Journal of Zoology

Journal of Zoology. Print ISSN 0952-8369

Blood lead levels in wintering and moulting Icelandic whooper swans over two decades

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Keywords
blood; lead; *Cygnus cygnus*; Iceland; Britain; Ireland; diet; grit.

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Editor: Nigel Bennett

Received 26 February 2008; revised 18 April 2008; accepted 23 April 2007

doi:10.1111/j.1469-7998.2008.00462.x

Abstract

Lead poisoning of waterfowl through the ingestion of spent gunshot and discarded anglers' weights continues to be a problem worldwide. We took blood samples from 363 whooper swans *Cygnus cygnus* at wintering sites in Britain and Ireland and at moulting sites in Iceland during 2001–2005, and analysed them for total blood lead. Lead levels were generally low in swans in Iceland; 6% of samples exceeded 1.21 μmol L^{-1}, the level indicative of elevated lead and above background levels. The proportion of swans with elevated lead was much higher in the wintering range, varying between 43 and 70% at three sites monitored over the winters 2003/2004–2005/2006, and with blood lead levels ranging up to 19.6 μmol L^{-1}. The highest levels were in samples taken from swans in Scotland, with a mean value of 3.0 μmol L^{-1}, but nevertheless they indicated a marked decrease compared with blood lead levels measured for whooper swans at the same site 20 years ago. There also appeared to be a significant long-term decrease in the proportion of swans with elevated blood lead in Iceland, from 60% of birds in 1984 to 8% in 2005, although this may be due to the birds being caught in different parts of Iceland. The most likely source of elevated lead in whooper swans is spent gunshot. Management measures to reduce the impact of lead in the environment on the birds are discussed.

Introduction

Lead poisoning remains a serious threat to waterfowl and terrestrial birds and has been well documented worldwide (Pain, 1996; Fisher, Pain & Thomas, 2006; Scheuhammer & Norris, 2006; Guillemain *et al*., 2007). While lead poisoning in the mute swan *Cygnus olor* has been studied in detail (Sears, 1988; Sears & Hunt, 1991; O'Halloran *et al*., 2002; Day *et al*., 2003; Perrins, Cousquer & Waine, 2003), few studies have focused on the whooper swan *Cygnus cygnus*. Recent concern in Japan over the numbers of whooper swans dying of lead poisoning as well as cases of secondary poisoning found in Steller's sea eagle *Haliaeetus pelagicus* and white-tailed sea eagle *Haliaeetus albicilla* (Honda, Lee & Tatsukawa, 1990; Ochiai *et al*., 1992; Kurosawa, 2000; Nakade *et al*., 2005) have raised awareness and some concern about this lack of information.

The first recorded incidence of lead poisoning in whooper swans in the UK occurred in Scotland when some 30 birds suspected of lead poisoning died on the river Teviot during the winter 1979/1980 (Spray & Milne, 1988). A further nine whooper swans were recovered during the winter of 1981/1982 from the river Ythan, seven of these recorded as having high levels in their tissues (Spray & Milne, 1988). O'Halloran, Myers & Duggan (1988b) reported the first case of lead-poisoned whooper swans in Ireland, which resulted from the ingestion of spent gunshot discarded at the site almost two decades ago. O'Halloran *et al*. (1988b) found that high densities of shotgun pellets at Kilcolman Wildfowl refuge in Co. Cork were due to the high prevalence of lead pellets in the underlying mud and these could still pose a threat to wintering populations. During the winter of 2005/2006, more than 100 swans died from lead poisoning following ingestion of spent gun shot at the Wexford Wildfowl Reserve in county Wexford, Ireland (P. Raleigh, pers. comm.), and over two-thirds of these were whooper swans. In recent decades, whooper swans have altered their feeding habits, and now spend considerable time foraging on agricultural land, mainly pasture (Rees, Kirby & Gilburn, 1997). This change has not been without its risks as hunting remains popular in some of these parts, with high densities of lead shot discarded annually. Such lead may pose a risk to birds as they actively seek grit, particularly if feeding on rougher pasture, which may require more grit for digestion.

