Feathers as a means of monitoring mercury in seabirds: insights from stable isotope analysis

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Abstract

Mercury concentrations, together with nitrogen and carbon stable isotope signatures, were determined in body feather samples from northern fulmars Fulmarus glacialis and great skua Catharacta skua, and in different flight feathers from great skua. There were no significant relationships between trophic status, as defined using isotope analysis, and mercury concentration in the same feather type, in either species. Mercury concentrations in body feather samples were markedly different between fulmars and skus, reflecting differences in diet, but there was no corresponding difference in trophic status as measured through nitrogen stable isotope signatures. We conclude that mercury concentrations and stable isotope values in feathers are uncoupled, mercury concentrations apparently reflecting the body pool of accumulated mercury at the time of feather growth whilst stable isotope values reflect the diet at the time of feather growth. There were significant positive correlations between the different flight feathers of great skua for all three parameters measured. These were strongest between primary 10 and secondary 8, suggesting that these two feathers are replaced at the same time in the moult sequence in great skua. Stable isotope analysis of different feathers may provide a means of investigating moult patterns in birds. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

There is a substantial body of published work using seabirds as biomarkers of mercury in a wide range of environments and locations (see Walsh, 1990; Burger, 1993; Monteiro and Furness, 1995 for recent reviews). Mercury is excreted via growing feathers, and once bound to the feather keratin molecule is relatively physically and chemically stable, being resistant to a variety of rigorous treatments (Appelquist et al., 1984). Thus, feathers afford a non-destructive and relatively non-invasive way in which to monitor mercury contamination in seabirds. Those feathers moulted and replaced towards the beginning of the moult process (usually the large flight feathers in seabirds) exhibit the highest mercury concentrations, with feathers moulted and replaced later in the moult sequence exhibiting correspondingly lower mercury concentrations (Furness et al., 1986; Honda et al., 1986; Braune and Gaskin, 1987). These authors inferred that this general pattern arises because during the inter-moult period, mercury ingested in the diet is accumulated within internal tissues. At the onset of moult, this 'body pool' of mercury diminishes as mercury is eliminated into growing feathers. However, this hypothesis remains to be tested.

The use of feathers as a means of investigating mercury in seabirds has several advantages. Mercury concentrations in feathers have been shown to correlate with those in internal tissues (Furness and Hutton, 1979; Thompson et al., 1991), thus reducing the need to kill individuals. In studies incorporating adult seabirds of known age, mercury concentrations in feathers were unrelated to age (Furness et al., 1990; Thompson et al., 1991, 1993a), removing this possible confounding factor. The stability of mercury bound to feather keratin and the fact that there are extensive collections of preserved seabirds in museum collections dating back...
over 150 years, has made it possible to investigate long-term patterns of mercury contamination using feathers from preserved and contemporary seabirds from a range of habitats (Appelquist et al., 1985, Thompson et al., 1992a, 1993a, b, in press). Mercury concentrations in feathers have been shown to reflect those in the diet in a dose-dependent fashion (Lewis and Furness, 1991), high dietary intake of mercury leading to correspondingly high levels in feathers.

Concentrations of mercury vary considerably between birds within a population, and mercury is the only heavy metal for which good evidence exists that bioamplification occurs up food chains (Bryan, 1979). On that basis, one would predict that seabirds feeding at relatively high trophic positions would exhibit elevated mercury concentrations, whilst those seabirds feeding at relatively low trophic positions would exhibit lower mercury concentrations. This could explain part of the intra-population variation in mercury concentrations. However, linking measured mercury concentrations in seabirds with intra- and inter-specific differences in diet has proved difficult beyond a very broad scale approach (Muirhead and Furness, 1988; Lock et al., 1992; Thompson et al., 1992b). In the case of feathers, this problem is compounded due to a paucity of detailed dietary information at the time of feather growth in seabirds, which often takes place away from the breeding colony outwith the breeding season. Furthermore, defining the trophic status of an individual or species requires a comprehensive assessment of its diet (for example, Sanger, 1987), which may not be practical in many seabirds which spend many months of each year away from land.

