# Mass mortality of adult Razorbills *Alca torda* in the Skagerrak and North Sea area, autumn 2007

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**Abstract**

An abnormal movement of auks occurred in the eastern Skagerrak in the third week of September 2007. Large numbers of Razorbills *Alca torda* were reported along the coasts of southeast Norway and western Sweden, many thousands entered Oslofjorden (Norway), and their migration past the northern tip of Denmark into the Kattegat began a month earlier than normal. This preceded heavy mortality of the species that lasted several weeks, and numbered thousands of individuals. Unusually for the time of year, Razorbills greatly outnumbered Common Guillemots *Uria aalge* in reports of live and dead birds. Of 376 Razorbills collected in Oslofjorden, 87% were adults, 9% immatures, and 4% juveniles. Among 326 adults, females (71%) outnumbered males, and 18% showed two white inner bill grooves instead of the normal one. All birds were extremely emaciated and had presumably starved to death. Virtually all adults and older immatures were still regrowing their outer primaries after the post-breeding moult, whereas those of juveniles were fully grown. Most, if not all, belonged to *A. t. islandica* populations breeding in the British Isles, Faroes or Iceland, and few, if any, were from *A. t. torda* populations of the Baltic, Norway or Russia; the 23 ringed birds found in the Skagerrak and Kattegat, mostly adults, all came from Scottish colonies. Population effects at these colonies were not obvious, but adult survival in 2007–08 was low at one colony in eastern Scotland. Long-term beached bird data indicated that while not on the scale of that in the Skagerrak and Kattegat, Razorbill mortality was abnormally high over a wide area of the North Sea in autumn 2007. The age and sex structure of the mortality and its possible causes are discussed.

**Introduction**

The Razorbill *Alca torda* is the least abundant pelagic auk in the Atlantic (Merne & Mitchell 2004). Two subspecies are recognised (Vaurie 1965; Cramp 1985). In the northeast Atlantic, *A. t. torda* breeds from the Baltic Sea along the Norwegian coast to Jan Mayen, Svalbard and Russia, in total 39,000–62,000 pairs, while in the northwest Atlantic, 40,000–43,000 pairs breed from Greenland south through eastern Canada to Maine, USA. All 530,000 pairs of *A. t. islandica* breed in northwest Europe: in France (25 pairs), the British Isles (145,000), Faroes (4,500) and Iceland (380,000). In total, 94% of the world population of 610,000–630,000 pairs breed in the northeast Atlantic (Merne & Mitchell 2004; Barrett *et al.* 2006).

There is a strong clinal increase in the size (wing length and bill depth at gonys) of breeding birds in the northeast Atlantic from southwest to northeast, most strongly correlated with geographical position (coarsely indexed as latitude + longitude) and, to a lesser degree, negatively correlated with sea surface temperatures in the colony area (Barrett *et al.* 1997).

Razorbills have a semi-precocial fledging strategy, the chick leaving the colony at 16–20 days old and 25% of adult body weight (Gaston 1985). It is accompanied by the male parent (Wanless & Harris 1986), which undergoes a full moult of contour and flight feathers at this time; the duration of this period of dependence is uncertain but lasts 'several weeks', or longer (Harris & Birkhead 1985; Jones & Rees 1985). Females continue to visit the breeding site after the male has gone, but then undergo the same moult as males.

The Skagerrak and Kattegat are important wintering areas for Razorbills (Skov *et al.* 1995; Petersen & Nielsen 2011). Birds in the Baltic population are relatively sedentary although a few may move into the Skagerrak and eastern North Sea in winter. Many birds from Russia and northern Norway winter off southern Norway, while some of the large Icelandic population winters in the North Sea (Hudson & Mead 1984; Lyngs & Kampp 1996; Bakken *et al.* 2003; Bønløkke *et al.* 2006; Bakken & Anker-Nilssen in press). Little is known of winter movements of Faroese birds (J.-K. Jensen pers. comm.). Some Razorbills from southwest Britain and Ireland may winter in the North Sea, but these will be greatly outnumbered by birds from eastern England and Scotland (Merne 2002). Migratory distance and the constraint of the post-breeding moult mean birds from different populations may arrive in the eastern North Sea, the Skagerrak and Kattegat at different times of autumn, while successful males, which must accompany the growing young at sea, may arrive later than females, failed breeders and immatures.

In the third week of September 2007, unusual numbers of Razorbills were observed flying into Oslofjorden, Norway. Over the following two weeks, many hundreds of dead and moribund auks were found along the coast of southeast Norway and western Sweden, some also being reported inland (Isaksen & Bredesen 2007). Most were Razorbills, but Common Guillemots *Uria aalge* and a few Atlantic Puffins *Fratercula arctica* were also found. A sample of dead Razorbills from the

Oslofjorden area was stored frozen for later post-mortem examination, while a small sample was also collected at Skagen, Denmark.

We describe the development and extent of the incident using sea-watching and beached bird survey data, and report on post-mortem examinations which provide information on body condition, the probable cause(s) of death, and the age and sex structure of the mortality. Heavy mortality of adults is more likely to have population effects than that of young birds, whose mortality in the first year of life is higher than that of adults (Lyngs 1994; Harris *et al*. 2000). A heavily biased sex ratio in the mortality, especially of adults in monogamous species such as auks, may also be more likely to result in population effects than a balanced one. We also present data on biometrics and ringing recoveries of Razorbills to help indicate breeding origins. Finally, we discuss possible reasons for the incident, and assess its effects at the population level.

**Methods**

Seawatching and other reported observations: In southeast Norway, counts usually lasting about 5–6 hours per day (but with no accurate measurements of effort) were made irregularly from Møringa (59°26'N 10°29'E; see Figure 7) by ornithologists of the Tønsbergfugl group (www.artsobservasjoner.no). Here, Oslofjorden is only 5 km wide and it is possible to count all seabirds entering or leaving the inner fjord. Counts in the second half-year of 2006 and 2007 were made on 29 and 56 days, respectively. Seawatching data from Skagen (57°45'N 10°36'E; see Figure 7), at the northern tip of Denmark, were obtained from the Danish Ornithological Society website (www.dofbasen.dk), mainly of timed counts by Rolf Christensen and Knud Pedersen, but with variable effort within and between days. Observations of auks from southeast Norway and southwest Sweden were extracted from national websites/databases for casual and systematic recording of birds (www.artsobservasjoner.no and www.artportalen.se), operated by the two national species/biodiversity information centres in collaboration with the national ornithological societies.

Collection of corpses and post-mortem examinations: In Norway, 470 Razorbill corpses were collected from beaches in the innermost Oslofjorden (mainly Oslo, Bærum and Nesodden municipalities) and in Skjebergkilen (Sarpsborg municipality) at the southeast entrance to the fjord, between 25 September and 17 October; most were collected in Oslo on 25 and 26 September. Of these, 407 were examined externally and internally using standard procedures and sexed by gonadal inspection (Jones *et al*. 1982; Camphuysen *et al*. 2007), with all biometric measurements taken by TAa. Birds were aged by the number of bill grooves (Jones 1988), and bill depth at gonys was measured to the nearest 0.1 mm. The presence and size (length x width, mm) of the bursa *Fabricii* was determined. As it was suspected that moult was not complete, the outer primaries were removed and examined to determine the state of wing moult. A subset of 77 Razorbills was also sexed using a standard molecular method based on primers P2 and P8 (Griffiths *et al*. 1998). A further 24 birds were examined in Denmark by IKP, 20 that had beached at Skagen from 30 September to 3 October, and four shot under licence at Djursland, eastern Jutland (56°06'N 10°33'E; see Figure 7) on 5 October.

Beached bird surveys (BBS) and ringing recoveries: Five year-round systematic BBS operated around the North Sea in autumn 2007, of which four had at least 10 years of data for September and October. In Germany, 64 km of beach on the East Friesian Islands had been surveyed twice monthly since 1995, while the Dutch BBS in Noord Holland and the Waddensee Islands averaged 101 km per month in 1977–2007. In Scotland, monthly surveys covered 40–50 km in Shetland (from 1979) and Orkney (from 1976), and 25–50 km in northeast England (from 2004). The nature of the coastlines surveyed and variable methodology precluded direct comparison between regions of the numbers of Razorbills found, but within each region their occurrence in September and October 2007 was compared with previous and subsequent years. The national ringing schemes of Norway, Iceland and the UK were contacted for details of ringed Razorbills reported from autumn 2007.

Data processing: Chi-square tests were calculated as described by Zar (1984) in a Microsoft Excel spreadsheet, using the Yates correction for continuity (Yates 1934) for all 2 × 2 and 2 × 1 contingency tables. All other statistical analyses were made using IBM SPSS Statistics (ver. 19.0, SPSS Inc.). Means are presented with their standard errors. Maps were made using Encarta Interactive World Atlas 2000 (Microsoft, Redmond, WA, USA).

## Results

Weather, seawatching, and reported observations: On 14 September 2007 a deep depression moved east between Iceland and Scotland, generating SW gales averaging (mean 10-minute wind speeds) up to 37 knots in the northern (59°50'N 02°20'E) and 28 knots in the central North Sea (56°30'N 03°10'E), changing to NW during the day. The following week was less windy, but September 2007 saw predominantly westerly winds in the central North Sea. On 14 September, meteorological stations on the Norwegian Skagerrak coast recorded mean 10-minute wind speeds from the SW of 36 knots (Svenner 58°58'N 10°09'E) and 35 knots (Færder 59°02'N 10°31'E).

