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Decreased survival of pink-footed geese *Anser brachyrhynchus* carrying shotgun pellets

Jesper Madsen & Henning Noer

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Pink-footed geese *Anser brachyrhynchus* caught during March-April 1990-1992 in western Jutland, Denmark, were examined for shotgun pellets by X-ray photography, marked by individual colour neck-bands and released. Based on resightings during 1991-1995, survival rates of pellet carriers (N = 114) and non-carriers (N = 230) were compared. Annual resighting probabilities were more than 99%, resulting in a high precision of survival rate estimates. No indications of differences in survival between sexes or age classes (first-year and older) were found, but pellet carriers had a significantly lower survival (0.765) than non-carriers (0.869), this difference being constant between years and cohorts. Since pellet carrying individuals could theoretically represent a non-random subset of the population, this is not conclusive evidence that infliction of pellets affects survival. The lower survival affects the frequency of adult pellet carriers found in X-ray samplings. Correcting for this, the evidence strongly suggests that pellets are inflicted upon at least 0.7 goose for each bagged one.

Keywords: pink-footed geese, survival, hunting, shotgun pellets, capture-recapture

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It has been known for many years that some individuals in hunted goose populations carry shotgun pellets (Elder 1950, 1955a,b, Bellrose 1953, Grieb 1970, Ankney 1975, Jönsson et al. 1985). In a recent investigation of pink-footed geese *Anser brachyrhynchus* belonging to the Svalbard population, Noer & Madsen (1996) found that of the X-rayed geese, 24.6% carried pellets after their first hunting season, while 36.0% of the older geese were carriers.

Using a simple theoretical model relating pellet carrier frequency, adult survival and annual infliction rate, Noer & Madsen (1996) demonstrated that these percentages are inconsistent: If pellets are inflicted upon ca 25% of the geese during their first hunting season, far more than the observed 36% older carriers would be expected. For example, in a similar investigation of bean geese *Anser fabalis* in Scania, Sweden, 28% carried pellets after their first season, compared with 62% of older birds (Jönsson et al. 1985).

Noer & Madsen (1996) concluded that this discrepancy could be explained by assuming that the true frequency of first-year carriers was close to the lower 95% confidence limit, 15.1%. In this case, the observed frequency would have been somewhat higher than the true value. Alternatively, the discrepancy could be caused by differential survival of carriers and non-carriers. The annual bag of pink-footed geese consists of ca 1,000 first-year and 2,000 older geese, and assuming that 24.6% of the geese carry pellets after one hunting season and that pellets are inflicted upon two older geese for each first-year, annual survival rates of 0.871 for non-carriers and 0.779 for carriers were predicted for the situation where differential survival caused the discrepancy.

In this paper, we analyse survival rates of pink-footed geese, comparing survival of carriers and non-carriers in order to examine the differential survival hypothesis.

Methods

The study population

The Svalbard breeding population of pink-footed geese winters in Denmark, the Netherlands and Belgium. In the

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early 1990s, the population numbered ca 34,000 individuals (Madsen & Mitchell 1994). Very little exchange takes place between the Svalbard and Iceland/Greenland populations of this species, the latter wintering in the British Isles (Ebbinge et al. 1984, Madsen unpubl. data), and the Svalbard population can be considered closed. Details of migration and hunting exploitation were given by Madsen (1987) and Noer & Madsen (1996). In Denmark, use of lead pellets for waterfowl hunting in Ramsar areas was banned in 1986. This would affect the four most important areas where pink-footed geese are hunted in Denmark, since they are all designated Ramsar Sites. A general ban of lead shot for waterfowl hunting was introduced in 1993. In Svalbard and Norway, use of lead pellets is still allowed. Hence, both lead and steel pellets are probably carried by the geese.

