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Wear and loss of rings used on Razorbills *Alca torda* – further caution in the estimation of large auk survival

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On Græsholmen in the central Baltic Sea, 3,583 Razorbill *Alca torda* chicks were ringed with triangular Incoloy rings, and about half the birds were subsequently resighted. The resightings were used to calculate rates of turned rings, and 119 retrieved rings were used to calculate rates of wear and ring loss. At 1.7%, the rate of turned rings was much lower than reported among Common Guillemots *Uria aalge* in Britain, most likely because the Razorbill rings were fitted with soft wax at the time of ringing. The mean annual rate of metal loss of rings on birds for 3–9 years was 1.51%. Ring loss due to abrasion was 50% by year 14 with no ring lasting longer than 24 years, thus severely biasing survival estimations based on ringing data.

When present at the breeding colony, Razorbills *Alca torda* and Guillemots *Uria* spp shuffle along on their tarsi over rocks. Since they are long-lived and the breeding season lasts for several months, any ring attached to the tarsus will be abraded. In the 1970s, the British Trust for Ornithology designed a new, triangular ring for auks (Lloyd & Perrins 1977). Since the early 1980s, large numbers of auks have been ringed with such triangular rings in many parts of their breeding range (*eg* Britain, Canada and the Baltic). These rings are made of a Nickel–Iron–Chromium alloy (Incoloy) with the return address on top of the ring, the ring number on both sides and a flat base. Originally designed to eliminate loss of ring number by abrasion, these rings are readable at a distance with a telescope.

The use of triangular rings is not without problems. Harris & Rothery (2004) reported that some 43% of the triangular rings used on Common Guillemot *Uria aalge* chicks on the Isle of May subsequently had turned upside-down, exposing the return address to abrasion. Rings without an address are less likely to be returned by the finder, introducing a serious bias when estimating the survival rate of older birds from ringing data.

In a study of Razorbills on Græsholmen in the Central Baltic Sea, the possibility of a triangular Incoloy ring turning was considerably reduced by adjusting the inner ring size with some soft wax. Even so, the rate of ring loss due to abrasion was high, with half the rings being lost before the birds reached an age of 15 years.

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METHODS

During 1986–98, 3,583 chicks and 98 adult Razorbills were ringed on the granite island of Græsholmen (55° 19'N 15° 11'E), and the wing length of most chicks (85%) was measured to the nearest mm (maximum length method; Svensson 1984). All these birds were ringed with triangular rings, size 'Razorbill', manufactured by Lambournes (Herefordshire, UK). The rings were made of Incoloy 825, a Ni–Fe–Cr alloy (UNS: N08825), consisting of 38–46% Ni, >22% Fe, 19.5–23.5% Cr and < 0.05% Carbon. All rings were fitted base down, except one adult that accidentally had its ring placed upside-down. The address of the Danish Bird Ringing Centre was stamped on top of the ring and an identification number on both sides. These rings are here referred to as the T-series.

The T-series ring was roughly triangular, with the apex (where the address is stamped) rounded (Fig 1). It has a small lip or 'lock' on the base that prevents the ring opening and this side is here referred to as the LOC side, the opposite side as the NOL side. The base should be flat after the ring is fitted to a bird, but often arches slightly outwards which concentrates the wear on either the LOC side or the NOL side, whereas the wear on rings with a flat base is distributed more uniformly. Rings worn on the LOC side will often lose the small lock some time before the ring itself is lost.

To reduce the chances of rings turning upside-down, all rings used on chicks were waxed using the 'Filia Decoration wax', produced in Denmark and normally used for flower arranging. This wax softens when warm