Spray & Milne (1988) found that whooper swan blood lead levels were consistently higher in swans caught in

Table 1 Number of whooper swans *Cygnus cygnus* sampled at each study site

Site	Location	Year	Adults	Cygnet	Total
Wexford Slobs, Ireland	52°21′N, 6°21′W	2002	7	0	7
Caerlaverock , Scotland	54°58′N, 3°28′W	2003	19	2	21
Skagafjörður	65°45′N, 19°31′W	2003	29	36	65
Mývatnsheiði/Fljótsheidi	65°37′N, 17°15′W	2003	31	5	36
Skagafjörður	65°45′N, 19°31′W	2004	10	8	18
Mývatnsheiði	65°37′N, 17°5′W	2004	41	20	61
Jökuldalsheiði	65°12′N, 15°31′W	2004	53	9	62
Martin Mere, UK	53°36′N, 2°50′W	2004	36	10	46
Martin Mere, UK	53°36′N, 2°50′W	2005	18	6	24
Caerlaverock, Scotland	54°58′N, 3°28′W	2005	20	3	23

Scotland than those caught in Iceland, suggesting that the lead had been ingested on the wintering grounds but has gone by the next moult. The residence time of lead in bird blood is generally about 20 days (O'Halloran, Myers & Duggan, 1988a), and so the measurement of blood lead levels is a useful tool in the screening of lead contamination.

The Icelandic-breeding whooper swans winter mainly in Britain and Ireland (Cranswick *et al.*, 2002; Rees *et al.*, 2002), and so these countries are largely responsible for the conservation of the Icelandic population. Given the recent evidence of the risk of lead poisoning to the birds, this study set out to examine blood lead levels in whooper swans both at wintering sites and at the summer moulting sites over the period of 2003–2005. Legislation making it illegal to sell or import lead fishing weights (size range: 0.06–28.36 g) in England and Wales was introduced in 1987, following studies showing that the ingestion of anglers' lead weights was a major cause of death in mute swans in England (review in Sears & Hunt, 1991). More recently, regulations prohibiting the use of lead shot for shooting listed species (including wildfowl) with a shot gun in England, and also banning the use of lead shot over all foreshores and at specified SSSIs, were put in place in 1999. The blood lead levels recorded in 2001–2005 therefore are compared with Spray & Milne's (1988) data, recorded in the mid 1980s, to determine whether there have been any long-term changes in the whooper swans' blood lead levels following the restrictions on the use of lead in parts of their wintering range.

Study area and methods

Study sites

Whooper swans were caught on the wintering grounds in Britain and Ireland and at their moulting sites in Iceland. In Iceland, blood samples were taken from swans caught during the annual moult in July–August 2003 and 2004 at three geographically discrete study areas in the northern part of the country: at Skagafjörður, Mývatnsheiði/Fljótsheiði (abbreviated Mývatn/Fljót in some tables and figures) and Jökuldalsheiði. Goose hunting takes place in Skagafjörður and Jökuldalsheiði but this is not thought to be significant. In winters 2002/2003–2004/2005, blood samples were collected from swans at three sites in Ireland and the UK: the Wildfowl and Wetlands Trust (WWT) at Martin Mere, Lancashire, England, the WWT at Caerlaverock, in Dumfries and Galloway, Scotland, and at the Wexford Slobs, Ireland (Table 1). Wildfowling has been common practice for many years at sites near Martin Mere and Caerlaverock.

Lead levels from swans sampled in 1984 at Skógalón (65°45′N, 14°52′W) and Álftafjörður (64°35′N, 14°27′W) and in 1985 at Snaefellsnessysla (64°00′N, 22°40′W) (Spray & Milne, 1988) were compared with the data collected from different parts of Iceland in 2003 and 2004. Similarly, lead levels in whooper swans at WWT at Caerlaverock, Scotland, in 1984, 1985 and 1986 were compared with our more recent data from the same site, and with lead levels recorded at the Wexford Slobs and WWT Martin Mere.

