Post-mortem examination of Great Northern Divers *Gavia immer* killed in the *Prestige* oil spill, Galicia, Spain, 2002/03

Camphuysen, C. J.[1*], Bao, R.[2], Fortin, M.[3], Roselaar, C.S.[4] and Heubeck, M.[5]

**Correspondence author. Email: kees.camphuysen@nioz.nl*
[1] *Royal Netherlands Institute for Sea Research, MEE-Seabirds and Marine Mammals Group, P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands;*
[2] *Faculty of Sciences, University of A Coruña, Campus da Zapateira s/n, E-15071 A Coruña, Spain;*
[3] *Réserve Naturelle des Marais de Séné, Bretagne Vivante SEPNB, Brouël Kerbihan, F-56860 Séné, France;*
[4] *National Centre of Biodiversity Naturalis, branch Zoological Museum University of Amsterdam, P.O. Box 94766, 1090 GT Amsterdam, The Netherlands;*
[5] *Aberdeen Institute for Coastal Science and Management, University of Aberdeen, c/o Sumburgh Head Lighthouse, Virkie, Shetland ZE3 9JN, UK.*

Abstract
Great Northern Divers *Gavia immer* collected during the impact assessment of the 2002/03 *Prestige* oil spill were studied and compared with similar casualties collected during three other major oil spills. It was concluded that adults tend to winter further to the north in Western Europe than juveniles, and that the sexes were evenly represented in all spills. Wing and bill lengths of adults were also compared with those of museum specimens collected during the breeding season in Canada, Greenland and Iceland in an attempt to determine the possible breeding origin of birds wintering in northwest Spain. Wing lengths suggested that Iceland and Greenland were possible breeding grounds, while the incidence of embedded gunshot (18% of adults) further suggested that at least some birds originated from Greenland, where hunting is still legal. However, biometrics and gunshot incidence alone were inconclusive in determining a possible breeding origin. DNA analyses are being considered, including comparisons with gene sequences for this species already available in the GenBank. Mortality during the *Prestige* oil spill may have affected 18–22% of the total wintering population in Spain. Besides oil-induced mortality, drowning in fishing gear is identified as a real threat in Galicia. A systematic beached bird survey in the region would help determine the relative importance of different causes of mortality in this species.

Introduction

Several major oil spills in Europe have affected wintering Great Northern Divers *Gavia immer* (Hope Jones *et al*. 1978; Heubeck & Richardson 1980; Heubeck *et al*. 1993; Weir *et al*. 1996; Heubeck 1997; SEEEC 1998; Cadiou *et al*. 2003b), and the *Prestige* incident off Spain in 2002 was no exception. The oil tanker *Prestige*, carrying a cargo of 77,000 tonnes of heavy bunker oil, sank off the coast of Galicia,

northwest Spain on 19 November 2002. Most of the Galician coast was severely polluted (González *et al*. 2006) and thousands of oiled seabirds were retrieved from beaches between November 2002 and summer 2003 (García *et al*. 2003). Pollution was not confined to Galicia, and other parts of the northern Spanish, the Portuguese and the French coastlines were repeatedly contaminated with oil. Statistics released by SEO/Birdlife indicated that 65 Great Northern Divers were retrieved from beaches, three of which were found in Portugal, two in France and the remainder in Spain (García *et al*. 2003).

Great Northern Divers are scarce wintering birds in Atlantic Iberia, with a conservative estimate of 270–340 individuals for its Spanish sector (Sandoval & De Souza 2005). Most occur in Galicia and Asturias, where they frequent shallow open coasts, small embayments, rías (river valleys flooded by the sea) and estuaries, and the Galician population has recently been estimated at 123 (95% CI 76–166) individuals (De Souza *et al*. 2010). Regular beached bird surveys in the 1980s and 1990s on the Atlantic coast of Iberia found only occasional strandings of Great Northern Divers (Arcos & Solís 1997; Granadeiro *et al*. 1997; Arcos *et al*. 2005). In the absence of current regular beached bird surveys in the area, there is little knowledge of the age- and sex-composition of the wintering population, and their breeding origin is unknown. Therefore, during the routine impact assessment organised in response to the *Prestige* spill (Heubeck *et al*. 2003), it was decided to pay special attention to this species.

Methods

At the University of A Coruña, we examined 41 of the 53 Great Northern Diver corpses collected from beaches or received from rehabilitation centres in the Provinces of Pontevedra, A Coruña and Lugo, Galicia (Table 1). Other Great Northern Divers recorded by SEO were not transferred to the University and therefore could not be examined. Those labelled with a date and location were all found between November 2002 and April 2003. Unfortunately, finding dates were not logged systematically in rehabilitation centres, in which case the date of delivery to the University of A Coruña was recorded. For four birds, there was no indication of the date of receipt. After the 2002/03 necropsies, which also involved examination of 6,170 individuals of 60 seabird species (data files University of A Coruña), the Great Northern Diver carcasses were stored frozen. They were then re-examined in November 2007 (CJC, RB, MH) under more controlled and less stressful conditions, to confirm or refine the earlier data; this re-examination included new specimens that had been stored frozen at rehabilitation centres.

Table 1. Regional distribution of Great Northern Divers *Gavia immer* found stranded following the *Prestige* oil spill, 2002/03 (from García *et al*. 2003).