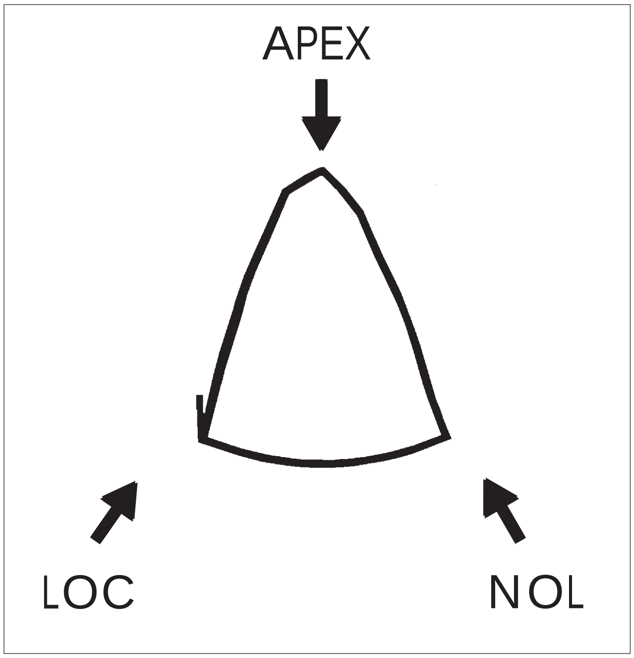

Figure 1. Schematic drawing of the triangular T-series ring used on Razorbills from Græsholmen, here depicted with a slightly arched base (see text).

and hardens when cold, but never gets so hard that the normal friction between the tarsus and the ring does not wear the wax off gradually. A small lump of wax was fitted inside the ring, adjusting the amount used to the actual size of the chick's leg.

During 1990–2005 using 60x-magnification telescopes, we read the rings on 1,939 returning Razorbills (1,852 ringed as chicks, 87 as adults) ringed with T-series rings and noted whether the rings had turned or not. To obtain information on wear, 73 rings were retrieved after re-ringing full-grown birds, 33 recovered rings were received from the Danish Ringing Department, and five lost rings and eight dead ringed birds were found in the colony. These rings were weighed to the nearest 0.0001 g on a Mettler AC-100 balance, and the position where the ring was worn was noted (apex, entire base, LOC or NOL). The mean weights of 20 unused T-series rings were used to establish the mass of unabraded rings. On a more subjective scale, I estimated whether the ring was likely to be lost during the current or following breeding season.

The retrieved rings were split into three groups: not turned (rings from birds ringed as chicks and worn at the base, n = 98), turned (rings from birds ringed as chicks that had turned upside-down and were worn at the apex, n = 7) and adult (rings from birds ringed as adults and worn at the base, n = 13; one turned ring excluded).

Table 1. Results of examinations of the state of Incoloy triangular rings on Razorbills ringed as chicks 1986–98, and subsequently seen on Græsholmen 1990–2005.

Year ringed	Birds seen (n)	Rings turned (n)	Percentage turned (%)
1986	85	2	2.4
1987	119	0	0.0
1988	118	2	1.7
1989	146	1	0.7
1990	128	2	1.6
1991	147	1	0.7
1992	136	1	0.7
1993	159	2	1.3
1994	184	0	0.0
1995	174	4	2.3
1996	213	10	4.7
1997	221	7	3.2
1998	22	0	0.0
Total	1,852	32	1.7

Where appropriate, the normality of data was tested using the Kolmogorov–Smirnov test. Statistical procedures were done using Graphpad Prism v 4 (GraphPad Software Inc., San Diego, USA), except the chi-square goodness-of-fit test in the 'Loss of rings' section, which was calculated in a spreadsheet. Means and standard errors (se) are given in the text and figures, as appropriate.

RESULTS

Turning of rings

T-series rings fitted adult birds well, and no cases of turned rings were observed on birds ringed as adults. Of the 1,852 Razorbills ringed as chicks and subsequently seen on Græsholmen, 32 (1.7%) of the rings had turned (Table 1). Most (82%) of these birds were between two and four years old when seen for the first time.

Table 2. Area of wear on retrieved Incoloy triangular rings used on Razorbills on Græsholmen.

Ring	Wear	Adult	Chick	Total
Turned	Apex	1	7	8
	LOC side	4	19	23
Not turned	NOL side	8	32	40
	Base	1	47	48
	Total	14	105	119

The chances of a ring turning were lower in chicks with a long wing length at ringing (Fig 2): among 297 chicks with a wing length of <56 mm, 12 (4%) of the rings had turned, compared with seven rings (0.9%) among 804 chicks with a wing length of >65 mm (P = 0.0012, Fisher's exact test).

Wear of rings

Of the 119 retrieved rings, 14 were from birds ringed as adults and 105 from birds ringed as chicks (Table 2). For both age-classes, the oldest rings retrieved had been on the birds for up to15 years. As some birds with turned rings were deliberately re-ringed, the proportion of retrieved turned rings was higher (6.7%; Table 2) than observed on live birds.