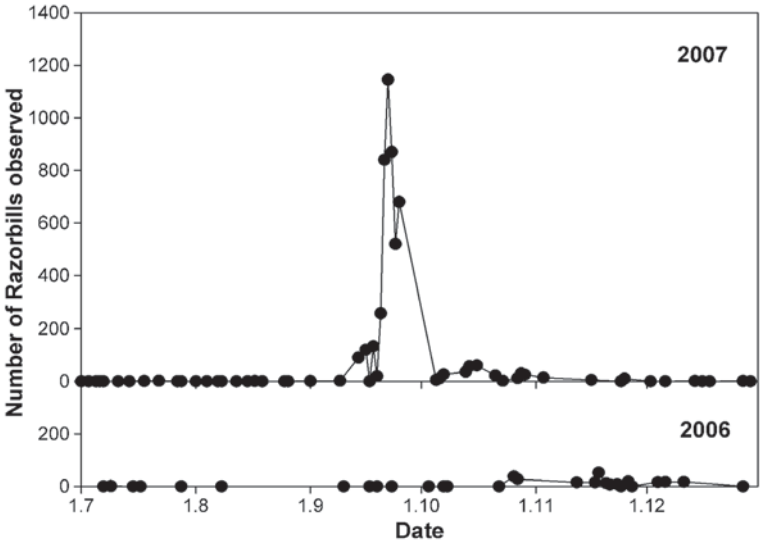


**Figure 1.** Numbers of Razorbills *Alca torda* entering or leaving the inner part of Oslofjorden, as counted from the observation site at Møringa on different days in the second half of 2006 (lower) and 2007 (upper). Counting effort was not standardised. The large movement in late September 2007 was almost exclusively of birds entering the fjord, whereas the small peak a few weeks later was mainly of birds leaving the fjord (E. Soglo pers. comm.).

Predominantly SW winds continued in this area until 25 September, with an overall mean speed of 17 knots at Svenner (www.eklima.no).

The first observation of high numbers of Razorbills moving past Møringa into Oslofjorden in autumn 2007 was of 90 birds on 14 September, and numbers peaked at 1,145 on 22 September; a small peak in mid October was mainly of birds leaving the fjord. In 2006 Razorbill numbers were much lower than in 2007, with most birds in late October–December (Figure 1).

At Skagen, southeasterly movements of Razorbills into the Kattegat normally begin in the third week of October (R. Christensen pers. comm.). In 2005, this was first recorded on 16 October, with 3,183 birds counted, and large movements continued until 23 October, when passage peaked at 14,962; the first dead bird was reported on 8 November. In 2006, the first large movement was also noted on 16 October (1,130 birds) but the main passage occurred on 21 October (7,635) and 22 October (11,444), with the last large movement on 29 October; no dead birds were reported to the end of the year. In 2007, passage was first noted on 17 September (3,164 birds), with high numbers on 20 September (3,029), 21 September (1,554), 22 September (2,597) and 25 September (1,602). Numbers were then much reduced, until 10 October when 3,689 were observed. This began a period of irregular movements that continued into early November, as in previous years. The first dead bird in 2007 was a juvenile on 22 September, but on 29 September there were five moribund adults in Skagen harbour, and 20 found dead on the beach between 30 September and 3 October were sent to IKP. Few Razorbills were recorded at Skagen in September 2008 (peak of 262 on 23 September), but there was a very pronounced peak of migration on 16 and 17 October (7,600 and 1,000, respectively) with high numbers also on 30 October (1,636).

On the west coast of Sweden in 2007, unusually large numbers of Razorbills were also first observed flying south on 17 September (N. Aronsson pers. comm.). Both the numbers of Razorbills and their ratio to Common Guillemots were exceptionally high in southeast Norway and along the Swedish west coast in autumn 2007 (Figure 2). In 2007, about nine times (8.6 and 9.1, respectively) as many Razorbills were observed in these two areas in September as in October. This contrasts with all other years in 2003–11, when considerably more Razorbills were recorded in October than in September (www.artsobservasjoner.no and www.artportalen.se).

Mortality in Oslofjorden and southeast Norway: In the innermost part of Oslofjorden only a few live Razorbills were observed on the morning of 20 September, whereas several hundred were present that afternoon. During the next week, in prevailing southerly winds, an estimated 15,000 auks (mostly Razorbills) passed Møringa, and c. 7,000 of these entered the innermost part of Oslofjorden. Many entered Drammensfjorden and Sandebukta, two western branches of Oslofjorden, and over 100 Razorbills were reported from lakes, rivers and other sites up to 200 km inland (Isaksen & Bredesen 2007; www.artsobservasjoner.no and www.nofoa.no).

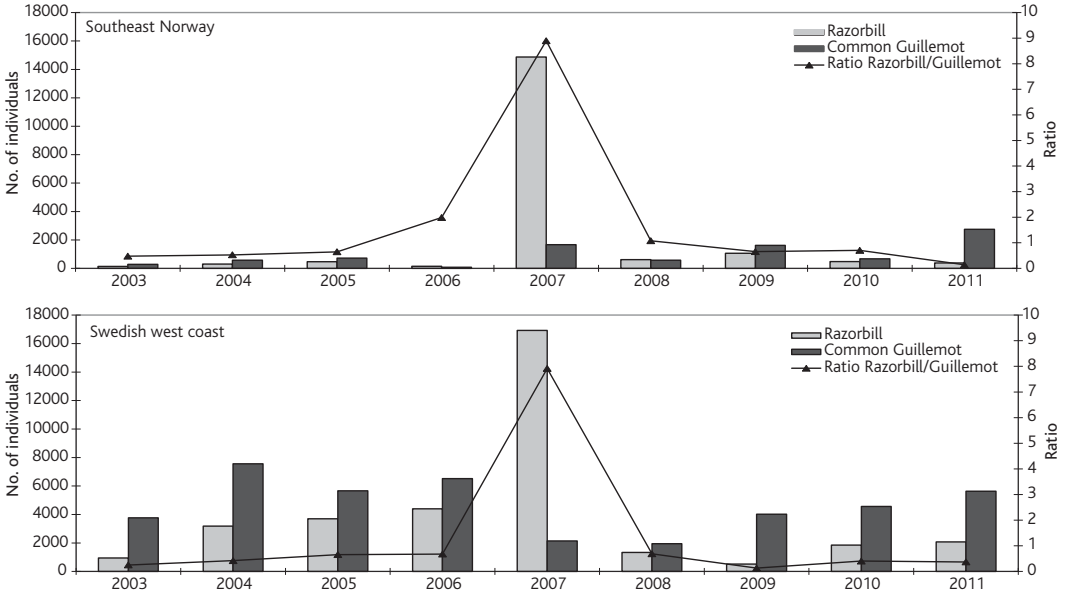


**Figure 2.** The number of Razorbills *Alca torda* and Common Guillemots *Uria aalge* reported from southeast Norway (from Telemark county to the Swedish border) and the west coast of Sweden (from the Norwegian border south to Öresund) in September and October 2003–11. The ratio of Razorbills to Common Guillemots is shown for each year. Data from the national websites www.artsobservasjoner.no and www.artportalen.se. Note that although some pre-2008 data have been included in the Norwegian database, the website itself was not established until 2008. The number of records submitted to both web sites has increased considerably over the period shown, and comparison of absolute numbers between years should be made with caution. The ratio between the species should, however, be comparable between years.

The first dead Razorbills in the innermost part of Oslofjorden were reported on 21 September. From 25 September, c. 440 Razorbills, 50 Common Guillemots and four Atlantic Puffins were collected from this area, but this was clearly only a small fraction of the corpses. Most were collected on 1.6 km of shoreline in Frognerkilen and Bestumkilen in Oslo, two bays in the innermost fjord, where southerly winds washed dead and weakened birds ashore. On 25 and 26 September, c. 350 dead Razorbills were collected, and when the same beaches were searched on 2, 9, 17 and 24 October, 19, 8, 3 and 2 Razorbills were found, respectively. Most had been dead less than a week. The number of live Razorbills in the inner part of the fjord decreased considerably during October, as birds either died or left the fjord again. This all suggests initial, heavy mortality soon after Razorbills entered inner Oslofjorden, and continued mortality among the reduced number that remained there in the following weeks.

Dead Razorbills were also reported from areas further out in the fjord (e.g. 300 along a short stretch of beach at Høysand, Sarpsborg municipality), as well as along the west coast of Sweden and in Denmark. It is difficult to assess the number of Razorbills that died in the wreck, but it must have been at least several thousand, perhaps over 10,000 individuals (Isaksen & Bredesen 2007).

Age and sex distribution of the mortality in Oslofjorden: Most Razorbills, 87.2%, were adult with three or more bill grooves (Table 1). Of these, 18.0% (59/328) had two white inner grooves (Table 1), a frequency twelve times higher than the 1.5% (3/196) found among adults killed in the *Stylis* oiling incident in the Skagerrak in midwinter 1980/81 (Anker-Nilssen *et al*. 1988; TAN unpubl. data; $\chi^2 = 30.3$, df = 1, $P < 0.001$). Twenty-four (41%) of the birds with two white grooves were apparently about to lose the white coating of the outermost white groove (i.e. changing bill type from '2Wb' to '1Wb+1'), and 19 of those classed as having only one white groove had visible traces of white in their innermost black groove suggesting they had recently done so (Figure 3). Thus, the proportion with two white grooves was probably at least 23.8% (78/328) a few weeks earlier.

The sex ratio among adults was heavily skewed (93:233, $\chi^2 = 59.3$, df = 1, $P < 0.001$) with five females for every two males, while the ratio among younger birds did not differ significantly from equality (20:28, $\chi^2 = 1.02$, df = 1, $P = 0.312$) although six of the seven one-year old birds were females (Table 2). Molecular sexing revealed no errors in sexing by gonadal inspection among the 53 birds sexed by both methods, and increased the sample size of sexed and aged birds by 19 (5%). The remaining five birds (all females) sexed by DNA had no bill, making it impossible to assign them to any age category. All 20 birds collected at Skagen were adults, either having three or more bill grooves (19) or well developed gonads (one male); six were males, eight were females, and six were not sexed.