Country	Province/Region	No.
Portugal		3
Spain	Pontevedra, Galicia	11
	A Coruña, Galicia	38
	Lugo, Galicia	4
	Asturias	7
	Cantabria	0
	Vizcaya	0
	Guipúzcoa	0
France		2
Total		**65**

Where the state of the body allowed, as many as possible of the following measurements or observations were made, at least during the re-

examination in 2007: bill length 1 (tip-feathers, 0.1 mm); bill length 2 (tip-nostril, 0.1 mm); bill depth 1 (at base, 0.1 mm); bill depth 2 (at gonys, 0.1 mm); nostril feathering (see below); wing length (left and right, maximum flattened chord, 1 mm); tarsus length (left and right, 1 mm) (Camphuysen 2007). In contrast to the 2002/03 necropsies, when different teams of observers were involved, measurements in 2007 were standardised by using the same observer for each feature measured (CJC, MH). To check for White-billed Diver *Gavia adamsii* (given that bill colour is unreliable), tail feathers were counted (20 in Great Northern, 18 in White-billed Diver), the smoothness of the gonys was checked (smooth in Great Northern Diver, a distinct bump in White-billed Diver), and the extent of feathering over the nostrils was measured: $(x - y) / (x - z) < 0.05$ in Great Northern Diver, > 0.05 in White-billed Diver, where x is nostril base, z is distal end of nostril, and y is the distal end of the feathering over the upper mandible (Camphuysen 2007).

Plumage was simplified to 'summer', 'active moult (winter to summer)' and 'winter' (but note that most adult birds retain at least some summer-plumage feathers on the mantle, back or upperwings). Body mass was not determined, as most carcasses were severely contaminated, decomposed, or scavenged. Sex and age were assessed by a combination of gonadal development, presence and size of the bursa of Fabricius, and plumage (Camphuysen & van Franeker 2007a). Age was simplified to 'adult' (developed gonads, no bursa, adult-patterned plumage), 'immature' (developing gonads, small bursa, mix of pattern in plumage) and 'juvenile' (undeveloped gonads, large bursa, juvenile-patterned plumage). An assessment was also made of physical condition (subcutaneous fat, deposited fat and breast muscle), and the condition of the liver, lungs, intestines and kidneys (Camphuysen & van Franeker 2007b). Few corpses were in good enough condition for a complete examination and conclusions often had to be drawn on a subset of features. Of the 41 specimens, age was determined in 39 cases, plumage in 36, sex in 34, bursa in 33, and most or all biometrics were recorded for 39 individuals.

Stomach contents were collected and stored but have not been analysed. Tissue samples were also taken for DNA analysis and work is currently in progress on gene sequencing (C. Bartolomé pers. comm.). Feather samples (with age characteristics) were taken, and parts of most birds (bill, head, wing, total body) were photographed (Nikon D70) as a reference, which could help resolve conflicting results obtained during examinations. Anticipating a high risk of Great Northern Divers having been shot at in Greenland where continued hunting is legal (Anon. 2009), and a low risk in Iceland and North America where the species is fully protected (Weir *et al*. 1996; Evers 2004), carcasses were X-rayed to check for spent shot or bullets at the *Rof Codina* Clinical Hospital, Faculty of Veterinary Medicine, University of Santiago de Compostela (USC). Finally, all corpses were refrozen and deposited in the Natural History Museum *Luis Iglesias* of the USC, where they await curation.

Results

Most of the 37 dated Great Northern Divers were found in December and January (Table 2). Of the 39 that could be aged, 22 were adults, one was immature and 16

were juveniles. The sex ratio was 50:50 among both adults and juveniles. In all, 35 specimens were oiled (85%), of which 15 were only slightly oiled (< 15% coverage), ten largely (20–50%), and ten completely (80–100%). Body condition of the more-or-less intact divers ranged from zero to nine on a nine-point scale but, contrary to expectation, highest condition (nine points) was not found exclusively in heavily oiled birds (indicative of a rapid death), but also in two clean individuals, and one slightly contaminated bird which was thought to have become oiled only after death. While the proximate cause of death in most birds examined was either oiling or starvation, in at least three cases drowning (presumably in

Table 2. Month of retrieval, from approximate finding dates, and age of 41 Great Northern Divers *Gavia immer* found in Galicia following the *Prestige* oil spill, 2002/03.

Age	Nov	Dec	Jan	Feb	Mar	Apr	No date	Totals
Adult	3	10	6			1	2	22
Immature		1						1
Juvenile	1	10	2			1	2	16
Unknown	1	1						2
Totals	**5**	**22**	**8**	**0**	**0**	**2**	**4**	**41**