The T-series rings were primarily abraded on the outer surface. For turned rings the abrasion was concentrated at the apex, for not-turned rings it occurred at the base, and in both cases the numbers on the sides usually remained legible throughout the life of the rings. On about half of the not-turned rings (Table 2), the bottom arched slightly outwards, which concentrated the abrasion towards one of the corners. The mean mass of rings placed on chicks and abraded mostly on the NOL or on the LOC side did not differ significantly from those abraded evenly at the entire base (U = 273.5, P = 0.083, Mann–Whitney U test; rings worn 5–9 years, n = 26 and 29, respectively). However, rings abraded mostly on the NOL side were probably lost earlier than rings abraded at the LOC side, since the entire bottom of the ring will fall off versus only the lock when the metal is worn through.

The mean mass of 20 unused T-series rings was 1.9766 g (1.9264 – 2.0730 g, se = 0.0998). For 61 not-turned rings, the mean annual rate of metal loss for years 3–9 was 1.51% (se = 0.33). On average, rings from five four-year-old birds weighed 1.9055 g (Fig 3), corresponding to a total metal loss of 1.6% of the mean initial mass. The mean mass of rings from 10 nine-year-old birds was 1.7581 g, a loss of 10.7%. For years 10–13, the mean annual rate of loss was 0.05% (se = 1.93; n = 22), an artefact caused by loss of the most worn rings (see below).

Rings on birds ringed as adults were apparently worn as much as rings from birds ringed as chicks after they started breeding (Fig 3). A mean annual metal loss rate of 1.36% was calculated for nine rings worn for 6–11 years.

Turned rings lost mass faster than not-turned rings (Fig 3), and at least for rings worn for five years the mean mass was lower (P = 0.008, t = 3.321, df = 10, t-test; n = 3 and 9, respectively). On seven turned rings, the return address was completely worn away on six (youngest five years) while one had part of the address still legible (eight years).

Loss of rings

Five lost rings from birds ringed as chicks were found in nests, all worn at the base: three had lost the entire base and weighed 1.2516–1.3187 g (64.3–66.7% of mean unused mass), one had lost the small lock (1.3601 g = 68.8%; if corrected for loss of lock then + 0.22 g = 1.5801 g = 79.9% of mean unused mass) and one still had the entire base intact (although very thin and

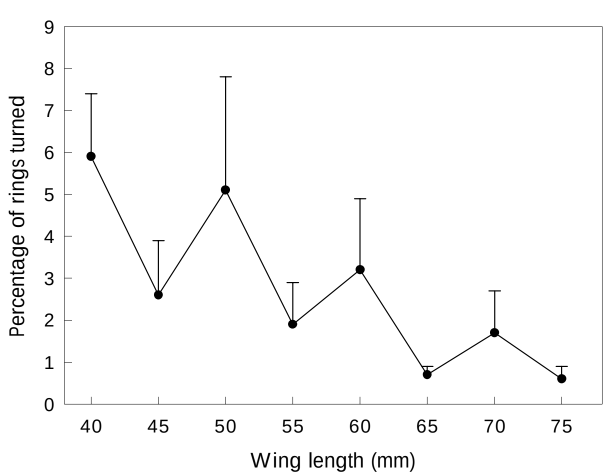

Figure 2. Percentage of rings later turned in relation to wing length at ringing of 1,560 Razorbill chicks measured and subsequently seen on Græsholmen.

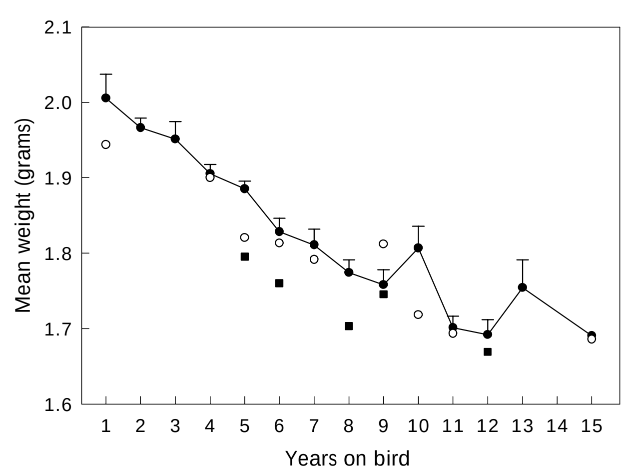

Figure 3. Mean weights of triangular rings worn by Razorbills from Græsholmen ringed as chicks (filled circles + se, n = 90), ringed as adults (open circles, n = 13) or ringed as chicks with turned rings (squares, n = 7).