Capture and marking

Geese were captured by cannon-nets on pastures at Vest Stadil Fjord, West Jutland, Denmark, on three occasions: 27 March 1990, 3 April 1991 and 25-26 March 1992. Captured geese were marked with a tarsus metal ring and a blue plastic neck-band with an individual one-letter/two-digit code. Under optimal visual conditions, neck-band codes can be read at distances of up to 600-700 metres using 20-60x telescopes. Sexing and ageing was based on cloacal examination and plumage characteristics. Geese were transported to a nearby farm where X-raying took place. The geese were masked and wrapped in cloth in order to restrain them during exposure. Picture frame size was 45 × 30 cm and pellets were easily identifiable (Noer & Madsen 1996). In two cases, the pellets may have resided in the gizzard (i.e. have been ingested); these individuals were excluded from all calculations. Following X-raying, the geese were kept in cages, to be released together after completion of the examination.

For lesser snow geese *Anser caerulescens* substantial neck-band losses have been documented by Johnson et al. (1995). In order to check for neck-band losses, 70 individuals were given additional plastic tarsus rings with unique two-digit codes in 1991. None of these birds had lost their neck-bands by 1995. Neck-band losses were further checked from recovered birds and from pairs where both mates were marked and one had lost its neck-band (identifiable by the tarsus metal ring). The total material up to and including May 1995 revealed two confirmed neck-band losses. The total annual rate of loss is estimated at less than 0.5%, and is thus negligible.

Resightings

In the 1991 and 1992 capture sessions, only one previously banded goose was recaptured (in 1992). Thus, this study is based on resightings and not recaptures. Resightings were recorded from April 1990 onwards by fulltime observers, augmented by a network of volunteer observers in Denmark, Norway, the Netherlands and Belgium. All major staging areas were covered. Although resightings are available from all times of the year except the breeding period, the most intensive data collection occurred during autumn (September-November) and spring staging (April-May). This study focusses on resightings made in April and May and hence expresses survival rates calculated from 1 April to 31 March the following year. During the whole study period, nearly all resighted individuals were observed in early April, and only a few were missed in that period but observed during the following month. Pooled resightings from April and May are considered a very good approximation to a full survey done by 1 April and are used in that context throughout the paper.

Estimation of survival rates

Survival rates were estimated from capture-resighting histories during 1990-1995. The basic model fitted to the data was the Cormack-Jolly-Seber (CJS) model for two data sets (Burnham et al. 1987, Lebreton et al. 1992, Lebreton et al. 1993). Notation follows Lebreton et al. (1992) and resembles that used for ANOVA. Model ϕ[g*t] denotes the general model of survival rates ϕ, varying freely across groups (g) and time (t), i.e. the model allows for group*time interaction in survival. Model ϕ[g+t] denotes parallel variation of group survival rates over time, on a logit scale, i.e. the test of this model versus model ϕ[g*t] is a test for group*time interactions in survival rates $\phi_{g,t}$. ϕ[g] denotes the model with no temporal variation in survival (but differences between groups) and ϕ[t] vice versa. Tests of these models versus more general ones thus become tests for differences between years or groups, respectively. For the resighting probability p, notation and testing is identical. All models are denoted by their structure in survival rates as well as resighting probabilities, e.g. ϕ[g] p[t] denotes the model including differences between groups (but not years) in survival and differences between years (but not groups) in resighting probabilities.

Tests of models against each other were done as standard likelihood-ratio tests. Goodness-of-fit of the CJS-model was calculated by χ^2-tests as suggested by Burnham et al. (1987) and Lebreton et al. (1992). In addition, we used Akaike's Information Criterion (AIC, see Burnham et al. 1987 and Lebreton et al. 1992) as a relative measure of the 'efficiency' of a model in describing the data. The AIC for a model is calculated as -2ln(L) + 2P, where L is the estimated likelihood and P the number of

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Table 1. Capture (1990-1992) and resighting histories (1990-1995) observed for pink-footed geese released in each of the three years (CH-matrix). '1' indicates years when an individual was observed, '0' unobserved, the first observation being marking. N_n and N_c denote numbers of non-carriers and carriers, respectively, at the time of marking and X-ray photography.

