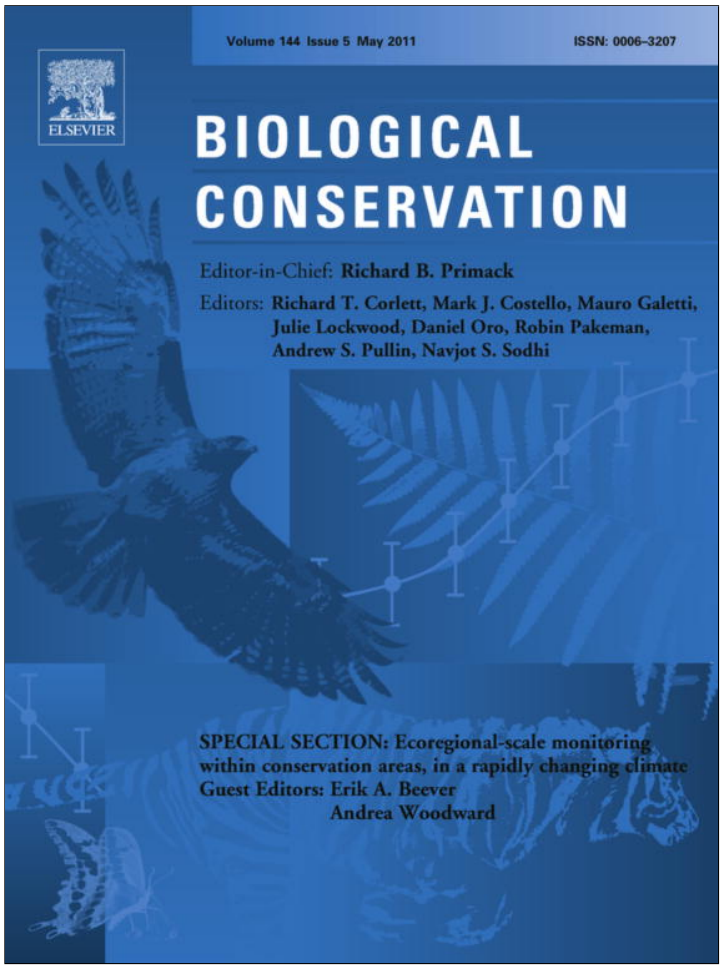

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Incidence of embedded shotgun pellets in Bewick's swans *Cygnus columbianus bewickii* and whooper swans *Cygnus cygnus* wintering in the UK

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ABSTRACT

The migratory whooper swans (*Cygnus cygnus*) and Bewick's swans (*Cygnus columbianus bewickii*) have been protected by national and international legislation throughout their migratory ranges since the mid 20th century, yet illegal shooting of both species still occurs. X-rays taken of wild caught swans at several sites in the UK were inspected to determine: (1) the incidence of embedded pellets in live birds, (2) inter-specific differences in the level of illegal shooting, and (3) trends in the prevalence of shot-in pellets between the 1970s and the 2000s. A significantly higher proportion of Bewick's swans (31.2%) contained shot-in pellets than whooper swans (13.6%). The likelihood of a bird having been shot increased with its age for both species. The proportion of Bewick's swans with embedded shot was higher during the 1970s and 1980s than in the 1990s and 2000s but the incidence remains high, with 22.7% of Bewick's swans X-rayed in the 21st century containing shot. The prevalence of whooper swans with embedded shot did not change significantly over time (14.9% with pellets in the 1980s compared with 13.2% with pellets in the 2000s). As the swans follow different migration routes, the results not only have implications for consistent and effective implementation of legislation, but show that illegal shooting must be addressed at both national and international levels.

1. Introduction

Unsustainable hunting has caused declines and even extinctions in wildfowl populations (Kear et al., 2005). It is of particular concern in long-lived species with delayed onset of breeding and low annual productivity, which are sensitive to increases in adult mortality (Perrins, 1991; Pianka, 1970). Such species include the migratory geese and swans which breed at high latitudes, but migrate to winter across Eurasia and North America where there's an open hunting season on many wildfowl populations during the winter months. Although the hunting of migratory birds has decreased significantly in Europe since the 1950s (McCulloch et al., 1992), and several populations have been protected by being removed from the quarry list (Kear et al., 2005), illegal hunting continues for some species. Birds may also be shot illegally for other reasons such as crop protection. Bag statistics are regularly recorded for legal wildfowling activity in a number of countries, and in North America hunting regulations have been designed to be flexible in order to take account of variations in population size for quarry species (Fox, 2005). Given the illicit nature of taking protected species, however, levels of illegal hunting are more difficult to determine and remain largely unknown.

In addition to bag statistics, taking X-rays of live-caught birds has been used to provide some indication of hunting levels for quarry species, and to measure levels of wounding in waterfowl. Earlier studies have shown that 28–62% of geese (Elder, 1950, 1955; Grieb, 1970; Jonsson et al., 1985; Noer and Madsen, 1996; Noer et al., 2007; Norman, 1976) and 25–35% of sea ducks (Falk et al., 2006; Hicklin and Barrow, 2004; Noer et al., 1996, 2007) carry embedded shotgun pellets. Analyses not only provided estimates of pellet infliction rates on different populations but assessed the impacts of carrying pellets on the survival of individuals. For instance, pellet-carrying pink-footed geese (*Anser brachyrhynchus*) had significantly lower annual survival rates (0.765) than non-carriers (0.869) (Madsen and Noer, 1996) and the relative survival of shot adult mallards (*Anas platyrhynchos*) was 19% lower than for those without pellets in their tissues (Tavecchia et al., 2001). Embedded shot did not, however, have a significant effect on survival rates for teal (*Anas crecca*) (Guillemain et al., 2007). For the pink-footed goose, 36% of adult birds were found with pellets, which on correcting for a lower survival of pellet carriers corresponded to an additional annual mortality of 7% for the adult population (Madsen and Noer, 1996).