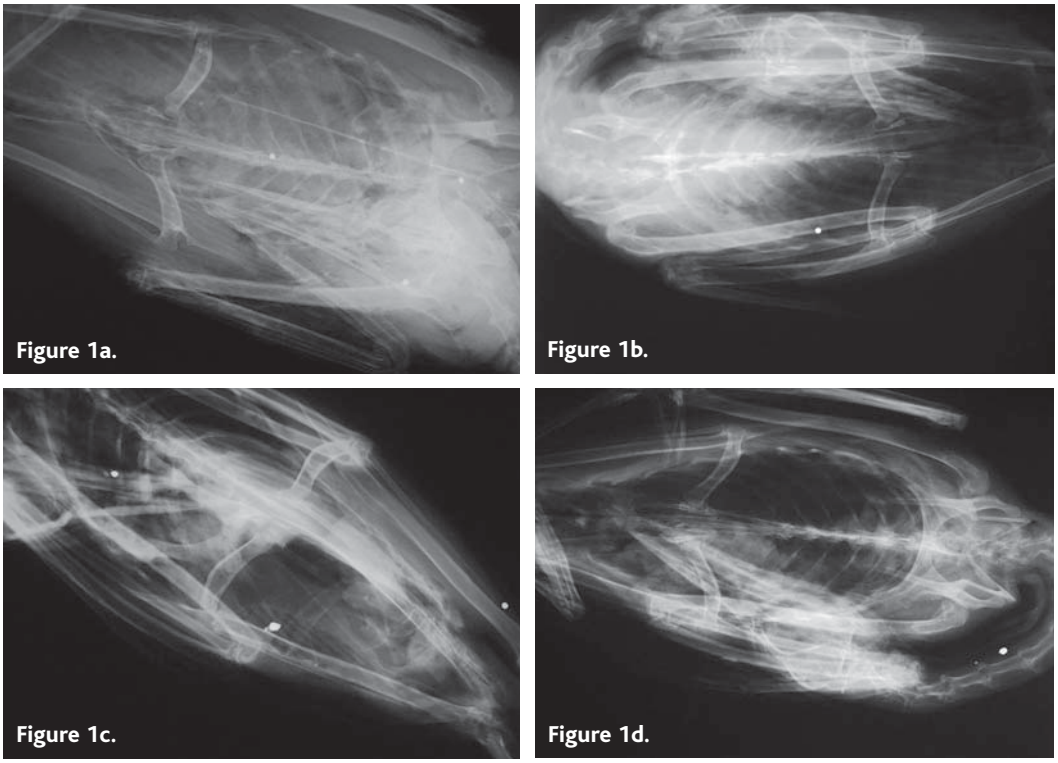

Figure 1. X-rays of four Great Northern Divers *Gavia immer* revealing non-lethal shot embedded in tissue: (a) double shot in the back, adult male, wing length 382 mm; (b) single shot in the wing, adult unsexed, wing length 389 mm; (c) four scattered shot, adult female, wing length 377 mm; (d) single shot in the neck, adult female, wing length 379 mm. © *Andrés Barreiro Lois* and *Ana López Beceiro*.

Table 3. Biometrics (mm) of Great Northern Divers *Gavia immer* found in Galicia following the *Prestige* oil spill, 2002/03.

All birds	**mean**	**± SD**	**range**	**n**	***t*-test, adult male versus adult female**
Bill length 1 tip-feathers	79.0	± 6.4	63.0–89.1	39	t_{17} = 1.93, P = 0.035
Bill length 2 tip-nostril	59.6	± 6.1	46.7–76.4	39	t_{17} = 2.18, P = 0.022
Bill depth base	24.5	± 2.0	21.0–28.4	39	t_{17} = 2.56, P = 0.010
Bill depth gonys	20.7	± 1.9	15.7–24.5	38	t_{16} = 0.74, n.s.
Tarsus	88.7	± 4.1	81–96	37	t_{15} = 3.24, P = 0.003
Wing	365.2	± 18.5	331–401	37	t_{16} = 2.32, P = 0.017

	Juvenile males				**Adult/imm males**				
Males	**mean**	**± SD**	**range**	**n**	**mean**	**± SD**	**range**	**n**	***t*-test, adult versus juv**
Bill length 1 tip-feathers	74.6	± 5.9	66.4–83.4	7	83.7	± 3.0	79.5–88.8	10	t_{15}= 4.20, P < 0.001
Bill length 2 tip-nostril	54.8	± 5.7	48.0–59.8	7	64.5	± 5.2	59.8–76.4	10	t_{15}= 3.62, P < 0.01
Bill depth base	23.1	± 1.0	21.6–24.9	7	26.3	± 1.1	24.1–28.4	10	t_{15}= 6.01, P < 0.001
Bill depth gonys	19.9	± 1.1	18.1–21.4	7	21.5	± 1.0	19.9–23.3	10	t_{15}= 3.01, P < 0.01
Tarsus	89.4	± 3.3	84–95	7	92.1	± 2.3	90–95	9	t_{14}= 1.91, P = 0.038
Wing	355.7	± 13.4	342–376	7	381.8	± 10.3	364–401	9	t_{14}= 4.64, P < 0.001

	Juvenile females				**Adult females**				
Females	**mean**	**± SD**	**range**	**n**	**mean**	**± SD**	**range**	**n**	***t*-test, adult versus juv**
Bill length 1 tip-feathers	75.1	± 6.2	68.6–84.8	7	80.2	± 4.8	72.0–87.9	9	t_{14}= 1.87, P = 0.04
Bill length 2 tip-nostril	56.2	± 5.4	50.4–64.8	7	60.4	± 2.2	56.0–63.2	9	t_{14}= 2.13, P = 0.03
Bill depth base	23.3	± 1.7	21.0–25.2	7	24.6	± 1.8	21.9–27.6	9	t_{14}= 1.57, n.s.
Bill depth gonys	18.9	± 1.9	15.7–21.5	7	21.9	± 1.6	19.8–24.5	8	t_{13}= 3.40, P < 0.01
Tarsus	87.4	± 3.4	84–95	8	87.5	± 3.6	83–93	8	t_{14}= 0.07, n.s.
Wing	357.3	± 20.6	337–380	4	367.5	± 10.2	355–380	7	t_{14}= 2.48, P = 0.01

fishing gear) was suspected to have caused death, indicated by characteristics such as good physical condition, no oiling (pre- or post-mortem), soaked plumage, the stomach full of prey remains, and organs in excellent condition apart from watery lungs. These three casualties (two from Pontevedra, one from Lugo) were considered unrelated to the oil spill.

