept to a minimum in this study.

The migratory flyway of Pink-footed Geese is relatively simple, being geographically restricted to cover few countries and breeding/wintering sites. Consequently, monitoring of this population might be somewhat simpler than for many other species of wildfowl. In principle however, the method is applicable to all well-defined populations with a ringing density large enough to enable a reasonable ratio estimation (which is highly influenced by the flock sizes of the species), but becomes more complicated when flyways overlap or ringing density is very low.

When managing populations by means of numerical population targets an accurate assessment of population size is of utmost importance. Because traditional field count methods may sometimes be inappropriate (Takeshita *et al.* 2016), difficult to evaluate (Madsen 2015) and expensive to replicate, additional and statistically independent methods can be used to quality assure and supplement these surveys. Although mark-resight approaches are built on important assumptions as outlined above and rely on comprehensive marking schemes and well-organized monitoring protocols, they enable estimates of error and do not rely on finding every single bird. Consequently, the parallel assessment of population size from these two methods inspire confidence in the estimates of population size so important to guide appropriate management.

This study confirms that, in general, total counts and mark-resight estimates were in good agreement for Pink-footed Geese, although estimates from the mark-resight approach was slightly higher. In the future monitoring of Pink-footed Geese, total counts and mark-resight estimates are planned to run in parallel to ensure a cross-checking by two independent measures of population size. In addition, the mark-resight estimate can provide an important backup in situations when total counts fail, either because of poor weather conditions, abrupt flock movements between sites or unexpected range expansions outside the survey areas.

In addition, the independent nature of the two estimates allow them to be integrated in combined approaches building on multiple data sets (e.g., integrated population models). Such models might assist in detecting potential biases in the two approaches, and improve the quality and economic costs of future monitoring schemes (Schaub and Abadi 2011, Johnson *et al*. submitted). Our analysis also highlights that the current (high) levels of ratio monitoring effort is needed for the mark-resight approach to produce reliable results, and therefore underlines that monitoring schemes should be carefully planned to ensure reliable and accurate estimates of population size using this method.

An adequately robust mark/resighting program to estimate population size is associated with substantial costs, and the Pink-footed Goose marking scheme might be used to exemplify what is needed to acquire the appropriate data. For this population, sufficient data can be ensured by one annual cannon-net capture (ensuring a proportion of marked Pink-footed Geese around 1% of the population), 20 days of gathering ratios by field observers (ensuring > 120 flocks scanned) and 7 days of analyzing data and database management by academic staff.

The total costs of these initiatives (including salaries, travel expenses, accommodation, neck-collars and baiting of geese to attract them to the catching area) amounts to approximately 28,700 euros per year. This estimate assumes that enough resightings are reported by volunteers to reliably assess detection probability of marked geese, which may or may not be realistic depending on the species and wintering sites. For Pink-footed Geese, professional observers are contributing to the reporting of neck-collared birds, but on the other hand, large and expensive captures are less than annual.

In reality, existing marking and resighting schemes are already in place for many goose and swan populations, partly or fully financed by needs to answer other study and/or management questions. For these species, the main additional costs associated with the method described in this paper might be reduced to collecting ratios and analyzing the data. For Svalbard-breeding Pink-footed Geese, a ringing scheme has been in place for 30 years, and the extra expenses needed to give a mark/resight estimate of population size (ratio collection and analysis) are approximately 11,100 euros.

For economically supported monitoring schemes, this additional cost is probably manageable. However, for schemes relying solely on voluntary contributions, implementation of this method depends on training and calibration of volunteers to carry out the collection of ratios, and the development of a platform to report the collected data. Finally, the expenses related to an adequate mark/resight program are likely to grow with population size, geographic scale and flyway complexity, because marking and resighting will have to account for possible heterogeneity in migration patterns. The total costs to set up and maintain an appropriate program are therefore likely to vary considerably depending on the species in question.

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Uudelleenhavainnointidatan hyödyntäminen lyhytnokkahanhen populaatiokoon arvoinnissa

Populaatiokoon luotettava arvioiminen on esimerkiksi riistakantojen hoidon edellytys, erityisesti kun kantoja hoidetaan tiettyjen tavoitekantojen saavuttamiseksi. Tutkimuksessa käytimme merkintä–uudelleenhavainnointi -menetelmää (kaulan lukurengas) hanhilla, ja kehitimme vaihtoehtoista menetelmää kokonaislaskennalle lyhytnokkahanhien populaatiokoon estimointiin. Hanhien populaatiokoon arviot kasvoivat havaintojakson aikana, vuoden 1991/1992 31,000 linnuista vuoden 2011/2012 100,700 lintuun, ja pysyttelivät 80,000 hanhen tienoilla viimeisen kuuden vuoden aikana.

Selvitimme populaatiokoon estimaatin epävarmuuden ja seurantapanostuksen yhteyttä:

Havaitsimme että on kartoitettava vähintään 120 parvea (kussakin vähintään 100 yksilöä), jotta merkittyjen ja merkitsemättömien lintujen suhde on riittävä populaatioestimaatin epävarmuuden minimoimiseksi. Tämä reunaehto täyttyi kyseisessä datassa vain viimeisen kuuden vuoden ajalta, mikä tarkoittaa että aiempien vuosien estimaatit ovat huomattavasti epätarkempia.

Tällä menetelmällä saadut estimaatit vastasivat kokonaislaskennasta saatuja arvoita, tosin yleisesti ottaen estimaatit olivat hieman suurempia. Tätä menetelmää voidaan siten käyttää perinteisten kokonaislaskentojen ”laadunvalvonnassa” huomioiden sen että kokonaislaskennat usein aliarvoivat populaatiokoon erityisesti lajeilla, joilla populaatiokoot ovat kasvussa, tai jotka ovat hyvin laajalle levinneitä.

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