1990 Cohort:			1991 Cohort:			1992 Cohort:		
History	N_n	N_c	History	N_n	N_c	History	N_n	N_c
{111111}	18	4	{011111}	58	19	{001111}	53	17
{111110}	5	3	{011101}	1	0	{001110}	6	3
{111100}	7	2	{011110}	16	9	{001010}	1	0
{111000}	6	4	{011010}	1	1	{001100}	5	3
{110000}	6	4	{011100}	11	7	{001000}	11	13
{100000}	3	6	{011000}	15	9			
			{010000}	7	10			
Total	45	23		109	55		76	36

parameters in the model. Thus, the smaller the AIC for a model the better its efficiency in describing the data.

Goodness-of-fit tests were calculated by means of the programme RELEASE (Burnham et al. 1987). Subsequent analysis, model fitting and testing was done by means of the programme SURGE (Lebreton et al. 1992). All estimates given below, including 95% confidence limits, are derived from logistically transformed parameters (Lebreton et al. 1992).

Results

Resighting histories and model fit

Observed resighting histories are given by cohort and group in Table 1. The data can be subdivided according to three criteria, viz. pellet carriers and non-carriers, sex and age (first-year and older). Ideally, these subsets should be compared before pooling, but if subdivided into the corresponding eight groups, most datasets became too sparse for meaningful analysis.

Instead, homogeneity of survival among groups was investigated by simple comparisons of numbers dying during the first three years following neck-banding versus numbers surviving. No indications of differences between first-year and older geese were found, neither for non-carriers (Table 2, $\chi^2 = 0.32$, df = 1, $P > 0.57$) nor for carriers (Table 2, $\chi^2 = 0.49$, df = 1, $P > 0.48$). Nor were there any indications of differences between sexes for non-carriers (Table 3, $\chi^2 = 0.01$, df = 1, $P > 0.98$) or carriers (Table 3, $\chi^2 = 0.01$, df = 1, $P > 0.91$). These comparisons were made as 2×2 χ^2-test with a Yates correction for continuity (e.g. Sokal & Rohlf 1983). Since none of these tests indicated differences in survival, we consider pooling of data of age and sex categories justified.

Goodness-of-fit was calculated for the CJS-model (model notation ϕ[g*t] p[g*t]) by the programme RELEASE. Because of the very high resighting probability (an average of ca 99% of the surviving geese were resighted each year), the m_{ij} array (Burnham et al. 1987) is essentially diagonal. Therefore, data for Test2 were too sparse. For the same reason, Test3 in reality tested for heterogeneity of survival between newly and previously banded individuals, and the largest contribution derived from components Test3.SR_i (since data also became too sparse for most of the Test3.Sm_i components). Test3 showed no significant components, neither for non-carriers ($\chi^2 = 2.58$, df = 3, $P = 0.46$) nor for carriers ($\chi^2 = 2.84$, df = 3, $P = 0.42$). Overall goodness-of-fit resulted in a χ^2-value of 5.44, which was not significant (df = 7, $P = 0.61$), and we conclude that the CJS-model fits the data.

Table 2. Comparison of survival of first-year and older pink-footed geese for non-carriers and carriers, respectively, expressed by numbers dying within three years after neck-banding and numbers still alive after three years.

	Non-carriers			Carriers		
	Dead	Alive	Total	Dead	Alive	Total
First-year	13	36	49	6	9	15
Older	58	123	181	53	46	99
Total	71	159	230	59	55	114

Table 3. Comparison of survival of male and female non-carriers and carriers, respectively, expressed by contrasting numbers dying within three years after neck-banding with numbers still alive after three years.

	Non-carriers			Carriers		
	Dead	Alive	Total	Dead	Alive	Total
Males	37	81	118	33	29	62
Females	34	78	112	26	26	52
Total	71	159	230	59	55	114

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The between groups comparison (Test1, Burnham et al. 1987) showed highly significant differences (overall χ^2 = 21.34, df = 7, P = 0.0033). Initial inspection of the results showed that this was due to differences between the survival components (Test1.R1-Test1.R5). Data for comparison of resighting probabilities were insufficient, because very few individuals appeared in the annual 'not seen' categories; we therefore conclude that, when for both groups ca 99% of the individuals are resighted on all occasions (see Table 1), differences in resighting probabilities between groups and individuals - should they exist - would be too small to affect the results.