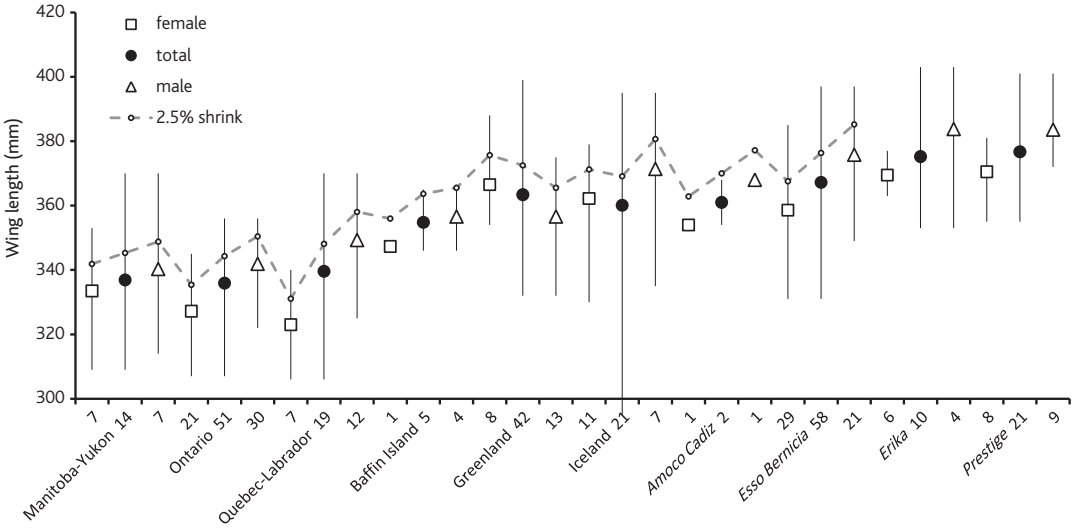

Figure 2. Wing length (mean, range, sample size (n) indicated) of adult Great Northern Divers *Gavia immer* from breeding locations in Canada, Greenland and Iceland (see Acknowledgements), compared with wing length in non-moulting adults collected during the *Amoco Cadiz*, *Esso Bernicia*, *Erika* and *Prestige* oil spills in Europe. The dotted line indicates means corrected for 2.5% shrinkage in museum specimens. Only *Prestige* and *Erika* birds were measured fresh. Note few data for the *Amoco Cadiz* oil spill, where most adults were in active wing moult.

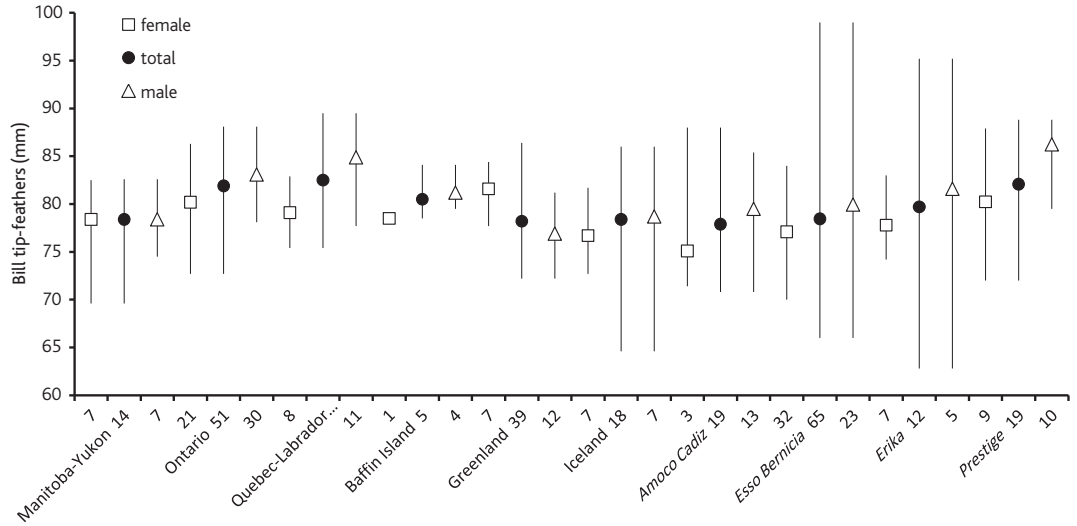

Figure 3. Bill length (tip to feathers, mean, range, sample size (n) indicated) of adult Great Northern Divers *Gavia immer* from breeding locations in Canada, Greenland and Iceland (see Acknowledgements), compared with that of adults collected during the *Amoco Cadiz*, *Esso Bernicia*, *Erika* and *Prestige* oil spills in Europe.

Primary moult (all flight feathers BTO score 4) was recorded in a single adult female, found on A Lanzada beach, Pontevedra on 17 April 2003. All aged birds were in winter plumage, except for an adult in December (transitional), the adult female in April (near-breeding plumage, active wing moult), and an undated adult male (in near-breeding plumage). X-rays of the 41 birds revealed that four, all adults, carried shotgun pellets (non-lethal, in the wing, spinal column, neck or elsewhere; Figure 1), but none could be considered heavily shot or seriously wounded, with a maximum of four pellets per bird. Adult males were significantly larger than females in all measurements, except bill depth at gonys (Table 3). Adults were also significantly larger than juveniles in all measurements, except bill depth at base and tarsus length in females.

Rather few impact assessments of major oil spills have had well co-ordinated necropsies in place, but some data were available to place the *Prestige* sample into context. After the 1978 *Amoco Cadiz* spill in Brittany, France, some Great Northern Diver carcasses were sent to the Zoological Museum in Amsterdam in a poor state and some remains were preserved (CSR), although Cadiou *et al*. (2003a) reported details of a larger sample of *Amoco Cadiz* birds examined while fresh (MF). Birds from the 1979 *Esso Bernicia* spill in Shetland, Scotland were sent to the National Museums of Scotland, Edinburgh for necropsy and curation (Heubeck *et al*. 2003), while data collected during the 1999 *Erika* spill in Brittany were also summarised by Cadiou *et al*. (2003a). Data from the Great Northern Divers collected during these four oil spills are compared (Table 4), and since there is both longitudinal and latitudinal variation in size across the breeding range (Storer 1988), wing and bill lengths were also compared with those of museum specimens collected in potential breeding areas (Figures 2 & 3; c.f. Heubeck *et al*. 2003).