**Figure 3. Left:** The bill of an adult Razorbill *Alca torda* with two white and one black bill grooves. Note the apparent on-going moult of the outermost white groove and the crumbled, broken-up appearance of the inner one on the upper mandible. On the lower mandible, the inner white groove looks much fresher, suggesting it had recently re-grown. **Right:** Shaft end of the longest, fully grown primary of a juvenile Razorbill (left feather) compared to that of an adult bird in the final stage of growth. Note the differences in transparency of the shafts and the shape of their ends (rounded vs. irregular), which were also very different in terms of softness (hard in juveniles, soft in adults). © Tycho Anker-Nilssen.

**Table 1.** Age distribution of 376 Razorbills *Alca torda* found dead in Oslofjorden in autumn 2007, as assessed from the number of grooves on their upper mandibles. The notation format is '***aWb+***' where ***a*** indicates the number of inner white (W) grooves, ***b*** the number of outer black grooves, and (if present) **+** an additional groove that was only partly developed. The presence of cloacal bursa (bursa *Fabricii*), which is typical of immature auks, is also indicated, together with a simple index of its size (length × breadth, $mm^2$).

| Bill type | Putative age | Frequency (%) | With bursa (%) | Mean bursa index (SE) |
|---|---|---|---|---|
| 0W0 | Juvenile, 1st autumn | 15 (4.0) | 15 (100) | 94 (8.7) |
| 1W0, 1W0+ | Immature, 2nd autumn | 7 (1.9) | 6 (86) | 89 (14.9) |
| 1W1, 1W1+ | Immature?, ≥ 3rd autumn | 26 (6.9) | 2 (8) | 98 (29.6) |
| 0W3+[1], 1W2, 1W2+, 1W3 | Adult | 269 (71.5) | 0 (0) | - |
| 2W1, 2W1+, 2W2, 2W2+ | Adult | 59 (15.7) | 0 (0) | - |

[1] One bird, apparently moulted from 1W2+

**Table 2.** Sex distribution of 374 Razorbills *Alca torda* found dead in Oslofjorden in autumn 2007. Sample size is two lower than in Table 1 because the internal organs of two corpses not sexed by DNA had been scavenged before collection.

| Bill type | Putative age | Males: Females | % Males | % Females |
|---|---|---|---|---|
| 0W0 | Juvenile, 1st autumn | 6 : 9 | 40.0 | 60.0 |
| 1W0, 1W0+ | Immature, 2nd autumn | 1 : 6 | 14.3 | 85.7 |
| 1W1, 1W1+ | Immature?, ≥ 3rd autumn | 13 : 13 | 50.0 | 50.0 |
| 0W3+[1], 1W2, 1W2+, 1W3 | Adult | 79 : 189 | 29.5 | 70.5 |
| 2W1, 2W1+, 2W2, 2W2+ | Adult | 14 : 44 | 24.1 | 75.9 |

[1] One bird, apparently moulted from 1W2+

**Table 3.** Mean body mass (g ± 1 SE) of Razorbills *Alca torda* found dead in Oslofjorden in autumn 2007. Sample sizes are slightly lower than in Table 2 because the internal organs of some corpses had been scavenged before collection. The last row refers to formerly unpublished data for birds killed in the *Stylis* oiling incident in the Skagerrak in midwinter 1980/81 (Anker-Nilssen *et al*. 1988), and are the estimated constants of linear regression models between observed mass and degree of oiling (0–100%) in order to remove the effect of oil mass (males: $F_{1,97} = 5.291$, P = 0.024; females: $F_{1,92} = 16.47$, P < 0.001).

| Bill type | Putative age | Males (n) | Females (n) | *t*-test |
|---|---|---|---|---|
| 0W0 | Juvenile, 1st autumn | 385.0 ± 16.5 (6) | 370.6 ± 9.8 (9) | $t = 0.804$, P = 0.436 |
| 1W0, 1W0+ | Immature, 2nd autumn | 440 (1) | 405.8 ± 15.8 (6) | $t = 0.818$, P = 0.451 |
| 1W1, 1W1+ | Immature?, ≥ 3rd autumn | 425.1 ± 9.1 (12) | 378.5 ± 10.0 (12) | $t = 3.451$, P = 0.002 |
| 0W3+[1], 1W2, 1W2+, 1W3 | Adult | 426.4 ± 4.3 (73) | 412.4 ± 2.3 (173) | $t = 3.082$, P = 0.002 |
| 2W1, 2W1+, 2W2, 2W2+ | Adult | 419.8 ± 9.2 (13) | 397.4 ± 5.6 (40) | $t = 2.009$, P = 0.050 |
| *Stylis* incident | Adult | 643.7 ± 13.0 (99) | 586.7 ± 16.4 (94) | $t = 2.005$, P = 0.046 |

[1] One bird, apparently moulted from 1W2+

Body condition and causes of death: The Razorbills collected in Oslofjorden were in very poor condition, with adult males and females respectively weighing 33.9% and 30.2% less than adults killed in the *Stylis* oiling incident in the Skagerrak in December–January 1980/81 (Table 3). All were extremely emaciated and had totally depleted their subcutaneous and internal fat deposits, as had the 20 birds collected at

Skagen. Stomachs inspected were empty, except for a few containing some small spines from sea urchins, an unusual prey for a pelagic diving auk. This strongly suggested that the birds had died from starvation. Except for two birds entangled in fishing line (one of which also had a small hook in its oesophagus), there were no signs that other external factors had affected the birds before they died. Veterinarian examination of nine birds (five females, four males, all adults) at the Norwegian

**Table 4.** Mean wing length (mm ± 1 SE) of Razorbills *Alca torda* found dead in Oslofjorden in autumn 2007.

| Bill type | Putative age | Males (n) | Females (n) |
|---|---|---|---|
| 0W0 | Juvenile, 1st autumn | 187.0 ± 1.0 (6) | 187.6 ± 1.0 (9) |
| 1W0, 1W0+ | Immature, 2nd autumn | 188 (1) | 187.7 ± 2.2 (6) |
| 1W1, 1W1+ | Immature?, ≥ 3rd autumn | 184.2 ± 1.7 (13) | 181.3 ± 3.1 (13) |
| 0W3+[1], 1W2, 1W2+, 1W3 | Adult | 182.7 ± 0.8 (79) | 179.9 ± 0.5 (189) |
| 2W1, 2W1+, 2W2, 2W2+ | Adult | 179.3 ± 2.2 (14) | 178.7 ± 1.2 (44) |

[1] One bird, apparently moulted from 1W2+

**Table 5.** Mean bill depth at gonys (mm ± 1 SE) of Razorbills *Alca torda* found dead in Oslofjorden in autumn 2007.

| Bill type | Putative age | Males (n) | Females (n) | *t*-test |
|---|---|---|---|---|
| 0W0 | Juvenile, 1st autumn | 13.73 ± 0.35 (6) | 14.33 ± 0.49 (9) | $t = 0.890$, $P = 0.340$ |
| 1W0, 1W0+ | Immature, 2nd autumn | 19.7 (1) | 16.33 ± 0.96 (6) | $t = 1.327$, $P = 0.242$ |
| 1W1, 1W1+ | Immature?, ≥ 3rd autumn | 19.25 ± 0.23 (13) | 18.12 ± 0.16 (13) | $t = 4.081$, $P < 0.001$ |
| 0W3+[1], 1W2, 1W2+, 1W3 | Adult | 19.77 ± 0.08 (79) | 19.17 ± 0.05 (188) | $t = 6.488$, $P < 0.001$ |
| 2W1, 2W1+, 2W2, 2W2+ | Adult | 20.08 ± 0.24 (14) | 19.03 ± 0.10 (43) | $t = 4.097$, $P = 0.001$ |

[1] One bird, apparently moulted from 1W2+

**Table 6.** Mean wing length and bill depth at gonys (both in mm ± 1 SE) of adult Razorbills *Alca torda* measured in various breeding colonies across the NE Atlantic region. Numbers refer to the map in Figure 5.

| Colony | Wing (n) | Gonys (n) | Source |
|---|---|---|---|
| 1. Seven Islands, Russia 68°49'N 37°20'E | 211.9 ± 1.6 (17) | 23.9 ± 0.3 (17) | Barrett *et al*. 1997 |
| 2. Hornøya, Norway 70°23'N 31°09'E | 212.7 ± 0.5 (≥139) | 23.3 ± 0.1 (≥139) | Barrett *et al*. 1997 |
| 3. Loppa, Norway 70°22'N 21°25'E | 214.1 ± 1.4 (7) | 23.6 ± 0.3 (7) | Barrett *et al*. 1997 |
| 4. Bleiksøya, Norway 69°17'N 15°52'E | 202.6 ± 1.2 (57–58) | 21.9 ± 0.2 (57–58) | Barrett *et al*. 1997 |
| 5. Røst, Norway 67°26'N 11°52'E | 208.6 ± 0.9 (41) | 22.2 ± 0.2 (41) | Barrett *et al*. 1997 |
| 6. Runde, Norway 62°25'N 05°38'E | 201.8 ± 1.4 (21) | 21.1 ± 0.2 (21) | Barrett *et al*. 1997 |
| 7. Stora Karlsö, Sweden 57°30'N 18°30'E | 208.6 ± 1.2 (17)* | 24.3 ± 0.2 (17)* | Salomonsen 1944 |
| 8. Græsholmen, Denmark 55°19'N 15°11'E | 208.0 ± ? (30) | 23.3 ± ? (30) | Jones 1990 |
| 9. Grimsey, Iceland 66°30'N 18°00'W | 196.1 ± 0.7 (36) | 20.9 ± 0.1 (37) | Jones 1990 |
| 10. Foula, Scotland 60°08'N 02°07'W | 197.8 ± 0.5 (62) | 20.6 ± 0.2 (31) | Furness 1983 |
| 11. Shiant Islands, Scotland 57°54'N 06°22'W | 197.2 ± 0.8 (31) | | Jones 1990 |
| 12. Canna, Scotland 57°03'N 06°33'W | 198.9 ± 0.7 (31) | | Jones 1990 |
| 13. Isle of May, Scotland 56°11'N 02°33'W | 195.0 ± 0.6 (78) | | Jones 1990 |
| 14. Bardsey, Wales 52°48'N 04°48'W | 197.8 ± 0.5 (66) | 20.6 ± 0.2 (31) | Jones 1990 |
| 15. Great Saltee, Ireland 52°07'N 06°42'W | 198.3 ± 0.7 (34) | 20.7 ± 0.1 (31) | Jones 1990 |
| 16. Kerry Islands, Ireland 52°06'N 10°24'W | 194.2 ± 0.9 (27) | | Jones 1990 |

*From museum specimens, corrected for shrinkage by adding 2.0 mm to individual wing lengths and 0.5 mm to gonys depths (Barrett *et al*. 1997).