Analysis of survival and resighting probabilities

In order to provide a starting point for detailed comparison between carriers and non-carriers, various 'global' models were fitted (see discussion of selection of global model in Lebreton et al. 1992). Fit was basically similar, and the final model resulting from the analysis was invariably the same.

Here, we use the CJS for two groups (model ϕ[g*t] p[g*t]) as a global model. Further analysis of models nested within the CJS for two groups showed no significant year or group differences in resighting probabilities (test of models ϕ[g*t] p[t] and ϕ[g*t] p[g] versus model ϕ[g*t] p[g*t] in Table 4). Both of these could serve as starting point for further analysis. Because of the slightly lower AIC for model ϕ[g*t] p[g] we chose the latter.

Differences in survival were highly significant between groups (model ϕ[t] p[g] vs. model ϕ[g*t] p[g] in Table 4). Model ϕ[g+t], p[g], however, was accepted, and it is concluded that there is no group*time interaction in survival, i.e. survival rates of carriers and non-carriers varied in parallel. Further analysis of model ϕ[g+t], p[g] showed once more that no significant differences between carriers and non-carriers in resighting probabilities existed (model ϕ[g+t] p vs. model ϕ[g+t] p in Table 4). The model postulating no differences in survival between years was only marginally acceptable (model ϕ[g] p vs. model ϕ[g+t] p in Table 4).

Finally, the hypothesis of no differences between groups in survival was rejected (model ϕ p vs. model ϕ[g] p in Table 4). Estimates from this rejected model, ϕ = 0.838, 95% c.l. [0.815; 0.859] and p = 0.993, 95% c.l. [0.981; 0.997], were those used in the initial analysis of frequencies of pellet carrying individuals by Noer & Madsen (1996).

In conclusion, the analyses showed highly significant differences in survival between carriers and non-carriers, and that variation across time and groups could be disregarded. Estimates resulting from the finally accepted model (ϕ[g] p) are ϕ_n = 0.869, with 95% c.l. [0.842; 0.892], and ϕ_c = 0.765, with 95% c.l. [0.715; 0.809]. Estimated overall resighting probability was p = 0.993, with 95% c.l. [0.981; 0.997].

Following the selection of the final model we used SURGE'S facility for fixing parameters to test the predicted values of ϕ_n (0.871) and ϕ_c (0.779). The hypothesis was accepted (model ϕ_{pred} p vs. model ϕ[g] p in Table 4).

This comparison of observed and expected survival of non-carriers, however, should be viewed with some caution. Non-carriers are only X-rayed once, and undoubtedly some geese in this group will be inflicted with pellets during the following years. This means that in the calculations, the 'non-carrier' group probably contains some 'hidden' carriers. For a long-lived species, the observed survival of a released cohort of 'non-carriers' may therefore gradually decrease, and eventually converge towards the survival rate of carriers.

We evaluated this potential bias in the observed value

Table 4. Results of model fitting with SURGE. Model notation is explained in the text; g denotes group and t time. For each investigated model, relative Deviance is given together with the number of parameters, χ^2-test statistic, degrees of freedom (Likelihood ratio tests) and Akaike's information criterion (AIC). The final model choice resulting from the analysis was model ϕ[g] p, though this model was just acceptable (P = 0.051) and it could be argued that model ϕ[g+t] p would be a better choice. The predicted survival rates (see text for explanation) are included as model ϕ_{pred} p. Rejected models are indicated by asterisks.