Complimentary to conventional dietary studies, the use of nitrogen and carbon stable isotope analysis has been employed in order to quantify trophic status and dietary overlap of seabirds (for example, Hobson, 1991, 1993; Hobson et al., 1994; Thompson et al., 1995). This approach is based on the fact that stable isotope signatures in proteins of consumers reflect those in their prey in a predictable manner (DeNiro and Epstein, 1978, 1981; Peterson and Fry, 1987). For nitrogen, the ratio \( ^{15}\text{N}:^{14}\text{N} \) (conventionally expressed as \( \delta^{15}\text{N} \)) exhibits a step-wise enrichment of about 4% at each trophic level (for example, Minagawa and Wada, 1984; Hobson and Welch, 1992; Hobson, 1993; Hobson et al., 1994). For carbon, the ratio \( ^{13}\text{C}:^{12}\text{C} \) (\( \delta^{13}\text{C} \)) may also provide some trophic information, increasing at each trophic level, but to a lesser degree than nitrogen (for example, Rau et al., 1983; Fry and Sherr, 1984; Hobson and Welch, 1992). Stable isotope signatures of feathers reflect the diet at the time of feather growth (Hobson and Clark, 1992), and have been used to infer temporal variation in the trophic status of free-living seabirds (Thompson and Furness, 1995; Thompson et al., 1995).

The use of stable isotope analysis to quantify trophic status has clear implications for the study of pollutant transfer up food chains. Several recent studies have combined stable isotope analysis with the assessment of a wide range of pollutant burdens (for example, Broman et al., 1992; Cabana and Rasmussen, 1994; Kidd et al., 1995a, b; Kiriluk et al., 1995; Muir et al., 1995; Jarman et al., 1996, 1997). Here we investigate the influence of trophic status, as defined using stable isotope analysis in feather samples, on mercury concentrations in the same feathers from northern fulmars \( 

\text{Fulmarus glacialis} \) and great skuas \( 

\text{Catharacta skua} \).

Specifically, we test the hypothesis that fulmars and skucas with high mercury concentrations in feather samples occupy correspondingly high trophic positions, defined from the stable isotope signatures. Then we incorporate analyses of different feather types regrown at different times within the moult sequence, to test the hypothesis that mercury concentration and isotope signature varies as the body pool of mercury is depleted through moult.

2. Methods

2.1. Sample collection and preparation

Body-feather samples (6–10 small feathers from each individual) were taken from the breast, flanks and dor-sal region of great skuas and northern fulmars during the breeding season at Foula, Shetland (60° 08' N 02° 05' W). A total of 27 northern fulmars and 25 great skuas were sampled for body feathers, although a small number of great skua samples were subsequently lost during some analyses. Additionally, from 10 individuals that had either been previously shot (under licence) by crofters or found dead at Foula and subsequently stored deep frozen at –20°C, the tenth (outermost) primary (1°10), and the first (outermost), eighth and sixteenth secondaries (2°1, 2°8 and 2°16) were removed from the right wing. Skuas moult the innermost primary first, then progress to primary 10, moult of secondaries starting once primary moult is well progressed. Thus all these selected feathers represent the latter part of the moult cycle. All feather samples were stored in poly-thene bags prior to further treatments. Any surface contamination (primarily blood from birds that had been shot or found dead) was removed by washing feathers in 0.25 M sodium hydroxide solution. This relatively mild agent, compared to organic solvents such as acetone, was assumed to have no effect on feathers. Cleaned feathers were dried in an oven at 50°C for 24 h.

In order to homogenise samples; all feathers were ground to an extremely fine powder using an impactor mill operating at liquid nitrogen temperature.
2.2. Mercury analysis

All feather samples were analysed for total mercury using a cold vapour technique following standard acid digestion (Furness et al., 1986). All mercury concentrations are expressed on a fresh weight basis as µg g⁻¹ (equivalent to ppm). The limit of detection was 0.01 µg g⁻¹, although no concentration measured in the present study approached this lower limit. Accuracy of mercury measurement was determined by analysing International Atomic Energy Agency horse kidney Reference Material H-8. The results obtained from these analyses fell well within the 95% confidence limits of the published mean for this material (Thompson and Furness, 1989).