Sample collection

In Iceland, swans were caught from a boat, using a swan hook, while flightless during the annual moult in late July and August. In winter, they were caught either in specially designed swan pipes (at WWT centres) or by a cannon net (at Wexford). Swans were temporarily held in a specially designed swan jacket for the ringing process (Evans & Kear, 1975). Birds were sexed by cloacal examination, and age was recorded (adults having white plumage, cygnets grey plumage). The birds were then marked with leg-rings, weighed (to the nearest 100 g), measured (skull length and tarsus length) and blood samples (2 mL) were taken using a 23 G needle, mostly from the tarsal vein but occasionally from the brachial vein. The blood samples were placed in a 5-mL lithium heparin tube and then frozen (−20 °C) until analysis.

Blood analysis

Blood lead concentrations were determined on a Varian SpectrAA-300 atomic absorption spectrophotometer (Vic., Australia) with a flameless atomizer attachment, at a wavelength of 217 nm. Certified reference material was used for standardizing. Samples were prepared and processed using the techniques described by O'Halloran *et al.* (1988a) and by O'Halloran, Walsh & Fitzpatrick (1997). Swans with blood lead levels exceeding 1.21 μmol L^{-1} were considered to have

elevated lead levels (Perrins *et al*., 2003), which are above background levels and indicative of lead ingestion (O'Halloran *et al*., 1988b). Blood lead has recently been documented in μmol L^{-1} by Perrins *et al*. (2003), a level of 1.21 μmol L^{-1} and above indicating elevated lead levels. This is a level lower than originally used by past workers when threshold levels of blood lead were >40 μg/100 mL (1.93 μmol L^{-1}). A simple conversion to enable comparison with earlier studies is the μmol L^{-1} unit multiplied by 20.7 giving the equivalent value in the μg 100 mL^{-1} unit.

All statistical calculations were carried out using Microsoft Excel 2000, Minitab statistical package (Pennsylvania University, USA) and SPSS version 11.0. As the data were not normally distributed, non-parametric Mann–Whitney *U* and Kruskal–Wallis tests were used throughout.

Results

Blood lead levels at all sites

A total of 121 whooper swan blood samples were collected during winter, and a further 242 during the summer months (Table 1). Lead was detected in all whooper swan blood sampled, and levels ranged from 0.002 to 19.60 μmol L^{-1}. There was significant variation in median blood lead levels across sites (Kruskal–Wallis, $H = 212.6$, $P < 0.05$, d.f. = 5), with the highest blood lead level (19.60 μmol L^{-1}) recorded in a bird in Scotland in 2003. The percentage of swans with elevated blood lead levels (>1.2 μmol L^{-1}) varied from 0 (Iceland 2003) to 88% (Martin Mere 2005), with the mean percentage of swans with elevated blood lead levels being 3.7, 70.0 and 51.1% for Iceland, England and Scotland, respectively (Table 2). The proportion of swans with elevated lead in Ireland was 43%, but the numbers sampled was low ($n = 7$).

Blood lead levels of swans in summer

In Iceland, blood samples were collected in both years from two of the same sites (Skagafjörður and Mývatnsheiði/Fljótsheiði), and also one new sites in 2004, Jökuldalsheiði (Table 3). The median blood lead levels were low and ranged from 0.06 to 0.24 μmol L^{-1}, with few showing elevated levels (Table 3). There was significant variation in median blood lead levels between the two sampling sites in 2003 (Kruskal–Wallis, $H = 8.33$, $P < 0.05$, d.f. = 1), with the median level being the highest at Mývatnsheiði/Fljótsheiði in 2003. Similarly, there was significant variation in blood lead between sites in 2004 in Iceland (Kruskal–Wallis, $H = 15.42$, $P < 0.05$, d.f. = 2), with the median level being highest at Jökuldalsheiði in 2004. About 8% of the birds sampled at Jökuldalsheiði had elevated levels. On considering the two sites sampled in 2003 and 2004, the median blood lead levels were found to be similar between the 2 years (Mann–Whitney $U = 2592$, $n_1 = 65$, $n_2 = 18$, $P > 0.05$ for Skagafjörður; Mann–Whitney $U = 2934$, $n_1 = 36$, $n_2 = 61$, $P > 0.05$ for Mývatnsheiði/Fljótsheiði) (Table 3). Overall, few birds with elevated levels were detected in Iceland.