Veterinary Institute in Oslo also concluded that death most probably was due to starvation. Three of these had a moderate number of nematodes in the stomach and one had a large number of platyhelminthes in the intestine (K. Handeland *in litt.*). A sample of 25 Razorbills picked up on the west coast of Sweden weighed on average 448 ± 9.0 g and probably died of starvation (E. Ågren *in litt.*). The four birds shot off east Jutland on 5 October were apparently in good condition, with stomachs full of fish and pectoral muscles almost twice as heavy (58.2 ± 2.5 g) as those beached at Skagen (30.3 ± 1.4 g, n = 14; $t$ = -9.674, df = 16, P < 0.001).

Population origin(s): Anker-Nilssen *et al*. (1988) used wing length and bill depth at gonys to distinguish between the two subspecies, whereas Barrett *et al*. (1997) found that the same two measurements independently also described the clinal size variation from southwest to northeast across the species' breeding range in the northeast Atlantic. The corresponding measurements of the birds in our sample are presented in Tables 4–5 and Figure 4.

All juveniles appeared to have completely grown their primaries, but only six (86%) of the seven one-year old birds, four (15%) of the 22 older immatures, and one of 327 adults had fully completed their primary moult (Figure 3). This explains why adult wing lengths (mean 180.4 ± 7.4 mm, n = 327) were, on average, 6.9 mm *shorter* than those of juveniles (mean 187.3 ± 0.7 mm, n = 15), whereas in a large sample from the same area in December–January 1980/81 the respective differences were 8.8 mm and 7.3 mm *longer* for the *islandica* and *torda* components (Anker-Nilssen *et al*. 1988).

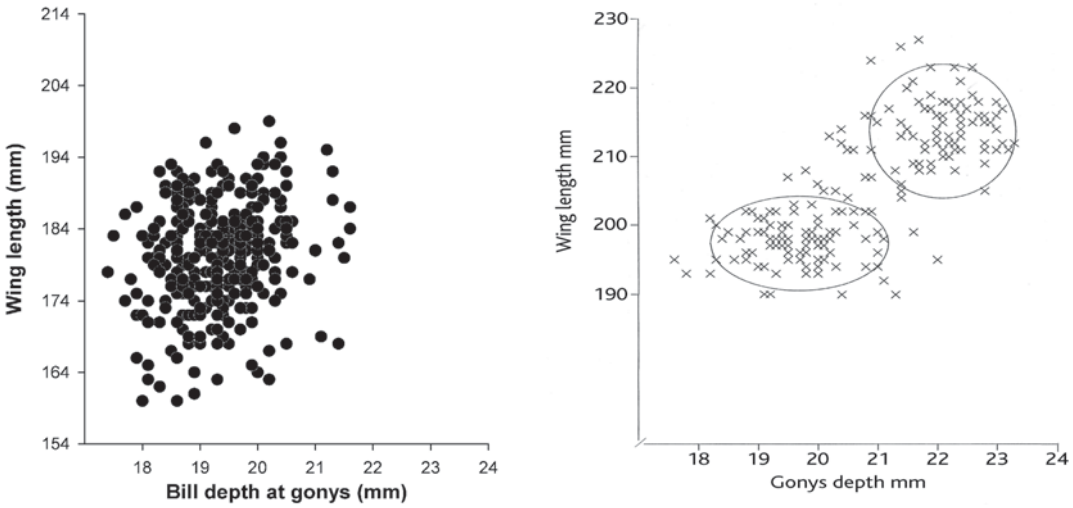


**Figure 4.** The relationship between bill depth at gonys and wing length of adult Razorbills *Alca torda* found dead in the Oslofjorden area in autumn 2007 (left graph) compared with the similar distribution of birds in the Skagerrak sample of winter 1980/81 (right graph); in the right graph, the 95% confidence ellipses for assumed *A. t. islandica* (lower left) and *A. t. torda* (upper right) are shown (from Anker-Nilssen *et al*. 1988). To help comparison, the graphs have been sized to approximately the same scale, with the wing length axis on the left graph aligned 16 mm shorter than that on the right graph (see explanation in the text).

Assuming that adults and juveniles came from the same breeding areas, which is at least probable for males since they accompany their young at sea for many weeks after leaving the colony, and considering the relatively short wings of juveniles, this indicates that the final mean wing length of these adults after completed moult should have been c. 15.7 mm (6.9 + 8.8, see above) longer than at the time of measurement, i.e. close to 196 mm, which is approximately the same length as birds breeding in the British Isles and in Iceland. Data on bill depth at gonys also indicate such an origin (Table 6, Figure 5; cf Jones 1990; Barrett *et al*. 1997). Very few, if any, birds from the longer-winged and deeper-billed *torda* populations breeding along the Norwegian coast and in the Barents Sea were present in the sample (cf Figure 4), either because they were not affected to the same degree or were not present in the area at the time. If the latter was true, this is in sharp contrast to the two-clustered composition of the mid winter population in the area 27 years earlier.

September and October beached bird surveys (BBS): On the German East Friesian Islands, the closest systematic BBS to the Skagerrak, a total of 17 Razorbills was found dead in 1995–2006 (annual mean: 0.06 ± 0.02; all means are given as corpses per 10 km). The 44 birds (1.72) found in September (14) and October (30) 2007 were 29 times this previous seasonal mean (Figure 6); only two birds were found in September or October 2008–10, both in October 2009. In Noord Holland and the Wadden Sea Islands, 18 Razorbills were found in 1977–2002 (annual mean: 0.10 ± 0.03). Numbers increased slightly in 2003–06 (16 birds, annual mean: 0.17 ± 0.08), and the 26 found in 2007 (1.53) were 14 times the annual mean for 1977–2006 (0.11 ± 0.02); one was found in 2008 but none in 2009 or 2010.

In Shetland, 58 Razorbills were found in 1979–2003 (annual mean: 0.24 ± 0.04), with increased numbers in 2004–06 (annual mean: 1.14 ± 0.27). The 24 recorded in 2007 (2.38) were ten times the mean for 1979–2003, and six times the mean for 1979–2006 (0.38 ± 0.09). Only two birds were found in 2008, and singles in 2009 and 2010. Razorbill numbers in Orkney were also low in 1976–2003 (annual mean: 0.41 ± 0.05), but also increased in 2004 and 2005. The 65 birds recorded on the October 2007 survey did not include 46 birds removed from one beach since the September survey; the incidence of dead Razorbills in Orkney in 2007 was therefore 18–30 times the average for 1976–2003. Just one bird was found in 2008, two in 2009 and three in 2010. In northeast England, the 13 Razorbills