Model	Deviance	Npar	χ^2	DF	P	AIC
ϕ[g*t] p[g*t]	962.21	18				998.2
ϕ[g*t] p[t]	962.83	15	0.62	3	0.892	992.8
ϕ[g*t] p[g]	966.98	12	4.77	6	0.574	991.0
ϕ[t] p[g]	986.80	7	19.82	5	0.001***	1000.8
ϕ[g+t] p[g]	969.52	8	2.54	4	0.637	985.5
ϕ[g+t] p	969.52	7	0.00	1	0.920	983.5
ϕ[g] p	978.98	3	9.46	4	0.051	985.0
ϕ p	995.42	2	32.59	13	0.002***	999.4
ϕ_{pred} p	979.34	1	0.36	2	0.835	-

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of ϕ_n numerically, using the theoretical values of ϕ_n and ϕ_c and an infliction rate of $\pi = 0.069$. These values showed that ca 23% of the 'non-carriers' would be hidden carriers after five years (i.e. the length of the period observed for the 1990 cohort), and the observed survival rate would have decreased to ca 0.84. A tentative correction suggested that the true value of ϕ_n would be ca 2.3% higher than the observed one. Since most of the geese were captured in 1991 and 1992 and so only contributed with four and three years of observation (see Table 1), the magnitude of accumulating bias in the observed value of ϕ_n would be less than 2%. We therefore conclude that the comparison between predicted and observed survival rates of non-carriers is not invalidated by accumulation of 'hidden' pellet carriers.

The possibility that pellets may subsequently have been inflicted to some geese that were non-carriers at the time of X-raying suggests that analyses of the resighting data and model choice may be refined in the future. In theory, this might be analysed by fitting of models including age-dependence. Analysis of such models could be used to test for the predicted decrease in survival with time after ringing. Indeed, preliminary fitting of age-dependent models suggested that the data could be described from this point of view as well. However, though the fit of such models is at least as good as the time-dependent models analysed here, data for estimation of survival become increasingly sparse for the older 'age' classes. For example, only the geese neck-banded in 1990 contribute to the estimated survival five years after ringing, and the resulting survival rate estimates have correspondingly large 95% c.l. Undoubtedly, a better discrimination of such models will be possible when some additional years of resightings have been compiled.

In the selection of the final model we noted that temporal variation in survival rates was nearly significant (see Table 4). Moreover, the lowest AIC - i.e. the 'best' and most parsimonious description of data - was for model ϕ[g+t] p. We take this to indicate that differences in survival between years may be real. Even in this case, however, temporal variation in survival is modest (Fig. 1), and for the time being we contend that the assumption of constant adult survival made by Noer & Madsen (1996) is justified.

Influence of number of pellets

Since ca 50% of the pellet carriers had only one pellet in their tissue, while the remainder had up to 10 (Noer & Madsen 1996) data were too sparse for a multi-group analysis of influence of numbers of pellets. We therefore tested the potential influence of pellet number by making a three-group comparison, viz. non-carriers (n), carriers of only one pellet (c1), and carriers of more than one pellet (c>1). The fitting of this model resulted in a relative deviance of 954.58 for a model with 27 parameters, which if used as a global model in Table 4 results in the same final model choice. In particular, test of this model versus the two-group version presented above resulted in a χ^2 of 5.49 (df = 14, P = 0.978). Estimates were $\phi_n = 0.869$, $\phi_{c1} = 0.762$ (95% c.l. [0.684; 0.827]) and $\phi_{c>1} = 0.767$ (95% c.l. [0.699; 0.824]). Given this result, we conclude that the data do not suggest that survival of pellet carriers is related to number of pellets.

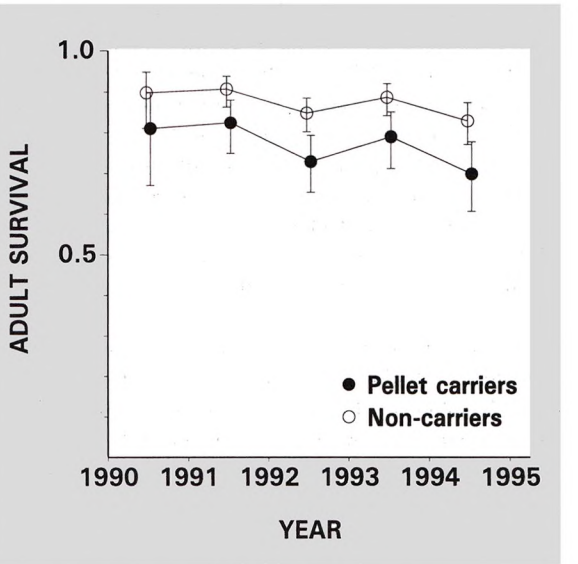


Figure 1. Estimated survival rates of pink-footed goose pellet carriers and non-carriers over the five investigated years; 95% confidence limits are given as vertical bars.