In summer 2004, seven swans were recaptured that had been sampled in 2003 (Fig. 1). In most cases, the levels of lead detected were below a level considered elevated, except in one bird (Swan 1), where the level increased from 0.84 to 1.39 μmol L^{-1}.

Table 2 Summary of blood lead levels (μmol L^{-1}) for whooper swans *Cygnus cygnus* sampled in 2002–2005 at sites in Ireland, Britain and Iceland

Location	Year	*n*	Median	Mean	SD	Range	% > 1.21 μmol L^{-1}
Ireland	2002	7	0.22	0.8	0.74	0.121–1.609	43
Scotland	2003	21	1.00	2.5	4.38	0.536–19.536	38
Iceland	2003	101	0.07	0.2	0.21	0.002–1.029	0
Iceland	2004	141	0.17	0.3	0.38	0.002–1.812	6
England	2004	46	1.37	1.5	1.00	0.014–5.478	61
England	2005	24	1.88	2.3	1.27	0.957–5.478	87.5
Scotland	2005	24	1.60	1.6	0.93	0.486–3.913	62.5

The proportion of birds with elevated lead levels (i.e. values >1.21 μmol L^{-1}) is also indicated (see text for details).

Table 3 Summary of median blood lead levels (μmol L^{-1}) for whooper swans *Cygnus cygnus* sampled at sites in Iceland from 2003 to 2004

		Adults		Cygnets		All swans			
Site	Year	*n*	Median lead	*n*	Median lead	*n*	Median lead	Range	% > 1.21
Skagafjörður	2003	29	0.10	36	0.03	65	0.06	0.002–0.628	0
Mývatn/Fljót	2003	31	0.18	5	0.05	36	0.13	0.01–1.029	0
Skagafjörður	2004	10	0.10	8	0.07	18	0.08	0.014–0.459	0
Mývatnsheiði	2004	41	0.17	20	0.04	61	0.13	0.002–1.449	5
Jökuldalsheiði	2004	53	0.25	9	0.08	62	0.24	0.014–1.812	8[a]

The proportion of birds with elevated lead levels (i.e. values >1.21 μmol L^{-1}) is also indicated.
[a]Two of these birds with levels >1.21 μmol L^{-1} were juveniles that is born on site/same year.

Blood lead levels of swans in winter

Blood lead levels of swans in winter ranged from 0.01 to19.54 μmol L^{-1} in winters 2002/2003–2004/2005 (Table 4). The median levels for adult swans (1.39 μmol L^{-1}) did not differ from the median levels found in cygnets (1.78 μmol L^{-1}) (Mann–Whitney $U = 1491.5$, $n_1 = 21$, $n_2 = 100$, $P > 0.05$; Table 4). There was significant variation in the median blood lead levels in all birds across sites in Ireland, England and Scotland (Kruskal–Wallis, $H = 15.84$, $P < 0.05$, d.f. = 4, Table 2), and median blood lead levels in adults also differed across sites (Kruskal–Wallis, $H = 15.59$, $P < 0.05$, d.f. = 4). Too few cygnets were sampled at Wexford and Caerlaverock (2003) to allow statistical analysis. The median blood lead levels recorded for the cygnets wintering at Martin Mere did not differ significantly from those caught at sites in Iceland in summer (Kruskal–Wallis, $H = 2.01$, $P > 0.05$, d.f. = 2, Table 3). One cygnet sampled in Caerlaverock in 2003 had a blood lead level of 19.54 μmol L^{-1}, the highest blood lead level recorded in this study.