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The migratory whooper swans (*Cygnus cygnus*) and Bewick's swans (*Cygnus columbianus bewickii*) which winter in the UK have been protected from shooting under national and international legislation throughout their ranges since 1954 and 1976, respectively (Rees, 2005, 2006; Robinson et al., 2004a), yet X-rays taken of birds caught for ringing on the wintering grounds have revealed that a high proportion of live birds carry shotgun pellets in their body tissues. Evans et al. (1973) found that 34% of live Bewick's swans X-rayed in the early 1970s had embedded shot, similar to levels found in legal quarry species such as pink-footed geese (Elder, 1955; Noer and Madsen, 1996), with adult birds (>2 years) more likely to contain shot than juvenile or sub-adult (yearling) swans. Preliminary studies by Rees et al. (1990) similarly showed that whooper swans wintering in Britain carry shotgun pellets which, given the geographic distribution of the population, must have been inflicted in Britain, Ireland or Iceland.

This paper aims to analyse the number of embedded pellets recorded in X-rays taken of live-caught Bewick's swans and whooper swans, for an inter-specific comparison of illegal shooting levels for two protected species wintering in Britain which have very different distributions and migratory routes. Variation in the levels of illegal shooting is also determined by analysing trends in the proportions of birds carrying pellets over several decades; for Bewick's swans X-rayed since 1970, and for whooper swans X-rayed since 1988. Incidence of embedded shot (i.e., whether or not the birds have pellets in their tissues), and also the number of pellets recorded, is analysed in relation to the age, sex, size and condition of the birds, to identify any patterns of targeting by poachers. For instance, selective hunting of juveniles affects age ratios (but not sex ratios) of wigeon (*Anas penelope*) in winter (Mitchell et al., 2008). Potential consequences of carrying embedded pellets for the health of the birds is determined by analysing the swans' body condition in relation to whether or not a bird has been shot and the number of pellets recorded. As the location of illicit shooting could not be determined from the X-ray analysis, the frequency and location of dead swans reported as having been shot is also described to provide a broad indication of where the birds may be most at risk. The results are discussed in relation to the migration routes followed by the two species.

2. Methods

2.1. Study populations

The Northwest European Bewick's swan population, which breeds on the arctic tundra of European Russia, makes a 3200 km migration to wintering sites across Northwest Europe (Delany et al., 1999; Rees et al., 1997; Fig. 1). Large concentrations (up to 50% of the population) occur at staging sites in Estonia and the Gulf of Finland in both spring and autumn and most of the population is thought to stage at the White Sea in spring (Luigujoe et al., 1996; Nolet et al., 2001; Rees et al., 1997). The Icelandic-breeding whooper swan has a much shorter migration; about 94% of the population winters in Britain and Ireland, and the rest remain in Iceland (Rees et al., 2002; Worden et al., 2009; Fig. 1). As most of the Icelandic whooper swans' migration is over the Atlantic Ocean there are no major staging sites separate from the breeding or wintering areas (McElwaine et al., 1995; Rees et al., 2002; Newth et al., 2007).

2.2. X-raying live birds

The swans were caught in decoy-type 'swan-pipes' at four sites in Britain. Bewick's swans were X-rayed at Slimbridge, Gloucestershire (51°43′98″N, 2°25′02″W) and at Welney, Norfolk (52°31′50″N, 0°16′98′E); whooper swans were X-rayed at Caerlaverock, Dumfriesshire (54°58′02″N, 3°25′02″W), and both species at Martin Mere, Lancashire (53°37′50″N, 2°52′02″W). A total of 1018 X-rays were taken of 735 individual Bewick's swans between winters 1970/71 and 2008/09 inclusive, and 474 X-rays of 397 whooper swans between 1988/89 and 2007/08 (Table 1). Following capture the swans were placed in plastic 'swan jackets' for sexing (determined by cloacal examination), ringing and taking X-rays (Evans et al., 1973; Evans and Kear, 1972). The swans were also aged using plumage characteristics, weighed and their skull, tarsus and wing lengths were measured (Evans and Kear, 1978). Only swans recorded in their first or second winter could be aged precisely; minimum age was determined for birds first seen as adults.