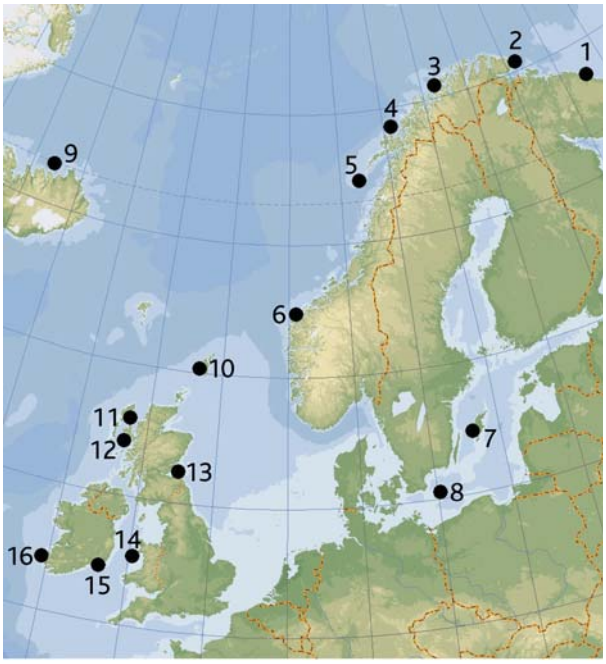


**Figure 5.** Map showing the locations of colonies listed in Table 6.

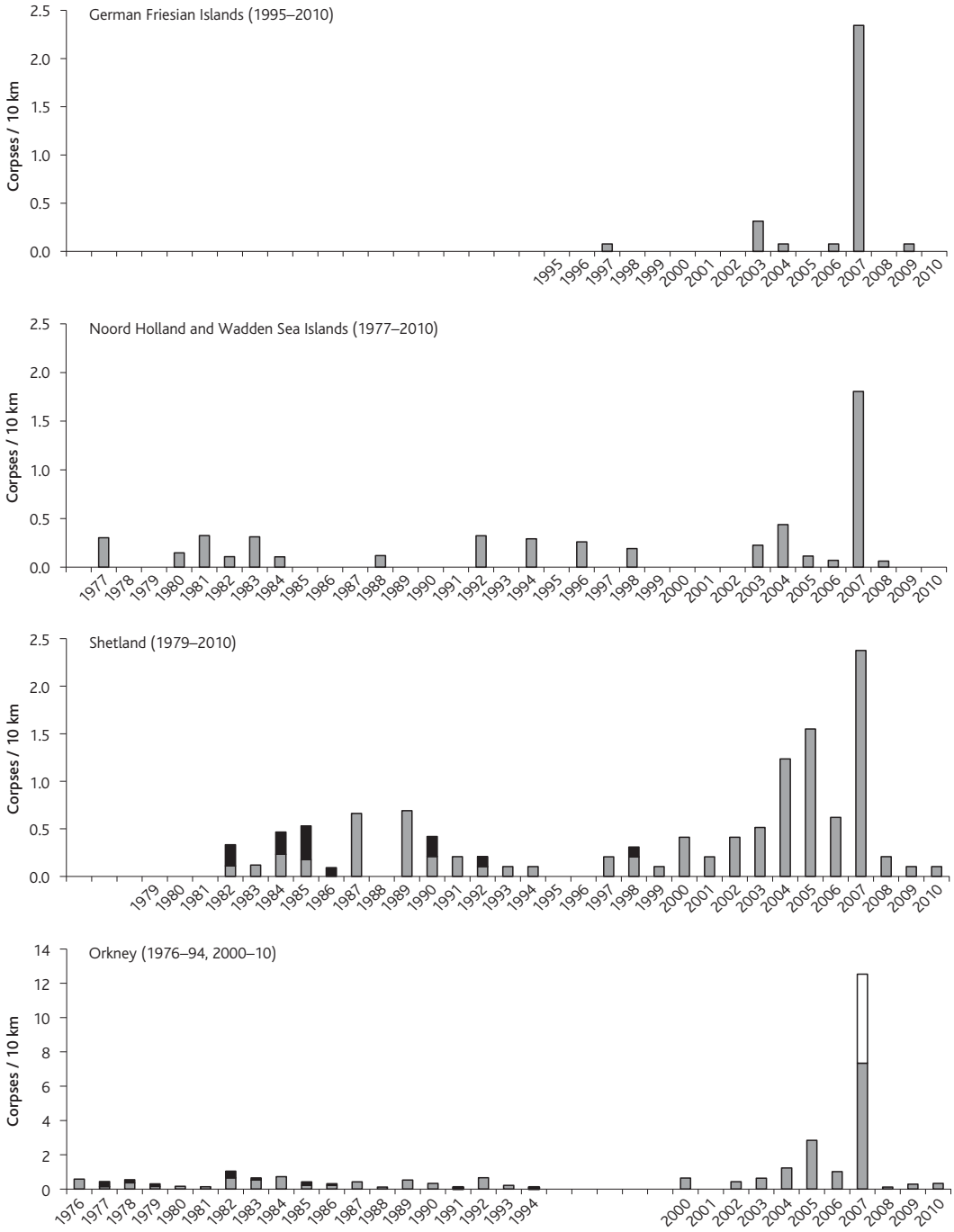


**Figure 6.** The number of Razorbill *Alca torda* corpses found per 10 km surveyed in September and October on standard beached birds surveys in four North Sea Regions. Data for Shetland and Orkney are split into oiled (black) and unoiled (grey) birds, those for Germany and the Netherlands include all birds. In Orkney in 2007, some birds were removed from a survey beach between the September and October standard surveys (white). Years without an x-axis label are missing data.

found in 2007 (1.32) were similar to the numbers found in 2004 (12, 2.16), 2005 (7, 0.94) and 2006 (10, 1.47). In accordance with the other BBS, only one Razorbill was found in 2008–10, in October 2010. Although numbers found dead on these systematic BBS were small compared to the mortality in the Skagerrak (including Oslofjorden) and Kattegat, they do indicate highly elevated mortality of Razorbills over a wide area of the North Sea in autumn 2007.

Further south in England, reports of 'hundreds' of dead Common Guillemots and Razorbills on the Norfolk coast in early October included few details of species ratio or actual numbers, although some photographs suggested many were Common Guillemots in their second winter or older (based on emails forwarded from RSPB Eastern England Office). No unusual numbers of Razorbills were reported from systematic BBS in Belgium in September or October 2007 (E. Stienen pers. comm.).

Ringing recoveries: Compared to mean values for 2002–06 the ringing scheme for Britain and Ireland reported an 86% increase in Razorbill recoveries in 2007 (117; Coffait *et al*. 2008). The 24 recoveries in September and October 2007 were all in the North Sea, Skagerrak and Kattegat (Table 7; Figure 7), and all had been ringed at colonies in Scotland, 14 in Orkney and Shetland, six in western Scotland, and four in southeast Scotland. Only 11 were ringed as chicks and thus of known age when they died; the youngest bird was a second-winter, 14 were at least ten years old and the oldest, ringed when full-grown in 1982, was at least 26 years old. Ten of the 11 recoveries in Norway (including one in November) were from the Oslofjorden area, the other being 148 km inland north of Oslo. Seven of the eight recoveries on the Swedish west coast were from 22 September to 3 October, and there were four recoveries in Denmark (including one in November), and singles in northeast England, eastern Scotland and Orkney. No recoveries of Icelandic- or Norwegian-ringed Razorbills were reported from autumn 2007 (A. Petersen *in litt.*, A. T. Mjøs pers. comm.).

**Discussion**

Comparisons with previous mortalities: Wrecks of emaciated and presumably starved auks have been recorded in the North Sea area and on western coasts of the British Isles, mostly in mid to late winter, but a combination of factors made that in the Skagerrak in 2007 unusual: (1) the early autumn timing, (2) the preponderance of Razorbills over Common Guillemots, and (3) the preponderance of adults over immatures and juveniles.

Post-breeding wrecks of auks have been recorded infrequently in the northeast Atlantic. The autumn 1969 wreck in the Irish Sea commenced in the second half of September and mainly involved juvenile Common Guillemots and Razorbills, but also adults of both species still in wing moult (Holdgate 1971). More recent wrecks on the west coast of Scotland in July 1985 (Craik 1992) and August 2004 (Swann 2004) were assumed to have been triggered by sudden, relatively localised food shortage and in the latter case, exacerbated by bad weather. In both incidents Common Guillemots greatly outnumbered Razorbills, in proportions broadly reflecting their regional breeding populations.

**Table 7.** Details of all Razorbill *Alca torda* ringing recoveries in September, October and November 2007 reported to the British and Irish ringing scheme. Except for birds ringed as pullus or adult, ages are given in years (y), not calendar years. Numbers refer to the map in Figure 7.

| Ringing colony location/ Year, age | Recovered 2007; date, location | Age |
|---|---|---|
| 1. Craigleith, Firth of Forth 56°04'N 02°43'W | | |
| 2005, pullus | 11/10, Oslofjorden, 59°53'N 10°38'E, Norway | 2y |
| 2. Isle of May, Firth of Forth 56°11'N 02°33'W | | |
| 1991, adult | 1/10, NW Kattegat, 56°37'N 10°20'E, Denmark | 19y+ |
| 1993, adult | 22/9, NE Kattegat, 57°30'N 12°00'E, Sweden | 18y+ |
| 2000, adult | 25/9, Oslofjorden, 59°55'N 10°41'E, Norway | 10y+ |
| 3. Berriedale, Caithness 58°10'N 03°31'W | | |
| 2002, 1y+ | 2/10, E Skagerrak, 58°34'N 11°16'E, Sweden | 6y+ |
| 4. Swona, Orkney 58°44'N 03°04'W | | |
| 1990, pullus | 30/9, NE England, 54°55'N 01°23'W, United Kingdom | 17y |
| 2000, 2y+ | 2/10, NE Kattegat, 57°03'N, 12°17'E, Sweden | 8y+ |
| 2003, pullus | 25/9, Oslofjorden, 59°58'N 10°38'E, Norway | 5y |
| 5. Fair Isle, Shetland 59°32'N 01°38'W | | |
| 1992, pullus | 17/11, Oslofjorden, 59°53'N 10°41'E, Norway | 15y |
| 1994, pullus | 24/9, Gausdal, 61°10'N 09°56'E, Norway | 13y |
| 1995, 2y+ | 28/10, NE Kattegat, 57°11'N 12°13'E, Sweden | 13y+ |
| 1998, pullus | 18/10, Oslofjorden, 59°48'N 10°36'E, Norway | 9y |
| 1998, 2y+ | 30/9, SE Kattegat, 56°53'N 12°30'E, Sweden | 11y+ |
| 1999, pullus | 23/9, E Skagerrak, 58°29'N 11°20'E, Sweden | 8y |
| 1999, pullus | 1/10, Oslofjorden, 59°25'N 10°30'E, Norway | 8y |
| 2005, pullus | 23/9, Oslofjorden, 59°35'N 10°35'E, Norway | 2y |
| 2006, pullus | 2/10, SE Kattegat, 56°07'N 12°37'E, Sweden | 1y |
| 6. Sule Skerry, Orkney 59°05'N 04°24'W | | |
| 1989, 2y+ | 5/11, SW Kattegat, 55°27'N 10°40'E, Denmark | 19y+ |
| 1996, 2y+ | 3/10, NE Kattegat, 57°27'N 12°04'E, Sweden | 12y+ |
| 7. Faraid Head, Highland 58°36'N 04°47'W | | |
| 2005, 2y+ | 22/9, Oslofjorden, 59°45'N 10°17'E, Norway | 4y+ |
| 8. Shiants, Western Isles 57°54'N 06°22'W | | |
| 1982, 1y+ | 25/9, Oslofjorden, 59°55'N 10°41'E, Norway | 26y+ |
| 1989, 1y+ | 23/9, S Skagerrak, 57°33'N 09°55'E, Denmark | 19y+ |
| 2006, 2y+ | 2/10, Oslofjorden, 59°54'N 10°45'E, Norway | 2y+ |
| 2006, 2y+ | 9/9, E Scotland, 56°45'N 02°26'W, United Kingdom | 2y+ |
| 9. Canna, Highland 57°03'N 06°33'W | | |
| 1991, pullus | 17/10, SW Kattegat, 55°10'N 11°00'E, Denmark | 16y |
| 10. Treshnish Isles, Strathclyde 56°29'N 06°24'W | | |
| 1989, 1y+ | 26/9, Orkney, 58°52'N 02°55'W, United Kingdom | 18y+ |