Table 4. Comparison of Great Northern Divers *Gavia immer* examined following four oil spills: *Amoco Cadiz* in 1978 (Cadiou *et al*. 2003a), *Esso Bernicia* in 1978/79 (Heubeck *et al*. 1993), *Erika* in 1999/2000 (Cadiou *et al*. 2003a), and *Prestige* in 2002/03 (this paper).

Oil spill	*Amoco Cadiz*	*Esso Bernicia*	*Erika*	*Prestige*
Period	Mar–Apr 1978	Dec 1978–Mar 1979	Dec 1999–May 2000	Nov 200–Apr 2003
Birds examined (n)	41	68	29	41
Age composition (all) %	72% adult (n = 36)	97% adult (n = 68)*	71% adult (n = 17)	56% adult (n = 39)
Adult sex ratio (% ♂)	50% ♂ (n = 26)	40% ♂ (n = 57)	44% ♂ (n = 23)	50% ♂ (n = 18)
Non-lethal embedded shot (%)	(unknown)	19% (n = 64)**	(unknown)	10% (n = 41)
Bill length tip-feathers	♂ 78.0 ± 4.6 (70.8–85.4)	♂ 81.7 ± 6.2 (71.0–94.0)	♂ 81.6 ± 11.8 (62.8–95.2)	♂ 83.7 ± 3.0 (79.5–88.8)
(adults, mean± SD, range)	♀ 77.8 ± 4.6 (71.4–88.0)	♀ 78.1 ± 3.6 (70.5–84.0)	♀ 77.8 ± 3.3 (74.2–83.0)	♀ 80.2 ± 4.8 (72.0–87.9)
Bill depth gonys	♂ 20.6 ± 0.6 (19.8–21.9)	♂ 21.9 ± 1.3 (19.5–24.0)	♂ 19.0 ± 3.2 (13.5–21.4)	♂ 21.5 ± 1.0 (19.9–23.3)
(adults, mean ± SD, range)	♀ 19.3 ± 0.8 (18.3–21.4)	♀ 20.3 ± 1.3 (18.5–23.0)	♀ 19.0 ± 1.2 (17.7–20.9)	♀ 21.9 ± 1.6 (19.8–24.5)
Wing length	♂ 368.0 (single wing)	♂ 375.7 ± 13.6 (347–397)	♂ 383.8 ± 21.6 (353–403)	♂ 381.8 ± 10.3 (364–401)
(adults, mean ± SD, range)	♀ 354.0 (single wing)	♀ 359.4 ± 11.3 (331–385)	♀ 369.5 ± 6.0 (363–377)	♀ 367.5± 10.2 (355–380)
Wing moult (adults) %	majority	8(1x Feb, 7x Mar), 11% (n = 66)	no data	Single ♀ (Apr), 5% (n = 22)

Esso Bernicia: *66 out of 68 in third winter plumage, 2 in second winter plumage; **excludes four birds fatally shot for humanitarian reasons

Some general conclusions can be drawn from these data. First, the proportion of adult birds was higher in Shetland (97%) than in Spain (56%), with French samples being intermediate (71–72%). Second, the sex ratio among adults was not biased in any of the samples (not significantly different from equal; G_{adj}-test, $P > 0.05$). Three biometric parameters could be compared with some confidence for each of the samples: bill length (tip to feathers), bill depth (gonys) and wing length, and significant differences were found in bill length of male birds from *Prestige* versus male birds from *Amoco Cadiz* ($t_{21} = 3.26$, $P < 0.01$); all the other measurements were similar probably due to small sample sizes; (Table 4). The patterns were fairly consistent, with females being smaller than males, but never significantly so.

All European oil spill birds had wing lengths that matched Icelandic and Greenlandic birds better than Canadian populations. When corrected for post-mortem shrinkage (assuming 2.5% shrinkage; birds from the *Prestige* and *Erika* were measured fresh, while the reference material comprised of dried museum skins) wing lengths were still larger than the Canadian reference material (Figure 2). For adult *Prestige* birds, after correction for shrinkage in the museum birds (2.5%), wing length in males ($t_{56}= 6.08$, $P < 0.001$) and females ($t_{43}= 7.72$, $P < 0.001$) was significantly larger than in Great Northern Divers originating from Canada (Manitoba to Labrador combined), whereas in both sexes wing length was similar to birds from Greenland and Iceland combined (males $t_{13}= 1.61$, n.s.; females $t_{24}= 1.08$, n.s.). For bill length, however, a rather confusing picture emerged (Figure 3). Although bill length was one of the few measurements available for all study samples, its value in distinguishing between biogeographical populations is doubtful.

X-rays of *Esso Bernicia* birds from Shetland found embedded shotgun pellets and .22 bullets (two) in a significantly higher proportion (19%, n = 64) than the *Prestige* birds (10%, n = 41; $G_{adj} = 9.50$, df = 1, $P < 0.001$; Table 4); no such data were collected in France. However, the *Prestige* sample contained a high percentage of juveniles, and adults would obviously have experienced a greater chance of having been shot at during their lives than juveniles and immatures. In both samples, non-fatal gunshot wounds were only found in adults, with no difference in its incidence in this age-class in Spain (4/22, 18%) and Shetland (12/62, 19%). While it is possible the *Prestige* birds had been shot at in Galicia, regulations introduced in 1980 reduced hunting from boats considerably. This was reflected in a decline in the recovery of ringed alcids by shooting from 55% in 1950–1979 to none since 1984 (Velando & Freire 2002; Munilla *et al*. 2007), and it is more probable that these four Great Northern Divers were shot at elsewhere.