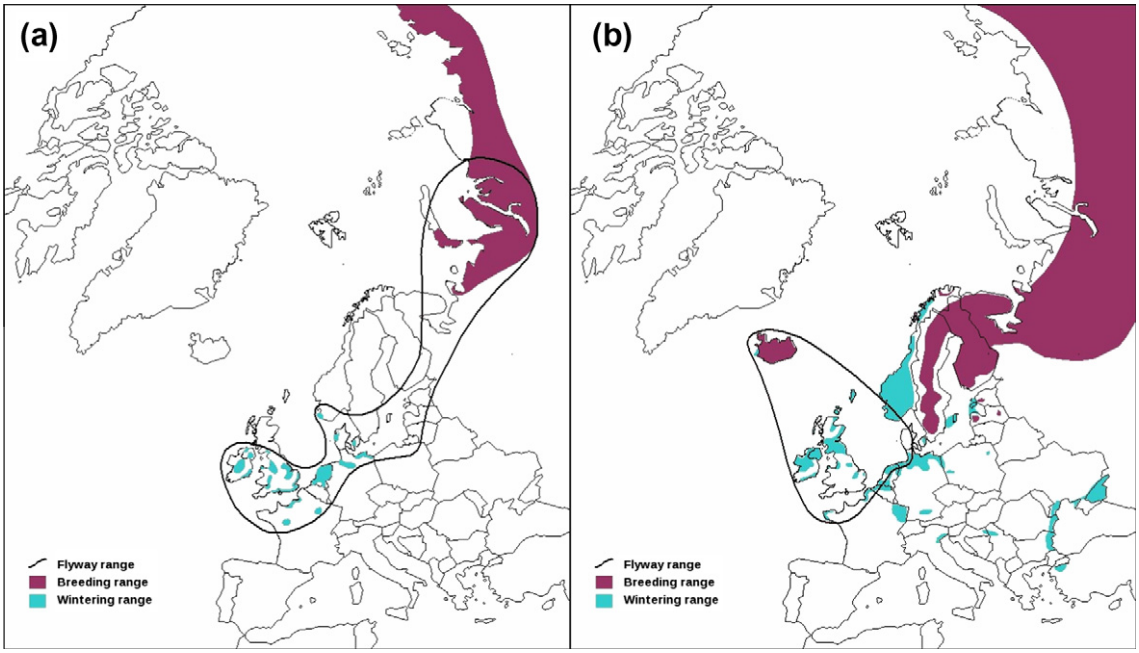

Fig. 1. Distribution of (a) the NW European Bewick's swan population and (b) the Icelandic whooper swan population (from Robinson et al. (2004a,b)).

Table 1
Number of Bewick's swans and whooper swans X-rayed at wintering sites in the UK, and the total number of X-rays taken. This includes 66 re-captured birds (54 Bewick's swans and 12 whooper swans) represented more than once in different age categories and 35 Bewick's swans represented across timeframes.

Timeframe	Winters	Site	No. individuals X-rayed (No. X-rays)	No. X-rays of adults (%)	No. X-rays of yearlings (%)	No. X-rays of cygnets (%)
Bewick's swans						
1970s	1970/71–1975/76	Slimbridge	390 (537)	335 (62.4)	80 (14.9)	122 (22.7)
1980s	1988/89–1989/90	Slimbridge	80 (94)	65 (69.1)	7 (7.4)	22 (23.4)
1990s	1990/91–1999/00	Slimbridge	208 (288)	174 (60.4)	39 (13.5)	75 (26.0)
	1990	Martin Mere	50 (50)	35 (70.0)	4 (8.0)	11 (22.0)
	1994	Welney	1 (2)	2	0	0
2000s	2000/01–2008/09	Slimbridge	44 (47)	25 (53.2)	8 (17.0)	14 (29.8)
Total			735 (1018)	636 (62.5)	138 (13.6)	244 (24.0)
Whooper swans						
1980s	1988/89–1989/90	Caerlaverock	131 (150)	104 (69.3)	25 (16.7)	21 (14.0)
2000s	2006/07–2007/08	Caerlaverock	90 (121)	90 (74.4)	13 (10.7)	18 (14.9)
	2006/07–2007/08	Martin Mere	176 (203)	152 (74.9)	14 (6.9)	37 (18.2)
Total			397 (474)	346 (73.0)	52 (11.0)	76 (16.0)

As Bewick's swans wintering at Slimbridge are identified by their natural black and yellow bill markings and also have a high level of winter site fidelity (Rees, 1987), the minimum age of an individual, and hence the minimum number of seasons that an individual had been exposed to shooting, included observations made of the swans prior to their being caught for ringing.

During the 1970s, Bewick's swans were X-rayed using a Watson MX1 portable machine at 65 kV potential and 15 mA, at a focal distance of 52.3 cm, and using Kodak R.P./D.X- Kodak R.P./D.X-omat radiographic film (30.5 cm × 38.1 cm) (Evans et al., 1973). From the 1980s onwards both species were X-rayed using a PLH Medical K6 Electronic portable machine, at 70 kV potential and 10 mA, at a focal distance of 75 cm, and using Mediphot X-ray HDC-UVB high contrast, blue sensitive radiographic film (30.0 cm × 40.0 cm). Exposure time was 1.2 s on each occasion.

After X-ray development, the total number of pellets embedded in the tissues was counted for each X-ray plate. Although pellets were readily identifiable as distinct, light dots, pellet composition (for instance, whether made of lead or steel) could not be determined from the X-ray alone. Information on materials used in the pellets can only be confirmed by extracting and analysing them, which was not have been easy to achieve or appropriate for live birds. Lead may be more likely than steel to deform on impact but this is not conclusive; during the 1970s and 1980s, when use of lead shot was almost universal, most pellets were found to be circular on the X-ray plates (Fig. 2). It therefore was not possible from inspection of the X-rays to determine the location of illegal shooting based on the type of shot used. Similarly it was not possible to assess compliance with the ban on using lead shot when shooting over wetlands, introduced in the UK and several other European Union countries during the 1990s; however, this paper aims to determine long-term changes the level of illegal shooting rather than the type of shot used.

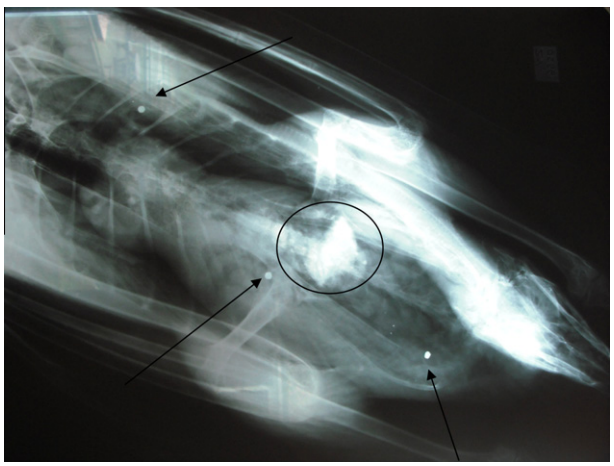

Fig. 2. X-ray of a Bewick's swan with embedded shotgun pellets (arrows) and showing the gizzard (oval).

