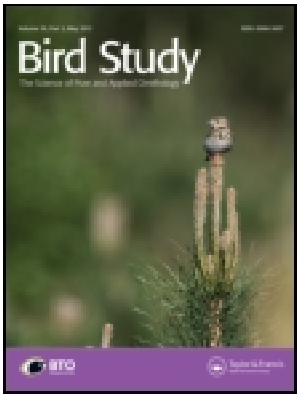

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SHORT REPORT

Mark–resight approach as a tool to estimate population size of one of the world's smallest goose populations

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Capsule The present study investigates the use of a mark–resight procedure to estimate total population size in a local goose population. Using colour-ring sightings of the increasingly scattered population of Light-bellied Brent Geese *Branta bernicla hrota* from their Danish staging areas, we estimate a total population size of 7845 birds (95% CI: 7252–8438). This is in good agreement with numbers obtained from total counts, emphasizing that this population, although steadily increasing, is still small compared with historic numbers.

Knowing the true population size of a species is fundamental to managing and protecting wild populations. Counting how many individuals make up a certain population, and regularly assessing how total numbers might change and result in population trends is core to wildlife management (Williams *et al.* 2002, Sinclair *et al.* 2006, Ronka *et al.* 2011). However, estimating population size is often difficult, and the use of methods to estimate population size should always be accompanied by a thorough consideration of strengths and weaknesses associated with each. Manually conducted total field counts over time usually provide good measures of population trends (Loison *et al.* 2006, Laursen *et al.* 2008), especially in circumstances where individuals are relatively confined in time and space. However, these are very time-consuming and rely on knowing the approximate whereabouts of every individual in the population. The joint knowledge of annual productivity and survival can likewise be used to provide good estimates of population sizes and trends (Baillie 1990, Ganter & Madsen 2001). If these demographic parameters are known, future population size can be precisely predicted, but quantifying them accurately (and keeping them up to date) necessitates detailed knowledge of both reproduction and annual bottlenecks. More recently, the use of mark–resight methods (rising from the umbrella of capture–mark–recapture analysis) has become a widespread way to estimate population size in wild populations (Sheaffer & Jarvis 1995, Walsh *et al.* 2010). The main advantage of this approach is that finding every individual becomes unnecessary, but at the same time it relies on important assumptions that are easily violated (closed populations, equal detectability among individuals), and these assumptions, if not treated carefully, might lead to biases in the final result (Kendall 1999, Willson *et al.* 2011). Ideally, the best estimate should be obtained by cross-validation of different methods in order to ensure the most reliable approximation of actual population size (Ganter & Madsen 2001).

An example of a species urgently needing cross-validation of its current population estimate is the East-Atlantic population of Light-bellied Brent Geese *Branta bernicla hrota*. This population is one of the smallest goose populations in the world, migrating between high-arctic breeding areas on the Svalbard archipelago and Kilen in northeast Greenland and winter staging areas around the North Sea, which during April–May is concentrated around areas in northwest Denmark, facilitating an intense monitoring effort in a comparatively small and well-defined area (Clausen *et al.* 1998, Denny *et al.* 2004).

In recent years the distribution and occurrence of this population's wintering areas in Denmark have become increasingly scattered, resulting in a growing number of Light-bellied Brent Geese wintering at hitherto unused

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sites outside the traditional staging areas (P. Clausen, unpubl. data). This behaviour questions reliability of the conventional total counts applied in these areas. Recognizing that East-Atlantic Light-bellied Brent Geese have a very small and fragile population, and acknowledging that Denmark and the UK are internationally obliged to secure the future viability of the population, these changes prompted the need to confirm the expected number of total individuals. To this end, we applied a mark–resight method that does not rely on finding every flock to estimate the size of the current population.

Fieldwork was carried out in April–May 2009, and collection of data mainly took place in the Mågerodde (56°47′N, 8°33′E) and Agerø (56°42′N, 8°34′E) areas of northwest Denmark, that encompass the most important spring staging sites for the population (Denny *et al.* 2004). Data were further supplemented with observations from Mariager Fjord, Hals and Skibsted Fjord, where ringing data on four additional flocks were submitted by voluntary birdwatchers during the same period. In these sites no ringing has taken place, and the inclusion of these supplementary data, therefore, broadened the scale of the survey beyond the main capture and marking areas.

Following the logic of Ganter and Madsen (2001) and Sheaffer and Jarvis (1995), the total population size (N) was approximated by multiplying the ratio of total geese per marked goose with the total number of marked geese in the population. Following the notation in Ganter and Madsen (2001), this means that:

$$N = R \times M \qquad (1)$$

Where R denotes the ratio of total to marked geese in the population, and M equals the number of ringed individuals. R is estimated from the observation of ringed individuals in screened flocks as:

$$R = \sum g_i/m_i \qquad (2)$$

Where g_i is the number of birds screened for rings in the i'th flock, and m_i is the number of identified ringed individuals in flock i. This estimate of R is built on the two underlying assumptions that (1) ringed birds are randomly distributed in the population; and (2) there is an equal probability of detection and classification among marked and unmarked individuals. The validity of these assumptions is discussed below. The variance of R is calculated following Sheaffer and Jarvis (1995), slightly modified and following our own notation, as:

$$V(R) = \sum((g_i - R * m_i)^2/(f(f-1)(\bar{a})^2)) \qquad (3)$$

Where f is the number of total screened flocks, and $\bar{a}$ is the average number of marked geese per flock (M. Frederiksen, pers. comm.).