Discussion

Great Northern Divers, as all Gaviidae, are highly sensitive to marine oil pollution. The largest documented oil-related mortality of Great Northern Divers in Europe followed the *Erika* incident in December 1999, when the 25-year-old single-hulled oil tanker sank 40 nautical miles off Pointe de Penmarc'h, southern Brittany. At least 248 Great Northern Divers were among 402 divers found oiled, the total number of affected birds identified, dead and alive being 56,727 (Cadiou *et al*.

2003b). In contrast, no divers were found among 915 dead birds identified to species collected on opportunistic beached bird surveys following the grounding of the tanker *Andros Patria*, which released 60,000 tonnes of heavy crude on the northern Galician coast in January 1979 (Sociedade Galega de Historia Natural 1979). In ten weeks following the spill of *Esso Bernicia* (a tanker that released 1,174 tonnes of heavy fuel oil into Sullom Voe, Shetland, December 1978) 3,702 oiled birds were found dead, including 146 Great Northern Divers (Heubeck & Richardson 1980; Foxton & Heubeck 1995). Great Northern Divers were prominent among casualties of the *Amoco Cadiz* spill (another tanker that ran aground off Les Sept-Iles, Brittany, in March 1978) when, of 175 oiled divers collected, at least 76 were Great Northern Divers (Hope Jones *et al*. 1978; Monnat 1978). Had the effect of the *Torrey Canyon* (a tanker that ran aground at Seven Stones reef, Cornwall, in March 1967) been more thoroughly investigated in Brittany, the results would probably have been similar (Bourne *et al*. 1967). This list could be made longer, and does not include the frequent losses to chronic oil pollution, many of which go unnoticed in the absence of regular beached bird surveys in most of Europe. Although these numbers of reported casualties per spill may seem low, in most cases they represented high proportions of local wintering populations. Great Northern Divers winter in relatively low densities off rocky shorelines in most of Western Europe and there is some evidence that individual (adult) wintering birds are site-faithful; once affected by an oil spill, local wintering populations may take a long time to recover (Weir *et al*. 1996; Heubeck 1997).

The total of 60 Great Northern Divers found stranded on the Spanish coastline during the *Prestige* oil spill would imply c. 18–22% of the Spanish wintering population (of 270–340 birds) being killed by the spill (Sandoval & De Souza 2005). Even in the case of higher wintering population estimates, such as c. 500 birds for the whole Iberian Peninsula in the early 1990s (Álvarez Laó 1993), more than 10% of this population would have been killed by the *Prestige* oil spill, as not all casualties would have been found. However, since proper estimates of national wintering numbers are still needed, this proportion affected may need to be re-evaluated. A recent estimate of an average of c. 123 birds wintering in Galicia alone (De Souza *et al*. 2010) suggests the *Prestige* oil spill could have killed at least 43% of this regional population, a not unrealistic figure given the scale, extent, and duration of the pollution.

Two questions are important in each of these major spills: where did the affected birds (indeed the local wintering population) originate, and what was the impact at the population level. Since there has been very little ringing of Great Northern Divers on the likely breeding grounds of European wintering birds (e.g. Lyngs 2003), comparisons of biometrical data collected during spills with those from different breeding areas were presented, which may help identify breeding origins (Heubeck *et al*. 2003; Camphuysen *et al*. 2007). The age structure of the mortality is also important, in order to draw conclusions on the likely timing of any population effects (immediate if mainly adults are affected, delayed if mainly juveniles are involved), while a biased sex ratio could lead to even greater population-level effects than if sexes were affected equally.

The results are inconclusive in determining a possible breeding origin of the *Prestige* Great Northern Divers. The frequency of non-fatal embedded shot among adults (18%, n = 22) discovered by X-ray alone was no different to that among adults oiled in Shetland in 1978/79 (19%, n = 62; Heubeck *et al*. 1993). However, a higher incidence of healed gunshot injuries (34%, n = 77 adults, 3 immatures) was found among birds in the National Museums of Scotland collection by a combination of X-ray, and visual examination during the skinning and skeletonisation process; these were all found dead in Scotland during 1978–1994, and largely comprised those from the *Esso Bernicia* and the 1993 *Braer* (12) oil spills in Shetland (Weir *et al*. 1996). Whether further healed wounds are found in the *Prestige* birds during their eventual curation remains to be seen, but this sample at least indicates that shooting remains a serious issue for the European wintering population of Great Northern Divers, particularly in Greenland where the reported annual bag even in recent years amounted to 153.0 ± 79.3 SD individuals (918 reported killed during 2003–08; Anon. 2009).

Based on curated wing length and the frequency and type of gunshot wounds, Weir *et al*. (1996) suggested that the breeding origin of 69 sexed adults from Scotland (mainly Shetland) was c. 45% Iceland, c. 45% Greenland-Baffin Island, and c. 10% mainland Canada. However, they highlighted problems in making such comparisons of wing lengths, including inherent differences between measurers, feathers being in different states of wear in winter and summer, sexual dimorphism, small sample sizes, and the degree of overlap in wing length between different breeding areas. Greenland and/or Iceland are perhaps the most likely breeding grounds of Spanish and French wintering adults, given the mean and lower limits to the range of wing lengths presented here. A more thorough comparison, based on a larger set of biometrics would be required to develop this further, but without a more extensive reference collection from breeding areas this cannot be achieved as yet; in this context, it would be useful to obtain skins (or at least measurements) of birds hunted legally in Greenland. In any future impact assessments, or studies in which biometrics from breeding birds are collected, standardisation of measurements would be a welcome improvement and we suggest following recommendations in Camphuysen (2007): bill tip to feathers, bill tip to nostril, bill depth at base, bill depth at gonys, tarsus, and wing length; head length in large Gaviidae is often difficult to measure with ordinary callipers. The possibility of using DNA should be considered for future studies, but this would also require a more complete reference collection from individuals from breeding populations than that currently available in the GenBank. Important oil spill derived series of European wintering Great Northern Divers are now held at Amsterdam (*Amoco Cadiz*), Edinburgh (*Esso Bernicia, Braer* and *Sea Empress*), and Santiago de Compostela (*Prestige*).