Pellets classed from their location on the X-ray plate as being in the digestive tract or in the gizzard were considered to have been ingested by the birds as grit. The gizzard is visible on the X-ray (Fig. 2), and ingested pellets can be readily identified not only by their location in the gizzard but by their shape and size as they are eroded by the muscular action of the gizzard and by the presence of grit. Grit is semi radio-opaque, so pellets in the gizzard can also be identified by their reduced clarity where they overlap with the grit. One Bewick's swan and seven whooper swans found to have ingested pellets, but with no evidence for embedded (shot-in) pellets in their tissues, were classed as not being shot.

2.3. Post-mortem data

The primary cause of death was recorded for ringed Bewick's swans recovered from 1970 to 2009 and for ringed whooper swans recovered from 1980 to 2009. The two main data sources were *post-mortem* examination carried out routinely for swans found dead in the vicinity of Wildfowl & Wetlands Trust (WWT) centres in the UK (Brown et al., 1992) and reports to the British Trust for Ornithology (BTO), the Icelandic Institute for Natural History and the Bird Ringing Centre Moscow for birds recovered elsewhere (Rees et al., 2002; Rees and Bowler, 2002). Although the sample is likely to be biased by regional variation in reporting of shot birds, the cause of death recorded on recovery was analysed to identify some of the areas where illicit shooting has occurred.

2.4. Treatment of the data

The number of embedded pellets was determined for each individual swan each time that it was X-rayed. In analyses of (1) the proportion of birds with pellets, and (2) the number of pellets per bird, within each timeframe (i.e., year, decade or overall), birds that were captured on more than one occasion were included as a single observation only, with the highest pellet count recorded for each individual being included in the analysis. Increases in the number of pellets recorded for re-captured individuals were analysed separately to provide further information on the timing of illegal shooting, within and across decades.

To assess inter-specific differences in the incidence of embedded pellets in the swans' body tissues and the effects of time period (decade), sex, minimum age and (minimum age)^2 on the incidence of embedded pellets we used Generalised Linear Mixed Models

(GLMMs) with binomial error distributions and logit link functions. Decade rather than year was used because there was a large gap in the timing of X-rays taken for whooper swans (i.e., late 1980s, then not again until the early 2000s). GLMMs were also used to test, for each species separately, whether the presence or absence of pellets (included as a binary response variable) varied significantly with the age, sex, size and body condition of the swans and the time period (year for Bewick's swans; decade for whooper swans) in which the X-rays were taken. GLMMs with a poisson error distribution and logarithm link function similarly tested for a significant association between the same variables and the number of pellets recorded per bird. Bird identity was included as a random factor to allow for the inclusion of the same bird in >1 year. Decade and sex were treated as categorical variables. Trends in the level of illegal shooting were considered in further detail by analysing the proportion of cygnets found to have been shot each year (using a Generalised Linear Model (GLM) for Bewick's swans and, because there were fewer years' data available, an Analysis of Variance (ANOVA) for whooper swans), on the basis that these birds would have been shot at $\leqslant$6 months before being X-rayed. Percentages were arcsine transformed prior to analysis.

Body size was included as an explanatory variable in the models to test whether larger birds were more likely to be targeted or hit; body condition was included on the basis that birds in poorer condition may be slower to respond to the presence of poachers. Size was calculated using Principal Component Analysis (PCA) to determine the first principal component (PC1) of the mean skull and mean tarsus measures recorded for individual swans (following Choudhury et al., 1996; Coleman et al., 2002). PC1s for cygnets, yearlings and adults were calculated separately to allow for increasing body size over the first 2 years of a swan's life (Evans and Kear, 1978). Body condition measures were the residual values obtained on regressing the swans' mass against their body size (PC1 of skull and tarsus; Green, 2001). Previous studies have shown that the body mass of migratory swans is relatively stable in mid-winter (Evans and Kear, 1978); maximum mass recorded for each individual in December–January in winters in which they were X-rayed therefore was used to determine body condition in the years in which the birds were X-rayed.

Whether the presence of embedded pellets had a significant deleterious effect on the swan's body condition was determined by including the swan's body condition as the dependent variable in GLMMs, specifying a normal distribution and identity link function, and with bird identity as a random factor. Decade, minimum age, the quadratic function of age (i.e., (minimum age)^2), sex, decade, whether or not the swan had embedded pellets, and interaction terms were included as explanatory variables in the initial model. Age treated as a categorical variable (0 = cygnet, 1 = yearling, 2 = adult) was tested in a separate model but the results (which also proved significant) are not reported here as minimum age provided a better fit to the body condition data. The quadratic function for minimum age was included to test in particular for any curvilinearity in the relationship between body condition and age, with birds potentially in better condition in their prime. The number of pellets recorded was also included as an independent variable to assess whether the pellet loading was significant. Non-significant variables were excluded sequentially from the GLMMS to ensure that the final models were parsimonious.

MINITAB and GenStat (version 12) software packages were used for analysis. Means are given ±SE values throughout.

3. Results

Of the Bewick's swans X-rayed, most (93% of individuals) were X-rayed at Slimbridge whereas 56% of whooper swans were X-rayed at Caerlaverock and 44% at Martin Mere (Table 1). There was no significant difference in the proportion of Bewick's swans of different age classes X-rayed in each decade ($\chi^2_6 = 7.49$, $P > 0.05$). For whooper swans, the proportion did vary, with a relatively high incidence of yearlings X-rayed in the 1980s ($\chi^2_2 = 7.46$, $P < 0.05$, Table 1), but there was no different in the proportion of adult to sub-adult whooper swans X-rayed in the 1980s compared with the 2000s ($\chi^2_1 = 1.49$, $P > 0.05$). In the 2000s, when whooper swans were X-rayed at both Caerlaverock and at Martin Mere, differences between sites in the percentage of birds found to contain shot (Caerlaverock: 17.8%, $n = 90$; Martin Mere 10.8%, $n = 176$) were not significant ($\chi^2_1 = 2.54$, $P = 0.11$, n.s.).