Discussion

Causes of differential survival

When geese are cannon-netted and X-rayed, it is not known whether the observed pellet-carriers belong to a random subset of the population. Thus, the investigation should not be confused with a design with an 'experimental' and a 'control' group, both randomised over individuals. The existence of differential survival, therefore, is not conclusive evidence that infliction of pellets causes increased mortality.

For North American mallards *Anas platyrhynchos*, Heitmeyer et al. (1993) showed that ducks killed by hunters had lower body weights and a higher incidence of ingested lead pellets than specimens collected by researchers. Within our data, we could find no tendency for differences in mean weight or size between pellet carriers

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and non-carriers (unpubl. data). Though this could be viewed as evidence against a socalled 'condition bias' (Greenwood et al. 1986, Heitmeyer et al. 1993) for hunter-killed pink-footed geese, it does not fully rule out the possibility that the population could be stratified, with some strata having an increased exposure to hunting. These strata might then either have an increased mortality from other causes than hunting, and/or the added mortality could simply be a higher harvest rate (because harvesting accounts for ca 50% of the total annual adult mortality).

Thus, at present both a 'pellet effect' and a 'stratified population' hypothesis could explain the differential survival. Potential effects of pellets, moreover, could include physical and/or biochemical (toxic) aspects. In the former case, lead and steel shots could have comparable effects, in the latter, they might affect geese in different ways.

Noer & Madsen (1996) predicted that to fully account for the observed discrepancy between frequencies of first-year and older carriers, survival of carriers should be ca 0.78. These calculations were based directly on the assumption that pellets are the cause of the decreased survival, and hence that once inflicted, the probability of surviving the following year(s) would change from 0.871 to 0.779. It is presently not clear to what extent a similar prediction could be derived from assuming a stratified population. We note specifically that some individuals belonging to a 'low survival' stratum would probably be non-carriers, while some individuals belonging to a 'high survival' stratum would be carriers. This would imply that the observed survival rates were mean values of 'mixed' groups, and that a 'stratified-population' hypothesis would have to assume that even larger differences in survival than those observed would exist within the pink-footed goose population. In our opinion, this is hardly likely. In the particular case of some subpopulation being more exposed to hunting, the probability of pellet infliction would be expected to be higher for that group of individuals, i.e. vary across the population (Noer & Madsen 1996). In this case, the observed difference in survival of carriers and non-carriers should have been less than the one predicted, since the latter was based on the assumption that the probability of pellet infliction was identical for all individuals. We consider the agreement between predicted and observed survival rates as evidence against this hypothesis.

Survival of pellet carrying individuals has only been investigated in two other cases known to us. Bellrose (1953) compared recovery rates of carriers and non-carriers for ringed North American mallards *Anas platyrhynchos*, and Norman (1976) made a similar comparison for Australian grey teal *Anas gibberifrons*. Neither study showed any tendency for differences, though we note that no corrections for subsequent infliction of pellets to non-carriers were attempted. For bean geese *Anser fabalis* in Sweden (Jönsson et al. 1985), the high frequency of adult pellet carriers (62% versus 28% for first-years) suggests that a similar difference in survival rates might not exist.

Thus, there is evidence to suggest that the differential survival found for pink-footed geese may be specific rather than general. This could be viewed as evidence against a 'pellet-effect' hypothesis. However, while the three cited studies concern species hunted with lead shots, our study undoubtedly also includes geese inflicted with steel pellets. Therefore, even though the combined evidence does not suggest that infliction of pellets *per se* reduces fitness or that lead shots have general 'toxic' effects, effects of steel shot remain a possibility that at present cannot be fully ruled out.