Comparison with historical data

A comparison of the blood levels recorded for whooper swans at Caerlaverock with the data from Spray & Milne (1988) indicated a long-term decline in lead levels for whooper swans wintering at the site (Table 4). The lead levels recorded in winters 2003–2005 were found to be significantly lower that those recorded two decades earlier in 1984–1986 (Mann–Whitney $U = 1537$, $n_1 = 177$, $n_2 = 44$, $P < 0.001$).

A comparison of the blood lead levels recorded in Iceland in the 1980s (Spray & Milne's data) with the 2003–2004 data (presented here) also found a difference in lead levels, with elevated lead (> 1.21 μmol L^{-1}) being recorded for 60–97.5% of birds sampled in 1984–1985 and just 0–8% in 2003–2005 (Mann–Whitney $U = 789$, $n_1 = 178$, $n_2 = 242$, $P < 0.001$; Fig. 2).

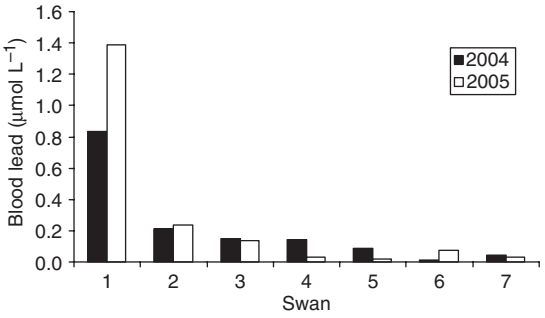

Figure 1 Blood lead concentrations in seven individual whooper swans *Cygnus cygnus* captured during 2003 and 2004 in Iceland.

Discussion

Blood lead is a widely used and a very useful tool for assessing the lead status of birds and mammals, with levels usually being indicative of recent exposure that is 35–40 days (O'Halloran, Myers & Duggan, 1988a). This reflects the life span of the avian red blood cell and because lead binds to the haemoglobin, this indicates the maximum time it is present in the red blood cells. Sources of lead for swans include background lead contamination, discarded anglers' lead weights and spent gun shot. Thus, blood lead levels detected in moulting swans in Iceland in July–August, having arrived there from Ireland and Britain in March/April, are indicative of exposure to lead in Iceland. In the same way, lead levels detected in December–March on the wintering grounds are indicative of exposure to lead on the wintering grounds in Britain and Ireland.

Iceland has *c.* 20 000 hunters registered, with 10 000 –11 000 renewing their licenses each year. In excess of one million cartridges are used there annually, and 95% of these are made from lead (Environment and Food Agency of Iceland, pers. comm.). As a result, spent shot is found in wetland pools where the swans are breeding and moulting. Work undertaken by Spray & Milne (1988) in Iceland in 1984 and 1985 revealed significant poisoning, with 60, 62 and 97.5% of swans sampled at Skógalón, Álftafjörður and Snaefellsnessysla reportedly exceeding the 1.21 μmol L^{-1}

Table 4 Summary of median blood lead levels (μmol L^{-1}) for the whooper swans *Cygnus cygnus* sampled in Ireland and Britain from 2002 to 2005

		Adults				Cygnets			
Site	Year	*n*	Median lead	Range	% > 1.21	*n*	Median lead	Range	% > 1.21
Caerlaverock, Scotland[a]	1984	37	1.93	1.06–5.99	97	7	2.03	1.69–2.61	100
Caerlaverock, Scotland[a]	1985	60	2.46	1.26–5.02	100	10	2.17	1.55–3.09	100
Caerlaverock, Scotland[a]	1986	51	2.37	0.92–22.17	94	12	2.13	0.97–4.25	92
Wexford, Ireland	2002	7	0.22	0.12–1.61	43	0	0	0	0
Caerlaverock, Scotland	2003	19	1.00	0.54–9.83	37	2	10.14	0.74–19.54	50
Caerlaverock, Scotland	2005	20	1.25	0.49–3.91	55	3	1.97	1.91–2.17	100
Martin Mere, UK	2004	36	1.36	0.01–5.48	58	10	1.55	0.62–2.65	70
Martin Mere, UK	2005	18	1.88	0.99–5.48	94	6	1.86	0.96–3.88	67
Total		100	1.40	0.01–9.83	59	21	1.78	0.62–19.54	71

The proportion of birds with elevated lead levels (i.e. values > 1.21 μmol L^{-1}) is also indicated.
[a]Spray & Milne (1988) data for reference.