3.1. Inter-specific comparison

Overall, 31.2% (SE 3.3, $n = 735$) of Bewick's swans and 13.6% (SE 3.4, $n = 397$) of whooper swans were found to be carrying pellets, rising to 43.2% (SE 4.6, $n = 438$) and 16.3% (SE 4.3, $n = 288$) for adult birds, respectively. There was a significant inter-specific difference in the incidence of embedded pellets for the years in which both species were X-rayed (1988, 1989, 2007 and 2008) (GLMM: $F_{1,552} = 10.32$, $P < 0.001$), and the incidence of pellets also increased with the age of the bird (GLMM: $F_{1,552} = 33.46$, $P < 0.001$; Fig. 3) but there was no significant difference between the sexes in the likelihood of a bird being shot (GLMM: $F_{1,552} = 2.79$, $P = 0.095$, n.s.).

For adult swans with pellets, the number of pellets recorded for individual birds did not differ between species (mean = 2.9 ± 0.2 pellets for Bewick's swans, mean = 2.2 ± 0.3 pellets for whooper swans; Mann–Whitney U test, $W = 23046.5$, $P = 0.1210$, n.s.). Most shot birds received 1–3 pellets but up to 30 pellets were recorded in Bewick's swans (one bird at Slimbridge in 1991) and up to 11 pellets in whooper swans (one bird at Caerlaverock in 2007; Fig. 4).

3.2. Increase in the number of pellets per bird

Of 176 Bewick's swans and 61 whooper swans captured and X-rayed on more than one occasion, 48 (27.3%) and 2 (3.3%) respectively were recorded with more pellets when caught subsequently. There was evidence that illegal shooting occurred at wintering sites in Britain; of 39 Bewick's swans re-captured within the same winter at Slimbridge, 5.1% (two individuals) were recorded with a higher pellet count when X-rayed on the second occasion. A total of 25 whooper swans were X-rayed more than once in the same winter of which one bird X-rayed at Caerlaverock had one additional pellet when X-rayed again.

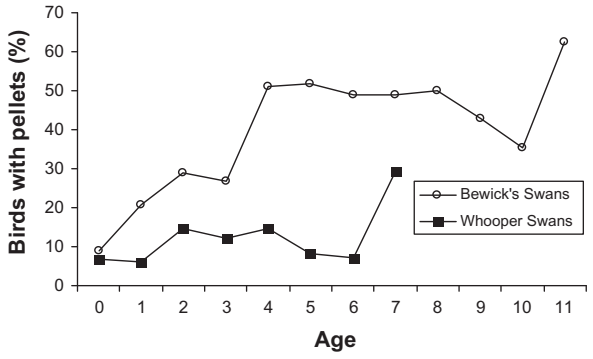

Fig. 3. Percentage of birds with embedded pellets in relation to their age (in years) for Bewick's swans X-rayed between 1970 and 2008 and for whooper swans X-rayed between 1988 and 2007.

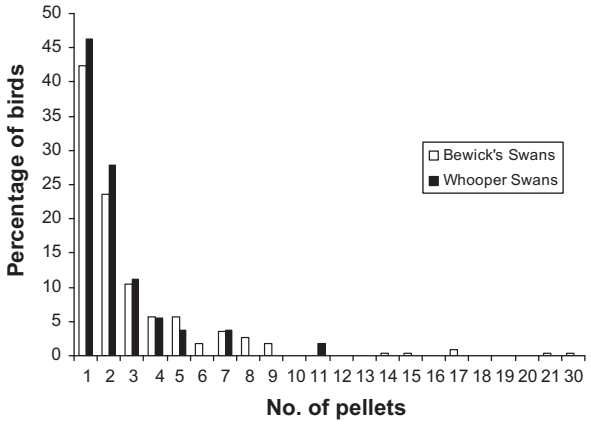

Fig. 4. Pellet count frequency in Bewick's and whooper swans, recorded as the percentage of swans of each species found to at least one embedded pellet.

3.3. Trends over time

The proportion of Bewick's swans recorded as shot each year varied significantly between the years (Fig. 5) and across the decades (1970s = 34.1%, 1980s = 38.8%, 1990s = 27.1%, and 2000s = 22.7%), with the incidence of pellets increasing significantly with the age of the bird (GLMM: $F_{1,961} = 69.61$, $P \leqslant 0.001$; Fig. 3) and decreasing over time (GLMM: $F_{1,961} = 12.52$, $P \leqslant 0.001$; Fig. 5). Moreover, more Bewick's swans were found to have incurred pellets when re-captured during the 1970s than during the 1980s ($\chi^2_1 = 2.60$, $P = 0.11$, n.s.) and the 1990s ($\chi^2_1 = 10.01$, $P = 0.002$); there was no such increase in pellet count for the small number ($n = 2$) of Bewick's swans re-captured in the 2000s (Fig. 6).

The proportion of whooper swans recorded as shot varied little between the years (Fig. 5) and across the two decades: 14.5% of those X-rayed in the 1980s and 13.2% of those X-rayed in the 2000s ($F_{1,438} = 0.01$, n.s. for time period). Moreover, there was no difference in the proportion of birds with increased pellet count on re-capture between the 1980s and 2000s, with only one bird having an increase in pellet count in each decade (Fig. 6). The proportion of shot cygnets recorded each year was analysed to provide a more definitive indication of trends in illegal shooting, but no significant differences were found for Bewick's swans (GLM: $R^2 = 0.32$, $F_{1,18} = 1.1$, $P = 0.314$, n.s.) or for whooper swans (ANOVA: $F_{1,3} = 0.68$, $P = 0.497$, n.s.).