2.3. Stable isotope analysis

Weighed sub-samples of the powdered feathers were placed into tin buckets (Elemental Microanalysis Ltd) and crimped. Sample size was dependent on the isotope being determined and was approximately 1 µg for carbon analyses and 3 mg for nitrogen analyses. Samples (in the crimped tin cups) were then combusted at 1030°C with silvered cobaltous oxide granules and chromium oxide in an elemental analyser (Carlo Erba) using oxygen from an external cylinder. Excess oxygen was removed using copper wire. The combustion products were dried using magnesium perchlorate and in the case of nitrogen analyses the CO₂ was removed using carbosorb. The dry gases were transported in a stream of CP grade helium to a gas source isotope ratio mass spectrometer (Micromass ‘Optima’). Each sample of combustion products was measured relative to a working standard gas (CO₂ or N₂), a sample of which was admitted to the mass spectrometer and measured immediately prior to each experimental sample. The working standard gases were characterized relative to the IAEA Nitrogen and Carbon standards (IAEA 305a and 309a) and an internal reference (leucine) was run at the start and end of all experimental batches to cross-check consistency. The standard deviations of the means of replicate in-house analyses were ±0.2 for carbon and ±0.3 for nitrogen.

Stable isotope ratios were expressed in conventional notation whereby:

\[ \delta X = \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000 \]

Where X is \(^{15}\)N or \(^{13}\)C and R is the corresponding ratio \(^{15}\)N:14N or \(^{13}\)C:12C. \(R_{\text{standard}}\) for \(^{15}\)N and \(^{13}\)C are atmospheric nitrogen (AIR) and PeeDee Belemnite (PDB), respectively.

3. Results

Nitrogen and carbon stable isotope signatures, together with mercury concentrations, for all feather types from both northern fulmars and great skuas are presented in Table 1. For body feathers, mean \(\delta^{15}\)N values were not significantly different between fulmars (14.96%; Table 1) and great skuas (14.90%; Table 1; \(t\)-test: \(t = 0.23, df = 50, p = 0.891\)), whereas there was a significant difference of 1% between mean \(\delta^{13}\)C values (fulmar, -15.57%; great skua -14.57%; Table 1, \(t\)-test: \(t = -2.21, df = 47, p < 0.05\)). Mercury concentrations in body feathers were markedly different between the two species, with no overlap in values (Table 1). There were no significant correlations between either \(\delta^{15}\)N or \(\delta^{13}\)C signature and mercury concentration in body feather samples for either species (Fig. 1; Pearson correlation \(p > 0.05\) in each case). For fulmars, there was a significant positive correlation between \(\delta^{15}\)N and \(\delta^{13}\)C values in body feathers (Pearson correlation \(r = 0.43, n = 27, p < 0.05\)), although the same was not true in great skuas (Pearson correlation \(r = -0.12, n = 22, p = 0.607\)).

There were no significant differences in mean \(\delta^{15}\)N and \(\delta^{13}\)C values nor mean mercury concentrations between the four different flight feather types sampled from great skuas (Table 1; 1-Way ANOVA: \(p > 0.05\) in