We found no evidence suggesting a higher mortality in the first-year(s) after infliction (first-years, see Tables 2 and 4). Instead, the data fitted the concept of a 'chronic' difference. Neither did we find evidence of an influence of number of pellets. This could likewise be viewed as evidence against a 'pellet-effect' hypothesis, but once again it must be emphasised that since steel shots only concern part of the inflicted individuals this possibility cannot be fully ruled out.

Thus, evidence that can be viewed as contradicting each of the possible hypotheses can be found, and definite conclusions are not possible yet. This means, however, that it is presently a possibility that infliction of pellets may be harmful to pink-footed geese. Clearly, further effort should be invested in clarifying this point.

Implications for estimates of annual infliction rates

The estimated survival rates of $\phi_c = 0.765$ and $\phi_n = 0.867$ conform closely to the values predicted by Noer & Madsen (1996) under the hypothesis that differential mortality was the cause of the observed discrepancy between percentages of first-year and older pellet carriers. This prediction was based on two assumptions: 1) that the observed frequency of 24.6% first-year carriers is realistic, and 2) that the ratio of inflicted to bagged geese is age-independent. If these assumptions were true, infliction rate of adults would be $\pi = 0.069$.

The finding of differential survival rates consistent with the resulting predictions is strong evidence that these assumptions are realistic. Hence, it is assessed that the observed frequencies of 25% first-year and 36% adult pellet carriers are produced by infliction of pellets upon ca 1,000 first-year and ca 2,000 older geese annually.

Given the lower survival of pellet carriers, this calculation can be expressed in a simpler way. The present population size is ca 29,500 adults, of which 36% or roughly 10,000 carry pellets. Of these, 23% or ca 2,300 die each

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year. To maintain a stable frequency of 36% adult carriers, pellets must therefore be inflicted upon 2,300 'new' carriers. Of these, recruitment of first-years account for ca 800 (at the time of X-raying, i.e. after second-year mortality), and thus pellets must be inflicted upon a further ca 1,500 'new' older geese in order to maintain the carrier frequency. However, with an equal probability of infliction of pellets to carriers and non-carriers, approximately one third of the inflicted geese carry pellets already, which means that the 1,500 'new' carriers have to be multiplied by a factor of 1.5 to approximate the overall figure. Accordingly, to maintain the observed percentages, pellets must be inflicted upon ca 1,000 first-year and more than 2,000 older geese annually.

To evaluate the minimum estimates of numbers inflicted, we repeated the calculation for the lower 95% confidence limits of θ_j and θ_a given by Noer & Madsen (1996), 0.151 and 0.300, respectively. In combination with the upper 95% c.l. for survival of carriers (0.809), these figures would correspond to ca 1,600 new adult carriers being 'recruited' annually, consisting of ca 600 first-years and ca 1,000 older geese. In addition, pellets would be inflicted upon a further ca 400 older geese that were already carrying pellets.

Compared to the bag of 1,000 first-year and 2,000 older geese, the minimum estimates therefore suggest that the ratio of inflicted to bagged geese is at least 2:3 - or ca 0.7 - while the most likely estimate is close to 1:1. Noting that not all wounded geese are recorded by X-ray examination, Noer & Madsen (1996) further pointed out that the ratio of wounded to bagged geese must be even higher.

The Svalbard population of pink-footed geese is presently increasing at a low annual rate, which shows that there is no reason for concern with hunting of the species at the present level of harvest rates. In addition to the concept of 'sustainable use' on which the present Danish Game Act (1994) rests, however, the act also emphasises that harvesting should be executed with the highest possible emphasis on animal welfare. The results and interpretations presented by Noer & Madsen (1996) and in this paper concern only one specific population, and care should be taken in making generalisations. But given these results, we submit that more research and management effort should be allocated into this field, and that improvements of hunting efficiency - interpreted to mean the ratio of wounded to killed geese - might be given consideration as an option for management.

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