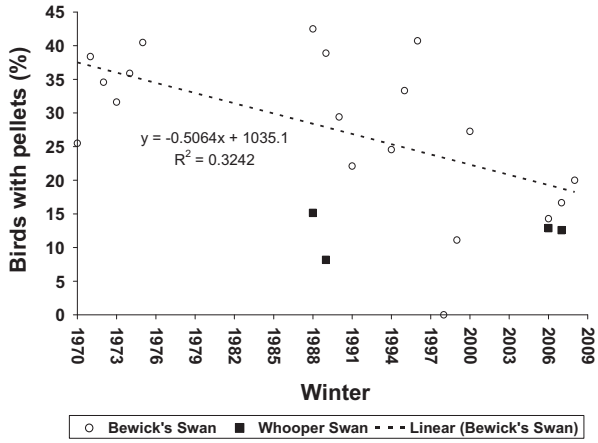

Fig. 5. Incidence of shotgun pellets for Bewick's swans X-rayed between 1970 and 2008 and for whooper swans X-rayed between 1988 and 2007.

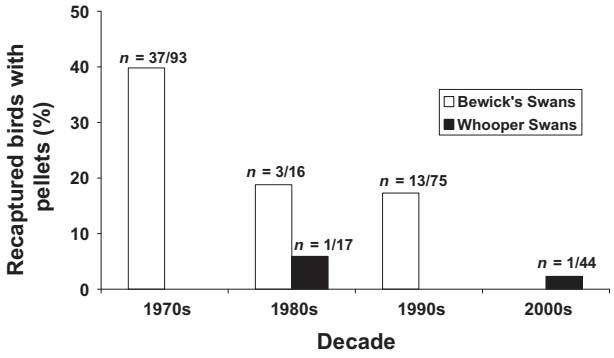

Fig. 6. Percentage of Bewick's and whooper swans with an increased pellet count on re-capture (n = number of birds shot/number of birds X-rayed more than once).

3.4. Variables associated with the presence or absence of embedded shot

For Bewick's swans, the minimum age of the swan and also the decade in which the bird was X-rayed were significantly associated both with the incidence of embedded shot (GLMM: $F_{1,961} = 69.61$, $P < 0.001$ for minimum age; $F_{1,961} = 12.52$, $P < 0.001$ for decade) and with the number of pellets recorded (GLMM: $F_{1,790} = 21.06$, $P < 0.001$ and $F_{1,790} = 14.62$, $P < 0.001$ respectively). Body size was associated with the number of embedded pellets found for Bewick's swans (GLMM: $F_{1,790} = 4.84$, $P = 0.028$) but not for whooper swans (GLMM: $F_{1,237} = 1.75$, $P = 0.186$, n.s.). Minimum age of the bird proved significant for whooper swans (GLMM: $F_{1,438} = 10.23$, $P < 0.001$ for incidence of shot; $F_{1,438} = 14.06$, $P < 0.001$ for number of pellets per birds) (Fig. 3), but sex and body condition did not have a significant effect on the likelihood of a bird having embedded pellets for either species.

3.5. Effects of embedded pellets on the swans' body condition

The body condition of the swans varied significantly with the sex and minimum age of the bird, and the swans' condition also varied across the decades (GLMM: $F_{1,624} = 129.31$, $F_{1,624} = 160.74$ and $F_{3,624} = 6.44$ respectively for Bewick's Swans; $F_{1,237} = 89.23$, $F_{1,237} = 28.59$ and $F_{1,237} = 17.64$ for whooper swans; $P < 0.001$ in each case). For Bewick's swans, condition was highest in the 1980s (mean residual = 0.40 ± 0.11) and lowest in the 2000s (-0.46 ± 0.23), with whoopers showing a similar pattern (0.34 ± 0.10 and -0.52 ± 0.08 in the 1980s and 2000s). The presence or absence of embedded pellets did not have a significant effect on whooper swan body condition, or on Bewick's swan condition when all birds were considered, but it approached significance for adult Bewick's swans (GLMM: $F_{1,375} = 2.98$, $P = 0.085$, n.s.) with swans with pellets apparently in poorer condition than those without pellets for adults of both sexes (Fig. 7). Bewick's swan cygnets with embedded pellets conversely appeared to be in better condition than those without pellets (Fig. 7), but only the sex of the bird was significantly associated with its body condition on analysing cygnet data only (GLMM: $F_{1,165} = 14.36$, $P < 0.001$ for sex; $F_{1,165} = 2.39$, $P = 0.124$, n.s. for pellets versus no pellets). The number of pellets recorded was not significantly associated with body condition, so was excluded from the final model.

3.6. Numbers reported killed by poachers

The cause of death was determined for just 98 of 202 ringed Bewick's swans found dead since 1970 and 361 of 962 ringed whooper swans found dead since 1980. Of these, 17 Bewick's