Late autumn and winter wrecks in the North Sea region have involved variable proportions and ages of Razorbills and Common Guillemots (Underwood & Stowe 1984; Heubeck *et al*. 1992; Aarvak & Anker-Nilssen 2005), but prior to 2007 the only large-scale event where Razorbills predominated was in the North Sea in February and early March 1983, when they outnumbered Common Guillemots in most regions of eastern Britain (in total, 1.88:1, n = 28,156; Underwood & Stowe 1984). In a sample of 724 Razorbills from eastern Britain aged by bill grooves, adults (64%) outnumbered immatures (23%) and first-winter birds (13%) (Jones *et al*. 1985). Compared to the 2007 incident, the age distribution of these birds was less skewed towards adults ($\chi^2$ = 66.7, df = 2, P < 0.0001) and the 60.8% females (281/462) among adults was lower ($\chi^2$ = 9.09, df = 1, P = 0.003), but the sex ratios for first-winter (49 males, 46 females) or immature (66 males, 101 females) birds did not differ much (first-winter: $\chi^2$ = 0.309, df = 1, P = 0.578; immatures $\chi^2$ = 0.014, df = 1, P = 0.906). Ringing recoveries also suggested all age classes of Razorbill were equally affected (Hudson & Mead 1984); most came from colonies in western Scotland (55%, n = 134) and Orkney and Shetland (33%), but two had been ringed in northern Norway and 11 (8%) in Iceland, the first direct evidence that Icelandic birds wintered in the North Sea. The wreck was believed to have been due to a combination of adverse weather and reduced prey stocks offshore (in particular Sprat *Sprattus sprattus*) in the north-western North Sea, with onshore gales having driven Razorbills into inshore waters with unfavourable feeding opportunities earlier than Common Guillemots (Blake 1984).

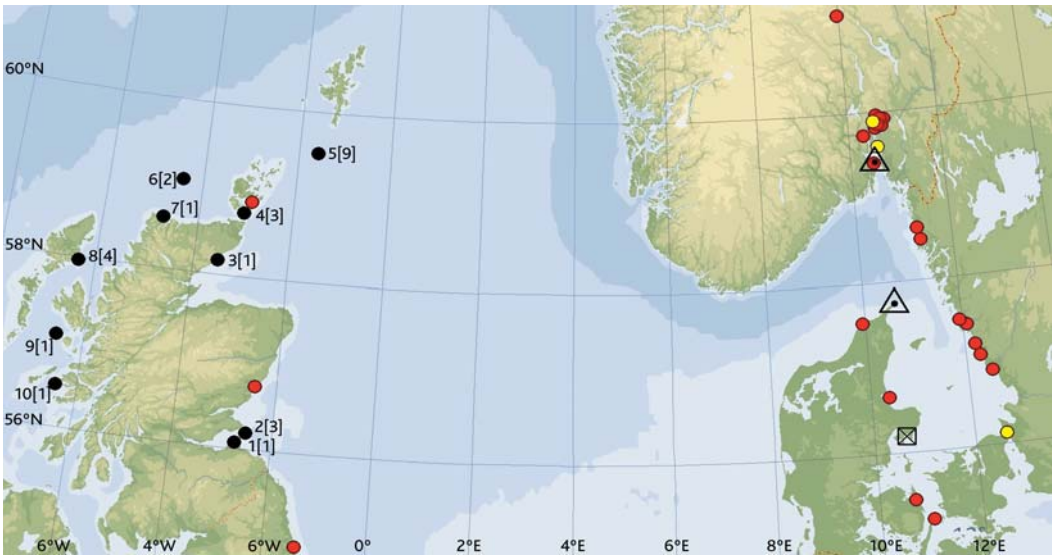


**Figure 7.** Map showing the finding locations of ringed adult (5+ years old, 23 red dots) and immature (2–3 years old, 3 yellow dots) Razorbills *Alca torda* recovered in the North Sea region in autumn 2007 and the location of their colonies of origin (10 black dots) with the number of recoveries indicated for each colony (see Table 7 for details). The positions of the two observation sites (Møringa, Oslofjorden, Norway; Skagen, Denmark) for counts of passing birds are indicated by dotted triangles, whereas the location where four Razorbills were collected at sea (Djursland, Denmark) is shown with a crossed square.

The high proportion of females (71.5%, n = 326) in the sample of adults from the 2007 Skagerrak mortality contrasts with that found in the 1981 oiling incident (49.0%, n = 198; Anker-Nilssen *et al*. 1988). This could suggest a higher proportion of females dying from poor condition brought about by environmental stress, rather than a skewed sex ratio among adults in the area at the time, as an oil spill is more likely to affect individuals present irrespective of sex or age. However, the wreck of 2007 occurred 3–4 months earlier than the 1981 incident, and adult females may reach the Skagerrak earlier in autumn than males, which accompany the flightless young after leaving the colony (note that the sex ratio in immatures and juveniles combined was not skewed).

The proportion of juvenile and immature Razorbills in the autumn 2007 wreck (12.8%; 48/376) was lower than in winter 1980/81 (33.6%, 100/298; $\chi^2 = 40.73$, $P < 0.0001$). As with adult males, it may be that many juveniles had not reached the Skagerrak by the time of the wreck. The ratio of juveniles to adult males in 2007 (c. 15:93 = 0.16) was probably lower than in 1981 (c. 26:101 = 0.26). Although these ratios did not differ significantly ($\chi^2 = 1.329$, df = 1, $P = 0.249$), the difference in timing of the two events and the lower survival of juveniles than of adults (Lyngs 1994; Harris *et al*. 2000) suggest the actual ratios of September 1980 and 2007 did differ. Such differences may also reflect reduced Razorbill breeding success in 2004–07 at some colonies from which birds migrate to the Skagerrak, resulting in a different age structure of the post-breeding population in autumn 2007 than in winter 1980/81. This was particularly the case at monitored colonies in Shetland (Fair Isle) and Orkney (Papa Westray) where Razorbill breeding success in 2007 was zero (Shaw *et al*. 2007; R. Mavor pers. comm.).

The 2007 Skagerrak incident appears to have been the first instance where a large sample of adult and immature Razorbills dying in early autumn has been examined. If the proportion of adults with two white bill grooves was already declining to the observed 18.0% (59/328) as a result of active moult or wear, the difference in sampling time could explain why it was much higher than the corresponding proportion of 1.5% (3/196) in the sample from the Skagerrak in mid winter 1980/81. Lavers *et al*. (2005) reported two white bill grooves in 10 (34%) of 29 adult Razorbills shot or drowned in Newfoundland between August and November, but we found no mention of two white grooves in examinations of birds from other wrecks or oil spills, which either occurred later in winter or involved few adults, nor from studies of adults at colonies.

The lack of a bursa in any adults differed from the corresponding 5% among 196 adults oiled in the Skagerrak in winter 1980/81 (Fisher's exact test, $P < 0.001$; Anker-Nilssen *et al*. 1988), and bursa size (when present) in younger birds was much smaller than in the corresponding age groups in that study (size indices of 200, 143 and 107 for groove types 0W0, 1W0 and 1W1, respectively; Table 1). This suggests that extreme emaciation had affected both the size and presence of this organ, and calls for caution when using the bursa to age starved auks, especially in species such as Common Guillemots where the putative age of immatures cannot be readily assessed from external features such as bill grooves.

Population effects: Razorbills are difficult to census accurately since many breed in rock crevices or among boulders and variation in repeated counts of individuals is relatively high, and the ability to detect significant population change at colonies correspondingly low (Richardson *et al*. 1981; Harris & Wanless 1989). Numbers of actual breeding pairs are only monitored at a few colonies, and adult survival rates at only two that may contribute significant numbers of Razorbills to the Skagerrak autumn and winter population (Isle of May in the UK, Hornøya in Norway).

At the time of the February 1983 wreck, auk populations in eastern Britain were increasing and, where known, Razorbill productivity and adult survival were high (Harris & Wanless 1984). On the Isle of May, 1982–83 survival of adult Razorbills was low (68%, 19 returns of 28 colour-ringed birds); there was a non-significant 12% decrease in total numbers at the colony in 1983, but breeding numbers remained stable, presumably because recruits from a pool of non-breeders filled vacant sites and replaced missing mates (Harris & Wanless 1984). This may also have occurred on Fair Isle in 1983, which lost at least 33 ringed adults in the wreck; there was a 42% reduction in numbers in population count plots, but little evidence of decreased breeding numbers (Riddiford 1984).

Adult wing lengths (corrected for active moult) and bill depths at gonys suggest a predominantly British/Faroese/Icelandic origin for Razorbills involved in the 2007 Skagerrak wreck, and while ringing recoveries further indicate a largely British (Scottish) origin, the presence of Faroese or Icelandic birds cannot be ruled out because of the low ringing effort at colonies there. Within this geographic range, annual monitoring at colonies is most intensive in the UK, and particularly in Scotland.