<table>
<thead>
<tr>
<th>Species</th>
<th>Feather type</th>
<th>(\delta^{15})N(%)</th>
<th>Range</th>
<th>(\delta^{13})C(%)</th>
<th>Range</th>
<th>Hg (µg g⁻¹)</th>
<th>Range</th>
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<tr>
<td></td>
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<td>Mean ± SE (sample size)</td>
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<td>Mean ± SE (sample size)</td>
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<tr>
<td>Northern fulmar</td>
<td>body</td>
<td>14.96 ± 0.15 (27)</td>
<td>13.65–17.19</td>
<td>-15.57 ± 0.34 (27)</td>
<td>-21.67–13.21</td>
<td>1.66 ± 0.14 (27)</td>
<td>0.60–3.28</td>
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<td>(Fulmarus glacialis)</td>
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<tr>
<td>Great skua</td>
<td>body</td>
<td>14.90 ± 0.21 (25)</td>
<td>12.91–17.12</td>
<td>-14.57 ± 0.28 (22)</td>
<td>-16.43–11.74</td>
<td>11.08 ± 1.05 (22)</td>
<td>4.68–28.50</td>
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<tr>
<td>(Catharacta skua)</td>
<td>primary 10</td>
<td>16.03 ± 0.31 (10)</td>
<td>13.64–17.03</td>
<td>-13.97 ± 0.53 (10)</td>
<td>-16.44–11.92</td>
<td>6.08 ± 0.92 (10)</td>
<td>2.25–12.50</td>
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<td></td>
<td>secondary 1</td>
<td>16.21 ± 0.39 (9)</td>
<td>15.28–18.35</td>
<td>-14.48 ± 0.38 (10)</td>
<td>-15.88–12.49</td>
<td>4.14 ± 0.73 (10)</td>
<td>1.53–9.11</td>
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<td>secondary 8</td>
<td>16.09 ± 0.34 (10)</td>
<td>13.55–17.10</td>
<td>-14.03 ± 0.44 (10)</td>
<td>-15.64–11.79</td>
<td>6.95 ± 1.64 (9)</td>
<td>3.40–18.00</td>
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<td></td>
<td>secondary 16</td>
<td>16.01 ± 0.39 (9)</td>
<td>13.94–18.49</td>
<td>-14.22 ± 0.44 (10)</td>
<td>-16.09–12.23</td>
<td>3.91 ± 0.66 (10)</td>
<td>2.17–8.91</td>
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each case). Similarly, there were no significant correlations between either $\delta^{15}N$ or $\delta^{13}C$ and mercury values in any of the four flight feather categories, nor between $\delta^{15}N$ and $\delta^{13}C$ in any of the flight feathers (Pearson correlation $p > 0.05$ in each case). For each variable measured ($\delta^{15}N$, $\delta^{13}C$ and Hg) there were significant and positive correlations between different flight feather categories. However, the strongest correlations were always between values in primary 10 and secondary 8 (Fig. 2; Pearson correlations $\delta^{15}N$, $r = 0.96$, $n = 10$, $p < 0.001$; $\delta^{13}C$, $r = 0.95$, $n = 10$, $p < 0.001$; Hg, $r = 0.84$, $n = 9$, $p < 0.01$).

4. Discussion

The usefulness of $\delta^{15}N$ signatures as a measure of trophic status in studies of pollutant accumulation has been reported recently for a variety of pollutants. In the case of mercury, Cabana and Rasmussen (1994) described positive correlations between $\delta^{15}N$ values and mercury concentrations in lake trout Salvelinus namaycush in Canadian shield lakes, whilst Kidd et al. (1995a) noted similar patterns for a range of freshwater fish species over a number of lakes. Similarly, Jarman et al. (1996) reported a positive correlation between $\delta^{15}N$ and mercury concentration in the eggs of seabirds from the Gulf of the Farallones food web. In addition, stable isotope analysis has been employed to investigate patterns of synthetic organic pollutant accumulation. For example, Broman et al. (1992) reported that the concentrations of some polychlorinated dibenzo-p-dioxin congeners correlated positively with $\delta^{15}N$ values in Baltic food chains, Kidd et al. (1995b) found similar relationships for hexachlorocyclohexanes, total DDT and total chlorinated bornanes in a subarctic lake and Muir et al. (1995) reported that levels of total PCBs, total DDT, total chlordane and toxaphene all correlated positively with $\delta^{15}N$ signatures in walrus Odobenus rosmarus.

In the present study we did not find any positive relationships between $\delta^{15}N$ values and mercury concentrations, in either species or for any feather type (see Section 3 and Fig. 1). The timing and duration of body feather moult has not been studied in detail in fulmars and great skuas. For fulmars, it is thought that body moult begins during July and continues until mid-February, with two successive generations of body feathers present at any time (Cramp and Simmons, 1977; Ginn and Melville, 1983). Similarly in great skuas, body feather moult is thought to begin around August and continue until mid-March (Cramp and Simmons, 1977; Ginn and Melville, 1983). Hence, for both species, a sample of 6–10 body feathers chosen randomly from an individual bird could be representative of many months’ feather growth. In both species, flight-feather
Fig. 2. The relationships between primary 10 and secondary δ for: (a) δ15N, (b) δ13C and (c) Hg.