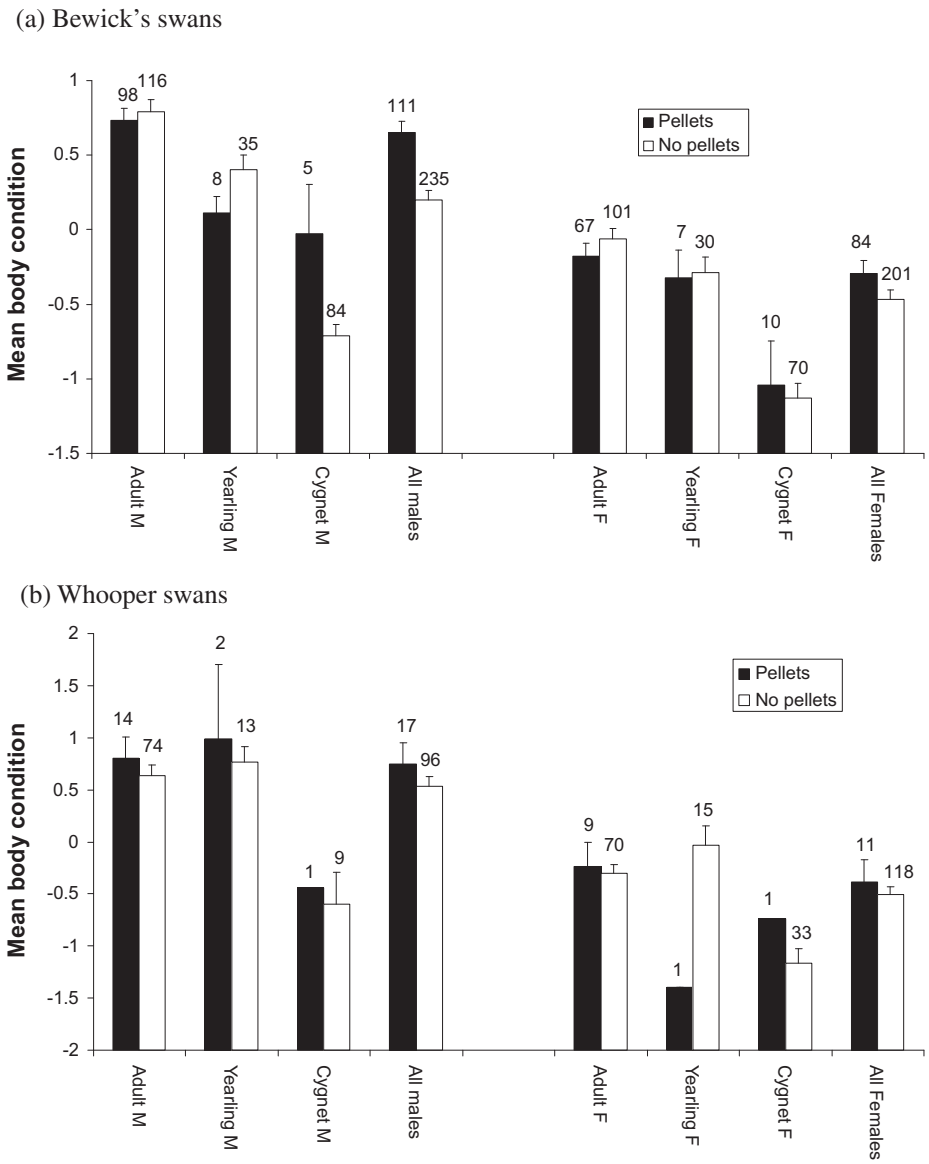

Fig. 7. Mean body condition (calculated as the residuals from regressing mid-winter mass with body size) recorded for swans with and without embedded shotgun pellets for (a) Bewick's swans and (b) whooper swans. For whooper swans, there was only one bird recorded with pellets for cygnet males, cygnet females and yearling females (n = number of birds recorded with mean body condition).

swans (17.3% of birds where the cause of death was known; 8.4% of all recoveries) and 30 whooper swans (8.3% of birds where the cause of death was known; 3.1% of all recoveries) were reported as having been shot. For Bewick's swans where the cause of death was known, the proportion found to have been shot across the decades was 15.8% (n = 6/38) in the 1970s, 14.3% (n = 5/35) in the 1980s, 26.3% (n = 5/19) in the 1990s and 16.7% (n = 1/6) in the 2000s. For whooper swans, the proportions were 23.9% (n = 11/46) in the 1980s, 7.0% (n = 14/200) in the 1990s and 4.3% (n = 5/115) in the 2000s. Of the Bewick's swans reported shot, 12 were found in Russia, one in Estonia and four in Britain. Of the whooper swans, 20 were shot in Iceland, five in Britain, two in Ireland and one in France.

4. Discussion

The Icelandic whooper swan population and the Northwest European Bewick's swan population are legally protected from hunting throughout their migratory ranges under national legislation (since 1885 in Iceland, 1954 in the UK, 1964 in Russia and 1976 in the Republic of Ireland) and international legislation (under 1979 EU Birds Directive and the 1999 African–Eurasian Waterbird Agreement), yet high levels of illegal shooting persist for both species. Overall, 31.2% of Bewick's swans and 13.6% of whooper swans X-rayed contained shot-in pellets, including 10 (22.7%) of 44 Bewick's swans and 35 (13.2%) of 266 whooper swans X-rayed in the 21st century. The particularly high incidence of pellets in Bewick's swans is similar to that recorded for quarry species such as the pink-footed goose, with 41% and 36% of geese X-rayed in Britain and Denmark found to be carrying pellets (Elder, 1955; Noer and Madsen, 1996). It is also similar to data recorded for six species of duck caught and X-rayed at Slimbridge between 1980 and 1982: 17.6% of mallard (*Anas platyrhynchos*; n = 91), 27.1% of pintail (*Anas acuta*; n = 108), 25.0% of pochard (*Aythya ferina*; n = 116), 14.9% of tufted duck (*Aythya fuligula*; n = 107), 25.8% of shoveler (*Anas clypeata*; n = 31) and 26.3% of gadwall (*Anas strepera*; n = 19) had embedded pellets (WWT unpubl. data), with the relatively low incidence for mallard perhaps reflecting a relatively localised, non-migratory group. The high level of embedded shot

found in Bewick's swans probably reflects their comparatively long overland flight across Europe to breeding grounds in arctic Russia, whereas most of the whooper swans' ~800 km migration is an overseas flight from Britain or Ireland to Iceland. Bewick's swans also cross more political boundaries and compliance with legislation may be better in some countries than others. Thus illegal shooting needs to be addressed at both national and international levels.