Any assessment of the impact of the 2007 wreck at the population level should take into account the fact that the Scottish Razorbill population had been declining for a number of years (Figure 8), and that the timing and extent of that decline varied regionally (Mavor *et al*. 2008). In southeast Scotland, the adult Razorbill return rate on the Isle of May from 2007 to 2008 (69%) was markedly lower than the long-term


**Figure 8.** Trend in abundance index (solid line) of Razorbills *Alca torda* at breeding colonies in Scotland, 1986–2010, with 95% confidence limits (dotted lines). Based on Seabird Monitoring Programme data from 26 colonies with 10 or more years of counts of individual birds (courtesy of JNCC Seabird Monitoring Programme http://jncc.defra.gov.uk/page-1550).

average, but the parallel reduction in breeding pairs was only 10% in plots, and 5% in the whole-island census of individuals (Alampo & Lamont 2008; Newell *et al*. 2008). Numbers had been declining since 2005 on other Firth of Forth islands, where 16% fewer birds were counted in 2008 than in 2007 (Bruce 2009). In Shetland, numbers of individuals in study plots at seven colonies had declined since 2000 (Mavor *et al*. 2008), and were particularly low in 2007, when some non-breeding and/or low colony attendance was suspected (Seabird Group 2007; Shaw *et al*. 2007); 2007–08 changes in numbers ranged from zero to -9% at the three colonies where sample counts exceeded 25 birds, with 17% fewer pairs in the only breeding success plot, on Fair Isle (Seabird Group 2008; Shaw 2008). On the west coast of Scotland, Razorbill numbers on Canna were 40% lower in 2008 than in 2007 (Swann 2008). In summary, while the mortality of adults in the Skagerrak in autumn 2007 almost certainly contributed to an estimated 33% decrease in the Scottish Razorbill population between 2005 and 2009 (Figure 8), it is difficult to quantify this further. Few Razorbills breeding in southwest Britain or Ireland were likely to have been in the eastern North Sea in autumn 2007 (Merne 2002; Bakken & Anker-Nilssen in press), and there was little apparent change in numbers at colonies in Wales in 2008, nor any marked reduction in adult survival on Skomer (JNCC 2011).

On Sklinna, the southernmost colony monitored in Norway, Razorbill breeding numbers dropped by 32% between 2007 and 2008 (Anker-Nilssen 2009), but the concurrent changes in colonies further north were inconsistent, and the study plots for the species contain relatively few birds and are not necessarily representative of the population on a larger scale (Lorentsen & Christensen-Dalsgaard 2009).

Possible causes of the 2007 wreck: The 2007 breeding season was particularly poor for a range of pelagic seabird species in western Norway (Anker-Nilssen *et al*. 2008), Faroes and northern and eastern Scotland (Seabird Group 2007), although there are few definitive data for Razorbills, which in Scotland experienced moderate breeding success on the Isle of May (Newell *et al*. 2007), but very low success in Orkney and Shetland (Shaw *et al*. 2007). Breeding success of Norwegian Razorbills in 2007 was moderate on Røst (Lofoten Islands) in the Norwegian Sea, and poor and moderate respectively on Hjelmsøya (near the North Cape) and Hornøya (Varangerfjorden) in the Barents Sea (Anker-Nilssen *et al*. 2008). Whether (presumed) poor feeding conditions in the northern North Sea persisted into August and early September 2007, or whether this had any influence on the timing or duration of the post-breeding moult is unknown. However, the abnormal movement of Razorbills into Oslofjorden and the early onset of passage into the Kattegat, largely involving adults still growing their outer primaries, suggest they were actively seeking more favourable foraging opportunities as soon as they were able to do so. Presumably, these did not exist (or were insufficient) in Oslofjorden, or birds were already in too poor a condition to exploit them. The condition of the birds shot off east Jutland suggests some entering the Kattegat early were able to feed normally, but the timing of recoveries and the ages of ringed birds found there indicate that even experienced adult Razorbills became moribund rapidly and died.

The preponderance of Razorbills over Common Guillemots in the 2007 wreck may have been due to differences in their respective distributions in the North Sea at the time, in diet and foraging capabilities, or the timing of moult. At-sea surveys in the Dutch sector of the North Sea in the last week of September 2007 recorded unusual numbers of Razorbills (mostly with a white groove and deep bill), outnumbering Common Guillemots by 1.5:1, with many of the latter still visibly in wing moult, which was considered late (C. J. Camphuysen pers. comm.). Unusual numbers of Atlantic Puffins (mostly adults) began to wash ashore in Orkney and Shetland in October 2007, as Razorbill numbers on beaches declined (Heubeck *et al*. 2009), suggesting that feeding conditions remained poor for pelagic auks in the far north-western North Sea well into autumn that year.

Beached bird surveys in Orkney, Shetland and The Netherlands recorded slightly elevated numbers of dead Razorbills in early autumn in the three years prior to the 2007 wreck, but not after 2007 (Figure 5), while adult return rates of Razorbills on the Isle of May in 2009 and 2010 were well above the long-term average (JNCC 2011).

Given the difficulties involved in monitoring Razorbill population change and demography through counts and observations of individuals at colonies, especially when data sets are punctuated by years of non-breeding or early breeding failures, integrated use of information from sources such as beached bird surveys (including recording age, biometrics and moult), standardised sea-watching, observations by local ornithologists collected in national or regional databases, and ringing recoveries provides further understanding of the species' fortunes in the North Sea area, and wider. This approach may shed light on the causes of demographic changes in a variety of seabird populations that cannot easily be uncovered by other methods.

**Acknowledgements**
We thank the Agency for Urban Environment, City of Oslo, for the collection and storage of birds, and Morten Bergan, Bård Bredesen, Bjørn Aksel Bjerke, Jan Erik Røer and Tormod Burkey for helping collect dead birds. Norwegian post-mortem studies were carried out at the Norwegian Institute for Nature Research (NINA) with financial support from the Norwegian Directorate for Nature Management. Natural History Museum of Oslo (Jan T. Lifjeld and colleagues) provided storage, genetic sampling and transport facilities, and Seblewengel Bekele Talle provided lab assistance. Kjell Handeland, Norwegian Veterinary Institute performed veterinary examinations. Egil Soglo permitted use of count data from Møringa organised by TønsbergFugl (http://home.online.no/~sve-a4/; data currently being transferred to www.artsobservasjoner.no). Sander Fiskvik, Signe Christensen-Dalsgaard and Jorunn Mittet Eriksen assisted during the post-mortem examinations at NINA. Beached bird survey data were provided by David Fleet and Martin Schulze Dieckhoff (Germany), Kees Camphuysen (The Netherlands), Eric Meek and Morag Wilson (Orkney), and Daniel M. Turner (northeast England). For providing other information, we thank: Niklas Aronsson (Sweden), Rolf Christensen and John Pedersen (Denmark), Aevar Petersen (Iceland), Jens-Kjeld Jensen and Bergur Olssen (Faroes). Alf Tore Mjøs, Bird Ringing Centre, Stavanger, Norway provided data on

ring recoveries. In the UK, Roddy Mavor (JNCC) provided information on population trends and Jacquie Clark (BTO) on ringing recoveries [The BTO Ringing Scheme is funded by a partnership of the BTO, the JNCC (on behalf of: Council for Nature Conservation and the Countryside, the Countryside Council for Wales, Natural England and Scottish Natural Heritage), The National Parks and Wildlife Service (Ireland) and the ringers themselves]. Rob Barrett, Mike Harris and Andy Webb kindly commented on a draft of the manuscript.

## References

**Aarvak, T. & Anker-Nilssen, T. 2005.** [Cause of death and the origin of auks beached at the coast of Rogaland in February 2003]. *NINA Report 95*. Norwegian Institute for Nature Research, Trondheim. (In Norwegian, English Abstract)

**Alampo, T. & Lamont, T. 2008.** 'Isle of May National Nature Reserve Annual Report 2008'. Unpublished Report, Scottish Natural Heritage, Cupar.

**Anker-Nilssen, T. (ed.) 2009.** 'Sjøfugl i Norge 2008. Resultater fra SEAPOP-programmet'. Programme pamphlet, www.seapop.no. Norwegian Institute for Nature Research, Trondheim. (In Norwegian)

**Anker-Nilssen, T. (ed.), Barrett, R. T., Bustnes, J. O., Christensen-Dalsgaard, S., Erikstad, K. E., Fauchald, P., Lorentsen, S.-H., Steen, H., Strøm, H., Systad, G. H. & Tveraa, T. 2008.** SEAPOP studies in the Barents and Norwegian Seas in 2007. *NINA Report 363*. Norwegian Institute for Nature Research, Trondheim.

**Anker-Nilssen, T., Jones, P. H. & Røstad, O. W. 1988.** Age, sex and origins of auks (Alcidae) killed in the Skagerrak oiling incident of January 1981. *Seabird* 11: 28–46.

**Bakken, V., Runde, O. & Tjørve, E. 2003.** *Norsk ringmerkingsatlas*. Vol. I. Stavanger Museum, Stavanger.

**Bakken, V. & Anker-Nilssen, T. in press.** *Herkomst av sjøfugler langs norskekysten utenom hekkeperioden*. Report to the Norwegian Oil Industry Association. Arctic Research and Consulting (ARC), Det Norske Veritas (DNV) and SEAPOP.

**Barrett, R. T., Anker-Nilssen, T. & Krasnov, Y. V. 1997.** Can Norwegian and Russian Razorbills *Alca torda* be identified by their measurements? *Marine Ornithology* 25: 5–8.

**Barrett, R. T., Anker-Nilssen, T. & Lorentsen, S.-H. 2006.** The status of seabirds breeding in mainland Norway. *Atlantic Seabirds* 8: 97–126.

**Blake, B. F. 1984.** Diet and fish stock availability as possible factors in the mass death of auks in the North Sea. *Journal of Experimental Marine Biology and Ecology* 76: 89–103.