springy), and a weight of 1.6324 g (82.6%). The found rings had been lost at an age of 12 (two birds), 13 (one bird) and 14 (two birds) years. The lightest ring found on a live bird weighed 1.4095 g (71.2%, age 15 years); this had lost the lock and corrected for lock loss the weight was 1.6295 (82.4%). Thus, the 10 lightest rings from birds ringed as chicks had a mean mass of 1.6648 g (1.6295–1.6903 g, se = 0.003) equal to 84.2% (82.4–85.5%) of the original mass and were found on birds aged 8–15 (mean 11) years. With a mean weight of 1.6737 g (84.7% of original mass), four of these were so heavily worn that they would probably have been lost during the following breeding season. Rings probably fell off when between 79% and 83% of the original mass. Here I use an end point of 80%, corresponding to a weight of 1.585 g.

Bailey *et al* (1987) assumed "that when losses [of rings] become frequent, the mean weights of the samples of bands arranged chronologically by duration on the birds, will level off or rise". Following this assumption, losses of not-turned triangular Incoloy rings on Razorbills ringed as chicks become frequent from year 10, when the mean weight levelled off (Fig 3) and the mean annual rate of metal loss dropped from 1.51 to 0.05%. For not-turned rings (Fig 4), only two of 25 weights for rings worn 10–15 years fell below the extended regression line calculated for rings worn 3–9 years. The extended regression line for rings worn for 3–9 years intersects the end point of 80% of the original weight at 14 years (Fig 4), while the extended 95% prediction lines intersect this point at 10–11 and 18–19 years. Thus the majority of rings appear to have been lost between year 11 and year 19, and about half the rings may be lost at year 14.

Several studies of ring loss on seabirds have found a constant annual rate of metal loss (Bailey *et al* 1987, Ludwig *et al* 1995 and references therein). Assuming a constant metal loss rate of 1.51% per year and an end point of 80% for 61 not-turned rings worn for 3–9 years, I calculated a mean age of loss of 14.9 years (range 11–19 years) with the majority (62%) of the rings lost at the age of 14–16 years. For rings worn for 10–13 years – after ring loss had started – the calculated maximum age was 24 years.

Further information on ring loss came from resightings in 1991, 1998 and 2004 (years with very high resighting activity) of the 1986 and 1987 cohorts. Using an estimate of 5.6% annual mortality (which is the mean mortality on a 16-year basis from our study plot with re-ringed birds) and assuming that survival remained constant for birds aged 5–18 years, I calculated the expected number of resighted birds if no rings were lost. The numbers resighted were significantly lower than expected (Table 3; goodness-of-fit test with the two cohorts combined, 1998: $\chi^2_1 = 53.5$, $P << 0.001$; 2004: $\chi^2_1 = 37.8$, $P << 0.001$), and the numbers suggested that about 40% of the rings were lost between 1991 and 1998 (from age 4–5 to 11–12 years) and 49% between 1998 and 2004 (from age 11–12 to 17–18 years), corresponding to mean annual loss rates of 7.1% and 10.5%, respectively. In other words, only 60% of the birds checked in 1991 and surviving to 1998 retained their rings, and by 2004 the proportion had decreased to 31%.

Five birds ringed as chicks in 1986–89 which had turned rings when first resighted on Græsholmen kept these rings for at least 10, 12 (three birds) and 16 years. On the other hand, the mean age of examined rings deemed to be lost after an additional 1–2 breeding seasons were 7.5 years for turned and 11.4 years for not-turned rings ($P = 0.003$, t = 3.369, df = 19, t-test; n = 6 and 15, respectively), suggesting that turned rings on average probably are lost some years earlier than not turned. An adult bird with a ring placed upside-down had kept the ring for 14 years when re-ringed.

DISCUSSION

Apparently (we do not have a control group), waxing of the Razorbill rings resulted in a significant reduction of the number of rings subsequently turned upside-down.

Table 3. Numbers of Razorbills from the 1986 and 1987 cohorts recorded as breeders or regular visitors on Græsholmen in 1991 and resighted in 1998 and 2004. The birds were ringed as chicks with T-series triangular rings; re-ringed birds and birds with turned rings are excluded.

Resighted	1986 cohort	Expected*	Age (years)	1987 cohort	Expected*	Age (years)
1991	70	-	5	95	-	4
1998	27	47	12	39	63	11
2004	10	33	18	14	45	17

* Numbers of birds expected to be recorded if the annual mortality was 5.6% (see text) and no loss of rings occurred before year 19.