Finally, it appeared that 7% of Great Northern Divers (two adults and a juvenile, n = 41) collected during the *Prestige* spill had actually drowned, probably in fishing gear. Inshore gill netting increased dramatically in Galicia in the 1990s and is considered the main cause of low adult survival rates in breeding

European Shags *Phalacrocorax aristotelis* (Velando & Freire 2002) and, along with the substitution of vegetal by synthetic nets, the collapse of the Iberian breeding population of Common Guillemots *Uria aalge* (Munilla *et al*. 2007). This study, and an observation of a live Great Northern Diver trapped in a gill net off Razo beach, A Coruña (Pombo 1998), highlights this new threat to the species in the region. Besides the chronic effect of shooting and the acute effect of large oil spills on European wintering populations of Great Northern Diver, accidental drowning in gill nets constitutes an additional anthropogenic mortality that needs serious consideration. We would therefore encourage the re-establishment of a systematic beached bird survey scheme in northwest Spain, perhaps including systematic necropsies of certain vulnerable or protected species, to provide baseline data that would help design effective conservation measures for these birds.

Acknowledgements

Postmortem examinations were part of the impact assessment operation organized by SEO/BirdLife in collaboration with the Faculty of Sciences of A Coruña University. Special thanks are given to the volunteer students that kept the operation working on a daily basis. We also thank the Dirección Xeral de Conservación da Natureza (Xunta de Galicia), and especially Miguel Lorenzo, Vicente Piorno and Marta Prieto, for giving us access to the bodies deposited in rehabilitation centres. Biometrics of breeding populations were derived from skin collections in the American Museum of Natural History (courtesy of Allison V. Andors), Museum of Natural Sciences, National Museums of Canada (Henri Ouellet), Reykjavik Museum (Aevar Petersen) and Zoologisk Museum, Copenhagen (Kaj Kampp). Andrés Barreiro Lois and Ana López Beceiro from the *Rof Codina* Clinical Hospital kindly gave us access to their X-ray facilities. María Isabel Fraga, from the Natural History Museum *Luis Iglesias* of the University of Santiago de Compostela, ensured that all birds examined were retained in Galicia for further study by the scientific community. Bob McGowan and Ævar Petersen kindly reviewed the manuscript, resulting in substantial improvements.

References

Álvarez Laó, C. M. 1993. Censo de aves marinas invernantes en la Península Ibérica 1992. In: Gorospe, G. (ed.) *Aves Marinas Ibéricas '92. Actas IV Congreso del GIAM 1992*: 17–29. Itsas Enara Ornitologi Elkartea, Donosti.

Anonymous 2009. *Piniarneq 2010; aallaaniartunut atassuteqaat pisanillu nalunaarsuiffiit*. Kalaallit Nunaanni Namminersorlutik, Aalisarnermut, Piniarnermut Nunalerinermullu Aqutsisoqarfik, Nuuk. Available online http://dk.nanoq.gl/Emner/Erhverv/Erhvervsomraader/Fangst_og_Jagt/~/media/B956B6000EB34785A567EA688ACF4A96.ashx

Arcos, F. & Solís, L. 1997. 16 años de inspecciones costeras de aves orilladas en Galicia (1980–1996). *Actas Primeras Jornadas Ornitológicas Cantábricas*.

Arcos, F., César, X., Salvadores, R. & Mouriño, J. 2005. *Plan de vigilancia ambiental de detección y evaluación de los efectos del vertido de petróleo sobre aves marinas en Galicia*. Informe final, Convenio de colaboración entre la Fundación Arao y ARCEA Xestión de Recursos Naturais S.L., Vigo.

Bourne, W. R. P., Parrack, J. D. & Potts, G. R. 1967. Birds killed in the Torrey Canyon Disaster. *Nature* 215: 1123–1125.

Cadiou, B., Cam, E., Fortin, M., Monnat, J.-Y., Gélinaud, G., Cabelguen, J. & Le Roch, A. 2003a. *Impact de la marée noire de l'Erika sur les oiseaux marins migrateurs : détermination de l'origine et de la structure des populations par la biométrie*. Rapport Bretagne Vivante-SEPNB, DIREN Bretagne.

Cadiou, B., Chenesseau, D. & Joslain, H. 2003b. *Marée noire de l'Erika - Contribution à l'étude de l'impact sur l'avifaune. Bilan national des échouages et de la mortalité des oiseaux (BNEMO)*. Rapport Bretagne Vivante-SEPNB, LPO Loire-Atlantique, Observatoire des marées noires, DIREN Bretagne.

Camphuysen, C. J. 2007. Gaviidae: Divers or loons. In: Camphuysen, C. J., Bao, R., Nijkamp, H. & Heubeck, M. (eds.) *Handbook on Oil Impact Assessment. Technical document 4.1, Assessing the damage*. Report to DG Environment, European Commission, Royal Netherlands Institute for Sea Research, Texel. Available online www.oiledwildlife.eu.

Camphuysen, C. J., Bao, R., Nijkamp, H. & Heubeck, M. (eds.) 2007. *Handbook on Oil Impact Assessment*. Report to DG Environment, European Commission, Royal Netherlands Institute for Sea Research, Texel. Available online www.oiledwildlife.eu.