The number of ringed individuals alive during the time of study (M in Equation 1) was estimated by stochastic modelling. The time of first ringing (summer 1986) is used as a baseline, and the model subsequently includes three annual phases with estimated survival probabilities from the study population (Table 1). The model assumes that birds survived the phase in which they were ringed, but had the same mortality as all other birds immediately thereafter. Survival rates for birds in their first year of life are typically different to older age-classes, but in the present study yearlings were caught and ringed in the non-breeding areas during winter and spring, where birds are at least six months old. At this age the elevated mortality of post-breeding and autumn migration has already taken place, and an analysis of Clausen *et al.* (2001) found no difference in survival rates between yearlings of this age and adult birds. Additionally, all birds were ringed either in Lindisfarne (UK) during winter or in Denmark during spring, and it is, therefore, reasonable to assume they were not subject to the elevated first-year mortality that has been recorded in cold Danish winters (Clausen *et al.* 1998). As a consequence, the two age-classes were pooled. The subsequent survival from phase to phase was estimated by using randomized phase-specific survival estimates drawn from normal distributions. Survival from spring to autumn was drawn with mean 0.914 ± 0.016 sd, and from autumn to winter with mean 0.996 ± 0.016 sd (Table 1). The latter occasionally generated some random survival estimates higher than 1.0, but as survival estimates higher than 1.0 are not biologically sensible these were set to 1.0 in subsequent calculations.

Survival from winter to spring was corrected for differences in winter temperature, because seasonal survival from winter to spring is dependent on cold or normal weather in the staging areas (Clausen *et al.* 2001). The winter conditions in Denmark can be considered as a dichotomy. Cold winters are associated with frozen estuaries and heavy snowfall induced by longer-lasting continental high-pressure situations with cold easterly winds, while milder winters are

Table 1. Seasonal survival rates and associated unpublished standard deviations from Clausen *et al.* (2001), and mark–resight estimates from the current study of East-Atlantic Light-bellied Brent Geese.

Season	Estimate	sd	95% LCL	95% UCL
Spring to autumn	0.914	± 0.016	0.877	0.940
Autumn to winter	0.996	± 0.016	0.960	1.000
Winter to spring (cold winter)	0.973	± 0.012	0.937	0.989
Winter to spring (normal winter)	0.907	± 0.033	0.802	0.954
Parameter	Estimate	*n*	95% LCL	95% UCL
R (Mågerodde)	25.88	14	24.80	26.96
R (Agerø)	160.05	18	147.50	172.59
R (Total)	68.21	36	65.69	70.74
M	115	200	114	116
N	7845		7245	8438

M, number of ringed birds alive during the study period (see Table 2); *R*, ratio of total to marked geese in the population; *N*, estimated total population size; *n*, number of screened flocks when calculating *R*, and the number of simulations used to estimate *M*; LCL, lower confidence limit; UCL, upper confidence limit.

characterized by regular low pressures with passage of fronts and westerly winds. This dichotomy is reflected in Brent Goose survival rates. In four years with a cold winter we thus estimated survival from winter to spring using a normal distribution with mean 0.907 ± 0.033 sd, and in 19 normal–mild winters we used a mean of 0.973 ± 0.012 sd (Table 1) (Clausen *et al.* 2001). To estimate M we ran 200 randomized models covering the period from summer 1988 to spring 2009 (23 years with 3 phases; i.e. 69 model steps) with the true input of newly ringed individuals, but with randomly drawn survival estimates for each step. The total variance of *N* was calculated as:

$$V(N) = R^2V(M) + M^2V(R) \quad (4)$$

Where M is the estimate for total number of marked birds alive during the study, and *V(M)* is the calculated variance of that variable (Sheaffer & Jarvis 1995). The variance of the estimate of M was calculated from the 200 random model simulations.

A total of 5221 screened birds resulted in 75 observations of marked individuals. This included a minimum of 51 different birds, and individuals originating from all marking sites used for this flyway population. Our estimated ratio of total to marked birds was 68.21:1, and the estimated number of marked birds alive was 115 individuals (95% CI: 114–116; Table 2). By inserting these findings into Equation 1 we were able to estimate the total population size of East-Atlantic Light-bellied Brent Geese as 7845 individuals (95% CI: 7252–8438; Table 1). The contemporary number from total counts of this subspecies carried out during October 2008 estimated the population size to be 7600 individuals. As this count estimate is within the confidence interval of the mark–resight estimate, no significant difference between the two methods was found. This indicates that the present approach of counting geese in regularly used sites in Lindisfarne and Denmark, supplemented with records from irregularly used sites through the BirdLife Denmark citizen science portal, DOFbasen, keeps sufficient track of the population.