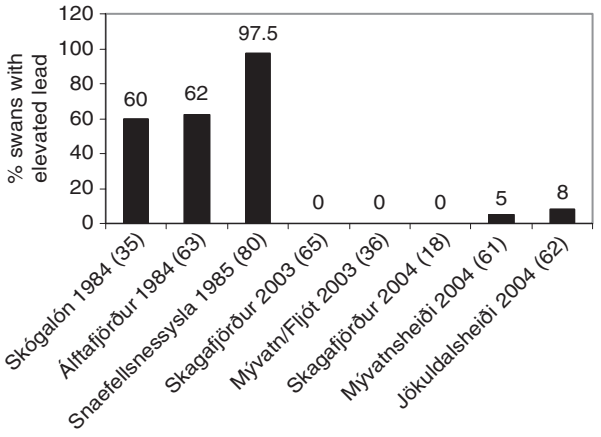

Figure 2 Percentage of swans with elevated lead sampled at sites in Iceland over 1984–2004.

blood lead threshold. Our more recent study found that only 0 and 6% of swans had elevated blood lead levels in Iceland in 2003 and 2004, respectively, indicating that they had ingested little or no lead at this time. The two studies were performed at different sites, however, and so it is likely that the lower lead levels reported at Skagafjörður, Mývatnsheiði/Fljótsheiði and Jökuldalsheiði reflect smaller quantities of lead at these particular sites rather than a large-scale long-term change in the abundance of lead in the environment in Iceland.

The increase from 0 to 5% in the proportion of swans with elevated lead levels recorded in Mývatnsheiði between 2003 and 2004 suggests that, although lead poisoning is minimal, there is evidence of an increasing risk. These birds have low mobility during this time of the year and as a result blood lead levels are particularly indicative of local levels. Another possible explanation for the low levels of lead observed in summer, in addition to regional variation in the swans' exposure to lead, is the elimination of lead through the moulting feathers during the annual moult. Although O'Halloran *et al.* (1988b) recorded the lowest blood lead levels in mute swans during primary moult, this was not due to excretion through the feathers, but a seasonal availability of lead.

In this study, despite an apparent decline in blood lead levels since the 1980s, levels remain quite high at some of the wintering sites. There was a 27% increase in the proportion of swans with elevated lead levels at Martin Mere between 2004 and 2005, and a 24% increase at Caerlaverock between 2003 and 2005. Cygnets had a greater range in blood lead values in comparison with adults, although sample sizes were generally smaller. One cygnet sampled in March of 2003 in Caerlaverock had a blood lead level of 19.54 μmol. Given the high persistence of lead in the environment, historical hunting may be responsible for the lead and that consideration should be given to mitigation measures using grit such as those used at Cork Lough (O'Halloran *et al.*, 2003).

Ireland, which hosts 62–66% of the flyway total in winter for the Icelandic whooper swan population (Cranswick *et al.*, 2002), has a particular responsibility for their conservation and protection. In Ireland, there are *c.* 77 000 native hunters in the State and *c.* 4000 out-of-State hunters are granted licences annually (Seanad Éireann, 1993), but yet the Irish whooper swan wintering sites are poorly monitored. Cannon netting is the only available method to catch whooper swans in Ireland at present. In this study, only seven swans caught by a cannon net were sampled for blood lead levels. All these were adults, of which three at the Wexford Slobs had elevated lead levels. An alternative approach for monitoring lead in this section of the population is through the reporting of die-offs and by determining through systematic post mortem examination the cause of death for any individuals recovered. For instance, O'Halloran *et al.* (1988b) reported cases of lead poisoning in whooper swan corpses examined at Kilcolman Wildfowl refuge, Co. Cork, where high densities of lead shot were found in the area from shooting more than 20 years earlier.