Camphuysen, C. J. & van Franeker, J. A. 2007a. Ageing and sexing manual for stranded seabirds. In: Camphuysen, C. J., Bao, R., Nijkamp, H. & Heubeck, M. (eds.) *Handbook on Oil Impact Assessment. Technical document 4.1, Assessing the damage*. Report to DG Environment, European Commission, Royal Netherlands Institute for Sea Research, Texel. Available online www.oiledwildlife.eu.

Camphuysen, C. J. & van Franeker, J. A. 2007b. Condition manual: the physical condition of stranded seabirds. In: Camphuysen, C. J., Bao, R., Nijkamp, H. & Heubeck, M. (eds.) *Handbook on Oil Impact Assessment. Technical document 4.1, Assessing the damage*. Report to DG Environment, European Commission, Royal Netherlands Institute for Sea Research, Texel. Available online www.oiledwildlife.eu.

De Souza, J. A., Barros, A., Sandoval, A. & Bao, R. 2010. A review of the status of Great Northern Diver *Gavia immer* in Galicia, northwest Spain. *Seabird* 23: 76–90.

Evers, D. C. 2004. *Status assessment and conservation plan for the Common Loon (Gavia immer) in North America*. U.S. Fish and Wildlife Service, Hadley, MA.

Foxton, P. & Heubeck, M. 1995. Response to the *Esso Bernicia* oil spill. *Proceedings of the Royal Society of Edinburgh* 103B: 233–245.

García, L., Viada, C., Moreno-Opo, R., Carboneras, C., Alcalde, A. & González, F. 2003. *Impacto de la marea negra del "Prestige" - sobre las aves marinas*. SEO/BirdLife, Madrid.

González, J. J., Viñas, L., Franco M. A., Fumega, J., Soriano, J. A., Grueiro, G., Muniategui, S., López-Mahía, P., Prada, D., Bayona, J. M., Alzaga, R. & Albaigés J. 2006. Spatial and temporal distribution of dissolved/dispersed aromatic hydrocarbons in seawater in the area affected by the *Prestige* oil spill. *Marine Pollution Bulletin* 53: 250–259.

Granadeiro, J. P., Silva, M. A., Fernandes, C. & Reis, A. 1997. Beached bird surveys in Portugal 1990-1996. *Ardeola* 44: 9–17.

Heubeck, M. 1997. The long-term impact of the *Esso Bernicia* oil spill on numbers of Common Loons *Gavia immer* wintering in Shetland, Scotland. In: *Effects of Oil on Wildlife. Fifth International Conference, November 3-6, Monterey, California*: 110–122.

Heubeck, M., Camphuysen, C. J., Bao, R., Humple, D., Sandoval, A., Cadiou, B., Bräger, S. & Thomas, T. 2003. Assessing the impact of major oil spills on seabird populations. *Marine Pollution Bulletin* 46: 900–902.

Heubeck, M. & Richardson, M. G. 1980. Bird mortality following the *Esso Bernicia* oil spill, Shetland, December 1978. *Scottish Birds* 11: 97–108.

Heubeck, M., Richardson, M. G., Lyster, I. H. J. & McGowan, R. Y. 1993. Post-mortem examination of Great Northern Divers *Gavia immer* killed by oil pollution in Shetland, 1979. *Seabird* 15: 53–59.

Hope Jones, P., Monnat, J.-Y., Cadbury, C. J. & Stowe, T. J. 1978. Birds oiled during the *Amoco Cadiz* incident - an interim report. *Marine Pollution Bulletin* 9: 307–310.

Lyngs, P. 2003. Migration and winter ranges of birds in Greenland. An analysis of ringing recoveries. *Dansk Ornitologisk Forenings Tidsskrift* 97: 1–168.

Monnat, J.-Y. 1978. Mortalités d'oiseaux a la suite du naufrage du pétrolier *Amoco Cadiz*. *Penn ar Bed* 11: 339–360.

Munilla, I., Díez, C. & Velando, A. 2007. Are edge bird populations doomed to extinction? A retrospective analysis of the common guillemot collapse in Iberia. *Biological Conservation* 137: 359–371.

Pombo, A. 1998. *Gavia immer*. In: De Souza, J. A., Martínez Lago, M., Monteagudo, A., Pérez Villa, G. & Sandoval, A. (eds.). *IV Anuario das Aves de Galicia 1996*. Grupo Naturalista Hábitat, A Coruña.

Sandoval, A. & De Souza, J. A. 2005. Colimbo Grande, *Gavia immer*. In: Madroño, A., González, C. & Atienza, J. C. (eds.). *Libro Rojo de las Aves de España*: 33–34. Dirección General para la Biodiversidad - SEO/BirdLife, Madrid.

SEEEC. 1998. *The Environmental Impact of the* Sea Empress *Oil Spill*. *Final Report of the Sea Empress Environmental Evaluation Committee*. The Stationary Office, London.

Sociedade Galega de Historia Natural 1979. Informe sobre las aves marinas afectadas por el "Andros Patria" en las costas Gallegas del 3 al 21 de Enero de 1979. *Braña, Revista da Sociedade Galega de Historia Natural* 1: 15–29.

Storer, R. W. 1988. Variation in the Common Loon (*Gavia immer*). In: Strong, P. V. (ed.) *Papers from the 1987 conference on loon research and management*: 54-65. North American Loon Fund, Gifford, NH.

Velando, A. & Freire, J. 2002. Population modelling of European shags (*Phalacrocorax aristotelis*) at their southern limit: conservation implications. *Biological Conservation* 107: 59–69.

Weir, D. N., McGowan, R. Y., Kitchener, A. C., McOrist, S. & Heubeck, M. 1996. Effects of oil spills and shooting on Great Northern Divers which winter in Scotland. *Dansk Ornitologisk Forenings Tidsskrift* 90: 29–33.