The relatively large variation in our estimate of *N* is because of a clear violation of the assumption that when calculating *R*, ringed birds are randomly distributed in the population. During collection of the data, there was a clear trend towards a proportionally larger ratio of marked birds in some areas (e.g. Mågerodde), while the ratio in other areas (e.g. Agerø) was far smaller (Table 1). In all probability, this is because of site faithfulness among Brent Geese, where certain family groups tend to exploit the same areas year after year (Reed *et al.* 1998). Consequently, the large number of birds ringed at Mågerodde will tend to return to this area, while birds originating from Agerø, of which only few are ringed, will spend comparably more time in the Agerø area. This problem of heterogeneity in the ratio of marked to unmarked birds is an intrinsic characteristic of the birds' spacing behaviour and, therefore, an inevitable consequence when sampling a scattered population. We agree with Ganter and Madsen (2001), that this problem might be considerably reduced if marking and resighting is both spatially and temporally separated, allowing for further mixing of the population. We chose in the

Table 2. Number of ringed birds, annual survival rates, estimated number of surviving ringed birds and total population counts of the East-Atlantic flyway population of Light-bellied Brent Geese 1986/87–2008/09. The annual estimate of ringed birds alive in any given year is estimated from the stochastic model described in the text.

Season	Number of individuals ringed	Estimated ringed birds alive in spring	Winter condition	Population count
1986/87	1	1	Cold	3800
1987/88	3	4	Cold	4500
1988/89	0	3	Normal–mild	5600
1989/90	10	13	Normal–mild	4400
1990/91	69	81	Normal–mild	5150
1991/92	64	135	Normal–mild	4200
1992/93	0	120	Normal–mild	4000
1993/94	31	137	Normal–mild	5800
1994/95	11	132	Normal–mild	5400
1995/96	69	178	Cold	4450
1996/97	104	262	Normal–mild	5500
1997/98	2	234	Normal–mild	6050
1998/99	0	207	Normal–mild	5100
1999/00	0	184	Normal–mild	5900
2000/01	78	241	Normal–mild	6600
2001/02	0	213	Normal–mild	6500
2002/03	0	189	Normal–mild	6469
2003/04	0	167	Normal–mild	6405
2004/05	1	149	Normal–mild	7637
2005/06	42	165	Cold	6185
2006/07	0	146	Normal–mild	7180
2007/08	0	130	Normal–mild	7126
2008/09	0	115	Normal–mild	7600

present study to allocate the same time in areas with many and few marked birds, respectively, thereby emphasizing the importance of a true measure of population size. The variance of N could have been drastically minimized, had we used only one site (e.g. Mågerodde) to calculate N. However, this would have resulted in a much lower R, thereby dragging the estimate of population size to a lower level. Faced with the trade-off between a biased population size with minor variance, and a realistic population size with larger confidence limits, we have chosen to emphasize the latter.

When approximating the ratio R, the underlying assumptions of flocks as independent units and random distribution of ringed birds within the population are probably simplifications. This is an inevitable consequence of both family grouping and site faithfulness in the birds. However, all ringed individuals in our analysis were caught prior to 2006, three years ahead of field work associated with the present study, thereby eliminating the problem of juvenile birds following adults in family groups. Furthermore, recordings of paired birds where both were ringed were only done twice and we are confident, therefore, that the effects from this are of minor importance when interpreting the results. To support this view, some birds seen together at one time were later recorded as separated, and at least two ringed individuals observed one day at Mågerodde were later recognized in the Agerø area.

Our analysis confirms that the population of Svalbard-breeding Light-bellied Brent Geese is still a small and vulnerable population comprised of only 7000–8000 individuals, and indicates that total counts are still an appropriate measure to monitor the population, even considering the recent scatter in local distributions. Our findings mirror the pattern seen in similar studies of mark–resight estimates, that these are generally slightly higher than alternative methods (Hestbeck & Malecki 1989, Ganter & Madsen 2001).

Based on these results the recent trend of slowly rising numbers in the population seems to have continued. Since being reduced to a mere 1500 individuals in 1966/67 (Denny *et al.* 2004) the population has expanded slowly in recent years, probably as a consequence of protection from hunting, habitat restoration projects and protected foraging areas (Madsen *et al.* 1998) (see Table 2). However, the total East-Atlantic population is still very small in terms of population dynamics and, therefore, vulnerable to environmental or demographic catastrophes. One point of concern relates to severe declines in area of preferred habitats within the winter staging areas, which threaten to compromise the energetic situation of individual birds (Clausen *et al.* 2012). Furthermore, recent decades have brought a steady decline in breeding success within this population (Clausen

2007), resulting in an increased number of very old birds which might negatively affect future reproduction. The lower breeding success might be related to competition from Barnacle Geese *Branta leucopsis* or predation by Arctic Foxes *Alopex lagopus* (Clausen *et al.* 1998), but determining the exact cause of the decline in reproductive output is an important next step to secure the future conservation of this population.

The persistently low level of total numbers in this population calls for continued management focus. East-Atlantic Light-bellied Brent Geese are still far from reaching historic numbers (Clausen *et al.* 1998) and it is, therefore, our clear recommendation that the population is monitored closely in the near future.

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