moult is thought to occur over a similar time-scale (Cramp and Simmons, 1977, 1983; Ginn and Melville, 1983), the body pool of accumulated mercury depleting over this period. Randomly selected body feathers will have been grown at different times during this depletion of the body pool of mercury and as such will have mercury concentrations dependent on how far this depletion had progressed: body feathers moulted and replaced towards the onset of post-breeding moult should have relatively high mercury concentrations, whereas those moulted and replaced towards the end of the mouling process, and when the body pool of mercury will be correspondingly diminished, should have relatively low mercury concentrations. Hobson and Clark (1992), in a study of captive American crows Corvus brachyrhynchos, demonstrated that δ13C signatures in growing feathers tracked those of the diet. If δ15N signatures in feathers similarly represent those in the diet at the time of feather growth, then isotope values and mercury concentrations in body feathers are effectively ‘uncoupled’, isotope signatures representing the diet at the time of feather growth, with mercury concentrations representing the extent to which the body pool of mercury had diminished when any given body feather was growing. Such an uncoupling of isotopic signatures from mercury burdens in body feathers would account for the lack of any significant relationships found here.

In a recent study of mercury concentrations in seabirds at Foula, Stewart et al. (1997) found a significant positive relationship between the amount of seabird prey in the diet (measured through regurgitated pellet analysis) and mercury concentration in body feathers of great skuas. In other words, those skuas feeding at relatively high trophic levels (with a large proportion of regurgitated pellets containing other seabirds) had higher mercury levels in their body feathers. That relationship further highlights that isotope values in body feathers may be an excellent index of diet and trophic status at the time they were grown, but explain little of the variation in mercury concentrations which reflect, in part, accumulation of mercury during the breeding season.

That there were no significant relationships between isotope values and mercury concentrations in flight feathers from great skuas (see Section 3) is perhaps more surprising. We chose flight feathers that are likely to have been regrown towards the end of the moult sequence, when the body pool of mercury should be at its lowest, and when dietary inputs of mercury are likely to have relatively more impact on concentrations in growing feathers. The primary feathers are lost and replaced sequentially, starting with primary 1, the innermost primary, and ending with primary 10, the outermost primary (Ginn and Melville, 1983). Moult of secondary flight feathers in great skuas has received little attention, but is likely to be ascendant (towards the body) starting with secondary 1 (the outer-most secondary). Therefore, particularly primary 10 and secondaries 8 and 16 chosen in the present study can be considered indicative of phases of the moult sequence when body pool levels of mercury should be relatively low, and when dietary inputs of mercury would be relatively more important. However, the lack of any significant relationships between mercury concentrations and isotopic signature in the present study may imply that even these flight feathers are not replaced late enough in the moult sequence for dietary sources of mercury be the principal determining effect.

Mean δ15N values for body feathers from fulmars and great skuas were remarkably similar (Table 1), indicating...
that these species feed at very similar trophic levels over the time these feathers were replaced. The diet of great skuas at Foula consists mainly of sandeels Ammodytes sp. and discarded whitefish and to a lesser extent other seabirds (Furness and Hislop, 1981; Hamer et al., 1991; Phillips et al., 1997). Fulmars at Foula feed mainly upon sandeels, other, mainly discarded, fish and fish offal (Furness and Todd, 1984; Thompson et al., 1995; Hamer et al., 1997). On the basis of conventional dietary information, one might predict great skuas to be at a higher trophic level than fulmars since seabirds, which occupy relatively high trophic positions, make up part of the skuas’ diet. Furthermore, this dietary difference should also result in higher mercury levels in great skuas, since seabird prey have been shown to exhibit much higher mercury concentrations compared to fish at Foula (Thompson et al., 1991). In contrast to the similarity in $\delta^{15}$N values, mercury concentrations in body feathers were indeed markedly different between these two species (mean 1.66 $\mu$g g$^{-1}$ in fulmars, 11.08 $\mu$g g$^{-1}$ in great skuas; Table 1), with no overlap in values. It is clear, therefore, that even on an interspecific basis, mercury burdens in body feathers cannot be predicted from corresponding $\delta^{15}$N values. However, the dietary information above represents the diet during the breeding season; almost nothing is known of the diet of these two species once they leave the colony after breeding. As mentioned previously, body feathers in fulmars and great skuas are replaced outwith the breeding-season, beginning just after breeding is completed. It may well be, therefore, that isotopic signatures in body feathers in these two species could be indicative of a very similar diet post-breeding, but that mercury concentrations in body feathers reflect breeding-season diet to some extent. The apparent anomaly between trophic status (as defined using $\delta^{15}$N signatures) and mercury concentrations in body feathers further illustrates that these two parameters are based on two different sources of information. This may go some way to explain why it has been difficult in the past to link interspecific differences in mercury concentrations in body feathers to known diet in seabirds (for example Thompson et al., 1992b). Alternatively, the close agreement in $\delta^{15}$N values between northern fulmars and great skuas may be indicative of winter feeding in two separate locations, which had different $\delta^{15}$N profiles. Variation in the nitrogen signal at the base of the food chain could produce essentially the same $\delta^{15}$N value for different prey at different trophic levels. Hence, fulmars and great skuas may indeed have markedly different diets and trophic positions outwith the breeding season. This difference could in part contribute to the considerable difference in mercury concentrations measured in these two species, but feathers grown at this time may exhibit the same $\delta^{15}$N signatures due to specific food chain nitrogen isotope profiles.