**Bønløkke, J., Madsen, J. J., Thorup, K., Pedersen, K. T., Bjerrum, M. & Rahbek, C. 2006.** *Dansk Trækfugleatlas*. Rhodos, Humlebæk.

**Bruce, B. 2009.** 2008 Breeding season news. Forth Islands. *Seabird Group Newsletter* 110: 13–15.

**Camphuysen, C. J., Bao, R., Nijkamp, H., Escuer, R. G. & Heubeck, M. 2007.** *Handbook on oil impact assessment*. Available at http://www.zeevogelgroep.nl/CJC/

**Coffait, L., Clark, J. A., Robinson, R. A., Blackburn, J. R., Grantham, M. J., Marchant, J. H., Barber, L., de Palacio, D., Griffin, B. D. & Moss, D. 2008.** Bird ringing in Britain and Ireland in 2007. *Ringing & Migration* 24: 104–114.

**Craik, J. C. A. 1992.** Exceptional mortality of auks, terns and Kittiwakes *Rissa tridactyla* in West Scotland in July 1985. *Sula* 6: 125–138.

**Cramp, S. (ed.) 1985.** *The Birds of the Western Palearctic*. Vol. IV. Oxford University Press, Oxford.

**Furness, R. W. 1983.** *Foula, Shetland, vol. 4: The Birds of Foula*. Brathay Hall Trust, Ambleside.

**Gaston, A. J. 1985.** Development of the Young in the Atlantic Alcidae. In: Nettleship, D. N. & Birkhead, T. R. (eds.) *The Atlantic Alcidae*: 319–354. Academic Press, London.

**Griffiths, R., Double, M. C., Orr, K. & Dawson, R. J. G. 1998.** A DNA test to sex most birds. *Molecular Ecology* 7: 1071–1075.

**Harris, M. P. & Birkhead, T. R. 1985.** Breeding Ecology of the Atlantic Alcidae. In: Nettleship, D. N. & Birkhead, T. R. (eds.) *The Atlantic Alcidae*: 155–204. Academic Press, London.

**Harris, M. P. & Wanless, S. 1984.** The effect of the wreck of seabirds in February 1983 on auk populations on the Isle of May (Fife). *Bird Study* 31: 103–110.

**Harris, M. P. & Wanless, S. 1989.** The breeding biology of Razorbills *Alca torda* on the Isle of May. *Bird Study* 36: 105–114.

**Harris, M. P., Wanless, S. & Rothery, P. 2000.** Adult survival rates of Shag *Phalacrocorax aristotelis*, Common Guillemot *Uria aalge*, Razorbill *Alca torda*, Puffin *Fratercula arctica* and Kittiwake *Rissa tridactyla* on the Isle of May, 1986–96. *Atlantic Seabirds* 2: 133–150.

**Heubeck, M., Meek, E. R., Mellor, R. M. & Wilson, M. 2009.** Numbers of Atlantic Puffins *Fratercula arctica* found on beached bird surveys in Orkney and Shetland over a 30-year period. *Seabird* 22: 19–35.

**Heubeck, M., Meek, E. & Suddaby, D. 1992.** The occurrence of dead auks *Alcidae* on beaches in Orkney and Shetland, 1976–1991. *Sula* 6: 1–18.

**Holdgate, M. (ed.) 1971.** *The Seabird Wreck of 1969 in the Irish Sea*. Natural Environment Research Council, London.

**Hudson, R. & Mead, C. J. 1984.** Origins and ages of auks wrecked in eastern Britain in February–March 1983. *Bird Study* 31: 89–94.

**Isaksen, K. & Bredesen, B. 2007.** Invasjon og massedød av alke høsten 2007. *Toppdykker'n* 30: 168–179.

**Jones, P. H. 1988.** Post-fledging wing and bill development in the Razorbill *Alca torda islandica*. *Ringing & Migration* 9: 11–17.

**Jones, P. H. 1990.** The occurrence of large ('northern') Razorbills in British and Irish waters. *Ringing & Migration* 11: 105–110.

**Jones, P. H., Barrett, C. F, Mudge, G. P. & Harris, M. P. 1985.** Examination of corpses of auks beached on East British coasts in February 1983. *Seabird* 8: 9–14.

**Jones, P. H., Blake, B. F., Anker-Nilssen, T. & Røstad, O. W. 1982.** *The examination of birds killed in oilspills and other incidents - a manual of suggested procedure*. Nature Conservancy Council, Aberdeen.

**Jones, P. H. & Rees, E. I. S. 1985.** Appearance and behaviour of immature Guillemots and Razorbills at sea. *British Birds* 78: 370–377.

**JNCC. 2011.** *Seabird Population Trends and Causes of Change: 2011 Report* (http://www.jncc.gov.uk/page-3201). Joint Nature Conservation Committee. Updated April 2011. Accessed 30 April 2011.

**Lavers, J. L., Muzaffar, S. B. & Jones, I. L. 2005.** Double white lines on the bill of the Razorbill *Alca torda*: remnants of an association with the extinct Great Auk *Penguinus impennis*? *Atlantic Seabirds* 7: 127–132.

**Lorentsen, S.-H. & Christensen-Dalsgaard, S. 2009.** [The national seabird monitoring programme for seabirds. Results up to and including the 2008 breeding season.] *NINA Report 439*. Norwegian Institute for Nature Research, Trondheim. (In Norwegian, English Abstract)

**Lyngs, P. 1994.** The effects of disturbance on growth rate and survival of young Razorbills *Alca torda*. *Seabird* 16: 46–49.

**Lyngs, P. & Kampp, K. 1996.** Ringing recoveries of Razorbills *Alca torda* and Guillemots *Uria aalge* in Danish waters. *Dansk Ornitologisk Forenings Tidsskrift* 90: 119–132.

**Mavor, R. A., Heubeck, M., Schmitt, S. & Parsons, M. 2008.** *Seabird numbers and breeding success in Britain and Ireland, 2006*. Joint Nature Conservation Committee, Peterborough. (UK Nature Conservation, No. 31)

**Merne, O. J. 2002.** Razorbill *Alca torda*. In: Wernham, C. V., Toms, M. P., Marchant, J. H., Clark, J. A., Siriwardena, G. M. & Baillie, S. R. (eds.) *The Migration Atlas: movements of the birds of Britain and Ireland*: 401–404. Poyser, London.

**Merne, O. J. & Mitchell, P. I. 2004.** Razorbill *Alca torda*. In: Mitchell, P. I., Newton, S. F., Ratcliffe, N. & Dunn, T. E. (eds.) *Seabird populations of Britain and Ireland*. Poyser, London.

**Newell, M., Harris, M. P., Daunt, F., Watts, E., Quinn, L. & Wanless, S. 2007.** 'Isle of May seabird studies 2007'. Unpublished Report. JNCC, Peterborough / CEH, Banchory.

**Newell, M., Harris, M. P., Quinn, L., Wanless, S. & Daunt, F. 2008.** 'Isle of May seabird studies 2008'. Unpublished Report. JNCC, Peterborough / CEH, Banchory.

**Petersen, I. K. & Nielsen, R. D. 2011.** *Abundance and distribution of selected waterbird species in Danish marine areas*. Report commissioned by Vattenfall A/S. National Environmental Research Institute, Aarhus University, Denmark.

**Richardson, M. G., Dunnet, G. M. & Kinnear, P. K. 1981.** Monitoring seabirds in Shetland. *Proceedings of the Royal Society of Edinburgh* 80B: 157–179.

**Riddiford, N. 1984.** The 1983 Razorbill Wreck. In: Riddiford, N. (ed.) *Fair Isle Bird Observatory Report No. 36, 1983*: 23–25. FIBOT, Edinburgh.

**Salomonsen, F. 1944.** The Atlantic Alcidae. The seasonal and geographical variation of the auks inhabiting the Atlantic Ocean and adjacent waters. *Göteborgs Kungliga Vetenskaps-Vitterhets-Samhälles Handlingar*. Serie B 3: 1–138.

**Seabird Group. 2007.** 2007 Breeding season news. *Seabird Group Newsletter* 106: 13–17.

**Seabird Group. 2008.** 2008 Breeding season news. *Seabird Group Newsletter* 109: 8–17.

**Shaw, D. N., Davies, S. J. & Breaks, M. T. 2007.** 'Fair Isle Seabird Studies in 2007'. Unpublished Report. JNCC, Peterborough.

**Shaw, D. N. 2008.** 'Fair Isle Seabird Studies in 2008'. Unpublished Report. JNCC, Peterborough.

**Skov, H., Durinck, J, Leopold, M. F. & Tasker, M. L. 1995.** *Important Bird Areas for seabirds in the North Sea*. BirdLife International, Cambridge.

**Swann, R. L. 2004.** Seabird wreck, northwest Scotland late summer 2004. *Seabird Group Newsletter* 98: 12–14.

**Swann, R. L. 2008.** 'Canna seabird studies 2008'. Unpublished Report. JNCC, Peterborough.

**Underwood, L. A. & Stowe, T. J. 1984.** Massive wreck of seabirds in eastern Britain, 1983. *Bird Study* 31: 79–88.

**Vaurie, C. 1965.** *The Birds of the Palaearctic Fauna. A Systematic Reference. Non-Passeriformes*. H. F. & G. Witherby, London.

**Wanless, S. & Harris, M. P. 1986.** Time spent at the colony by male and female Guillemots *Uria aalge* and Razorbills *Alca torda*. *Bird Study* 33: 168–176.

**Yates, F. 1934.** Contingency tables involving small numbers and the $\chi^2$ test. *Journal of the Royal Statistical Society Supplement* 1: 217–235.

**Zar, J. H. 1984.** *Biostatistical analysis. Second edition.* Prentice-Hall, Inc., New Jersey.