The likelihood of being shot appeared to increase with age for both species, reflecting the greater time that older birds have been exposed to the risk of shooting. Potentially lower survival rates of younger pellet carriers may also explain the differences in pellet frequency across age cohorts. Although survival rates of shot pink-footed geese have been found not to vary between age classes (Madsen and Noer, 1996), Merkel et al. (2006) found that juvenile common eiders (*Somateria mollissima*) with embedded lead shot were more likely to have a poorer body condition than pellet carrying adult birds. For Bewick's swans, however, there was some indication of body condition being lower in adults with pellets, but not for cygnets with pellets, which may perhaps reflect the cygnets having carried the pellets for a relatively short time. Previous studies have demonstrated a relationship between body size and pellet incidence, whereby larger birds have a greater surface area for pellets to hit (Elder, 1955; Evans et al., 1973; Hoffman, 1965). The likelihood of having been shot was not associated with body size for the swans in our study, though the number of embedded pellets was significantly higher for larger Bewick's swans suggesting that if a bird is targeted then size may affect the extent to which it's peppered with shot.

With such high levels of wounding, significant shooting mortality seems likely. Earlier studies report that pink-footed geese and mallards carrying pellets in their tissues have a significantly lower survival than non-carriers (Madsen and Noer, 1996; Tavecchia et al., 2001). Illegal shooting is an established cause of death in both swan species; earlier studies reported that 7.4% of adult Bewick's swans (Brown et al., 1992) and 13% of whooper swans (Rees et al., 2002) were illegally shot or deliberately taken by man. *Post-mortem* data analysed for this study indicated that illegal shooting caused the death of 8.4% of 202 Bewick's swans recovered since the 1970s (17.3% of 98 birds where the cause of death was known) and 3.1% of 962 whooper swans recovered since the 1980s (8.3% of 361 birds where the cause of death was known), though it should be noted that there is probably a bias in reporting rates, with shot birds more likely to be reported than swans dying of disease or exhaustion during migration. Further analysis is needed to determine the impact of illegal shooting on the survival of the migratory swans, including an assessment of whether illegal shooting provides additive or compensatory mortality to that of birds dying of other causes (Fox et al., 2006).

4.1. Trends over time

The prevalence of pellets in Bewick's swans varied over the decades but remained high throughout the study. However, higher proportions of shot birds were recorded during the 1970s and 1980s than in the 1990s and 2000s and significantly more Bewick's swans had an increase in pellet count on re-capture in the 1970s than in the 1990s. This apparent reduction in levels of illegal shooting may perhaps be due to legislative messages being communicated and absorbed more effectively, for instance with fewer hunters being unaware of the protected status of swan species.

Protective legislation has had some success in reducing illegal shooting for other waterfowl species. The establishment of hunting restrictions and hunting-free zones within EU Special Protection Areas in Denmark was linked to a reduction in illegal shooting of mute swans (*Cygnus olor*), with suggestions of increasing legislative compliance since 1979 EU Birds Directive (Andersen-Harild et al., 2002). The Greenland white-fronted goose (*Anser albifrons flavirostris*) population doubled following shooting restrictions and site protection on both wintering and breeding grounds (Fox et al., 2006). There is evidence that hunting levels have declined for other species in Europe, with McCulloch et al. (1992) demonstrating a significant overall decrease in hunting for most of 20 migratory species surveyed since 1950, with changes thought to be at least partly attributable to a real decline in addition to changes in reporting the shooting of species which are now protected. More recently, in southern Europe, there has been a significant decrease in the proportion of birds admitted to rehabilitation centres due to shooting and an increase in those admitted due to impacts with infrastructure since the mid 1990s, with the number of hunting licenses also decreasing during this time (Martínez-Abraín et al., 2009).

Despite indications that levels of illegal shooting have reduced for Bewick's swans, complacency should not prevail. Illegal shooting levels were comparatively low in the whooper swan population, but there was little variation between the 1980s and 2000s in the proportion of shot birds. This suggests that adherence to protective legislation has not improved in the range countries of this population (i.e., Britain, Ireland and Iceland) since the 1980s, although the extent to which legislation has influenced the frequency of wounding cannot be determined as there are no pre-legislative X-ray data available for swan species.

4.2. Location of illicit shooting

Despite the high levels of illegal shooting, determining 'hot-spot' areas where the birds are at risk is more difficult, although there is evidence to suggest that birds are shot throughout their ranges. Some birds X-rayed more than once in a winter were found with an increased pellet count on re-capture, revealing that both species have been shot at wintering sites in Britain. WWT-ringed Bewick's swans have also been found shot dead in Estonia and Russia, whilst shot whooper swans have been recovered in Iceland, France and Ireland. Although Morozov (2006) suggested that violation of hunting regulations is rife in Russia, the precise locations of illegal shooting hot-spots remain unclear for both flyways. Whether and where accidental shooting occurs, with swans potentially being hit inadvertently when in mixed flocks with quarry species of geese, also needs to be determined.

4.3. Conservation implications

Although illegal shooting of Bewick's swans has declined since the 1970s it remains a threat for both Bewick's and whooper swans. Given the long migrations undertaken, during which political boundaries are repeatedly crossed, a flyway approach is important if tackling the level of illegal shooting is to be effective. International collaboration in coordinating research and conservation activity is required for the successful reduction of poaching, as demonstrated for other hunted species, particularly as adherence to national and international legislation is likely to vary between countries. In particular, the threat may be reduced through stricter enforcement of legislation at the national level and by increasing public awareness of the issue. Improved engagement with hunting organisations across the flyways is needed to ensure that hunters are fully aware of which species are protected, to provide training in bird identification where this is found to be needed, to identify areas where the birds are most at risk, and to determine and address any other reasons (e.g. crop protection) for illegal shooting.

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