During December 2005, *c.* 100 swans (66% whooper and 34% mute) were found dead or dying at the Wexford Slobs. Blood and tissue analysis revealed acute lead poisoning with lead levels ranging from 10.8 to 22.0 μmol L^{-1} (O'Halloran, 2006). The most likely explanation for this incident is that the birds were actively seeking grit, and ingesting lead pellets as an alternative, in an area also used by hunters. The situation may have been exacerbated by the swans being attracted to food put out by the hunters as bait for duck, and thus staying longer and in greater numbers in 'hunting areas'. This incident highlights the need to monitor potential hotspots where hunting practices are concentrated, particularly in areas of ecological importance to wintering waterfowl species.

Whooper swans appear to be more susceptible to lead poisoning than mute swans. This is generally thought to be related to differences in diet and grit requirements, with whooper swans spending more time feeding on agricultural and hunted land, while mute swans have a more aquatic diet (Spray & Milne, 1988). Whooper swans were first recorded feeding on potatoes in Ireland in severe weather in the 1940s and have since increasingly used arable habitats. A similar trend became evident in Denmark and the Netherlands at the same time (Crowe, 2005). Studies from the lead poisoning incidence on the Wexford Slobs in 2005 revealed that whooper swans seemed to be more vulnerable to ingestion of lead pellets than the mute swans (A. Walsh, pers. comm.). This may be explained by the fact that the whooper swans spent more time on the baited and hunted grounds, feeding on barley, which requires a lot of grit to masticate. Mute swans, on the other hand, feed more in the channels that surround the slobs. Thus, the whooper swans have a greater chance of encountering discarded shot on the hunted areas.

It is believed that lead pellets take between 100 and 300 years to break down, depending on the climatic and environmental conditions (De Francisco, Ruiz Troya & Aguera, 2003). As a result, incidences of poisoning are occurring at present despite the fact that the lead may have been scattered/discarded decades ago (Beer & Stanley, 1965; O'Halloran *et al.*, 1988b). Because of habitat loss and the

high densities of birds inhabiting wintering sites, availability of grit may be lowered. Moreover, when swans occasionally feed on barley, corn and potatoes to supplement wintering feeding, this may be quite indigestible and as a result require large quantities of grit. The swans therefore have to actively seek grit alternatives, sometimes in the form of spent lead shot or weights.

To provide better information on how lethal and sub-lethal lead levels are affecting the whooper swan population, routine blood sampling should be adopted at all major wintering sites, particularly at known 'hot spots' of lead contamination such as the Wexford Slobs, Lough Spynie and the Ythan estuary in Scotland. Additionally, the effects of elevated but apparently sub-lethal lead levels on the swans' subsequent survival rates should be investigated. Some published data for other waterfowl species should also be reviewed (Tavecchia *et al*., 2001; Spears, Hansen & Audet, 2007; Guillemain *et al*., 2007). Stricter hunting controls on the use of lead shot with particular emphasis on wintering sites need to be prioritized by conservation agencies. The conservation of the whooper swan requires measures to be taken along its flyway. Clearly, there are needs to monitor lead and implement both a monitoring and, where appropriate, a mitigation strategy.

Acknowledgements

Financial support was provided by the Higher Education Authority, Ireland, and the Environmental Research Institute, University College Cork, Ireland. For assistance with field work, we wish to thank Richard Hesketh, Chris Tomlinson and Ruth Cromie of the Wildfowl and Wetland Trust for invaluable assistance with sampling in Caerlaverock and Iceland. Thanks are also due to Aevar Petersen of the Icelandic Museum of Natural History for help in the field in Iceland. Special thanks are also due to Alyn Walsh, Barry O'Mahony and Pat Smiddy for their invaluable assistance in the field in both Ireland and Iceland. We also thank the technical staff at University College Cork, including Nora Buttimer and Xie Quishi, for their assistance with lead analysis of blood samples. We also thank Professor Christopher Perrins and Dr Sandra Irwin for helpful comments on earlier drafts.

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