At least, only 1.7% of the rings on Razorbills ringed as chicks and subsequently seen alive on Græsholmen (Table 1) had turned, a much lower proportion than the 43% reported on 'unwaxed' Common Guillemots on the Isle of May (Harris & Rothery 2004).

Thus, turned rings posed a much smaller problem in our study than in the Guillemot study of Harris & Rothery (2004). Unfortunately, loss of rings due to abrasion was very serious as we estimated that the first rings were lost at year 8–9, that 50% were lost by year 14 and that all rings were lost by year 24. For a species that can live for at least 42 years (JA Clark, pers comm), this rate of loss is clearly unsatisfactory, and will have significant negative influence on mortality rates of older age classes when calculated from ringing data.

Breeding Razorbills arrive at Græsholmen in March and depart from late June to early August. On a daily basis, the breeding birds may spend more than 60% of their time in the colony (Benvenuti *et al* 2001). A long time spent in a colony with a rock substrate of very hard granite will inevitably lead to heavy abrasion of rings. In Finland the same type of triangular Incoloy rings has been used since 1992 on Razorbills breeding in the same habitat as on Græsholmen. Here ring losses have been reported after just four breeding seasons, and are considered a major problem by the Finnish Ringing Centre (J Haapala, personal communication). Hence, the results from Græsholmen could be representative for that (major) part of the Baltic Razorbill population breeding on granite islands. For other populations or other large auk species with different breeding habitats (*eg* sandstone or limestone), the rate of ring loss might be considerably lower.

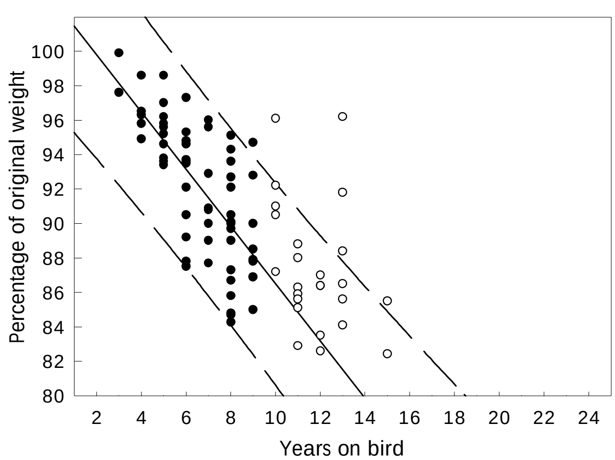

Figure 4. Relationship of weight lost over time for triangular rings on Razorbills ringed as chicks on Græsholmen and worn for 3–9 years (n = 62, closed symbols) and 10–15 years (n = 25, open symbols). The regression line and the 95% prediction line (dashed) were calculated for years 3–9, and extended through the axes.

In 1998 we switched to using triangular steel rings manufactured by IÖ Mekaniska AB in Sweden (referred to as the D-series rings). These rings are made of an alloy called EN10088-1-X5 CrNiMo17-12-2 (1.4401) containing 10.5–13.5% Ni, 16.5–18.5% Cr and < 0.07% C, *ie* an alloy with much less Ni than the Incoloy 825. This series are slightly larger than the T-series Incoloy rings, 17.7% thicker (1 mm versus 0.85 mm) and weigh about 40% more. As yet we do not know whether these rings are more resistant to abrasion than the Incoloy rings, but the increased thickness alone should prolong the life of the ring by at least three years.

Despite their shortcomings, the triangular rings have been immensely useful for our study, enabling us to get data on immature occurrence, age at first breeding and site fidelity. Round rings are difficult to read with a telescope, and colour rings only last a few years on Græsholmen, so our only option was to use triangular rings. Due to factors such as cost, mechanical limitations in the ring production and a trade-off between resistance to corrosion and to abrasion, the perfect large auk ring probably does not exist. At present the best solution – at least for the Baltic – seems to be to increase the overall thickness of the triangular rings, and IÖ Mekaniska is currently experimenting to see if this is mechanically possible for the D-series rings.

Though the high rates of ring loss reported here may be a Baltic problem, I support Harris & Rothery (2004) in urging ringing schemes and auk workers to be aware that loss of the triangular rings may introduce an important source of bias when estimating large auk survival from ringing data.

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