Feathers have clear advantages as monitoring tools for mercury contamination in seabirds. However, timing of moulting and of the replacement of specific feathers within the moult sequence, would appear to have a pronounced effect of mercury burdens in feathers (see Furness et al., 1986), extending to body feathers. The diet (and trophic status) at the time of feather growth, as indicated here through stable isotope measurements, would seem to have far less impact on mercury concentrations in feathers. However, since wintering ranges of these species are very large and overlap extensively (Cramp and Simmons, 1977, 1983), the similarity in $\delta^{15}$N signatures may reflect a corresponding similarity in diet and trophic status at this time. The large difference in the mercury concentrations found in body feathers would appear, therefore, to reflect differences in summer diet (see previously).

Whilst we did not find any significant relationships between mercury burdens and isotopic signatures in any feather type, there were significant positive correlations between different flight feathers for both mercury concentration and isotopic signature (see Section 3 and Fig. 2). In particular, mercury concentration, $\delta^{15}$N and $\delta^{13}$C values were most strongly correlated between primary 10 and secondary 8. Agreement between isotopic signatures in two feathers may be indicative of diets consumed at different times but which were coincidentally very similar isotopically. If this were the case then isotope values would not be useful as a means of elucidating timing of moult and feather growth in birds. Only when isotope values were different between two feathers could one be absolutely certain that those feathers were not grown at the same time. However, the fact that in the present study two isotope signatures and a heavy metal concentration (in this case mercury) were all positively and significantly correlated between two feather types (primary 10 and secondary 8) is perhaps indicative that these feathers may have been regrown together. Since mercury concentrations in feathers represent the level of depletion of the ‘body pool’ of mercury at the time of feather growth (see previously), this alone would tend to suggest that similar mercury concentrations represent concurrent position in the moult sequence. The fact that two isotope values also concur supports this since it is clear that variation exists in isotope signatures between different flight feathers in great skuas (Table 1), a pattern previously noted for northern fulmars (Thompson and Furness, 1995), indicating that these species' diets can vary during the course of flight feather replacement. The application of stable isotope analysis to different feathers may prove to be a useful approach to the elucidation of moult patterns in seabirds, which would otherwise be difficult or impossible to study as much of the mouling process in seabirds takes place away from land following the completion of breeding.
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References


Honda, K., Nasu, T., Tatsukawa, R., 1985. Seasonal changes in mercury accumulation in the black-eared kite, Milvus migrans lineatus. Environmental Pollution (A) 42, 325–334.


Thompson, D.R., Furness, R.W., Lewis, S.A., 1993a. Temporal and spatial variation in mercury concentrations in some albatrosses and petrels from the sub-Antarctic. Polar Biology 13, 239-244.


Thompson, D.R., Furness, R.W., Lewis, S.A., 1995. Diets and long-term changes in \( \delta^{15}\)N and \( \delta^{13}\)C values in northern fulmars Fulmarus glacialis from two northeast Atlantic colonies. Marine Ecology Progress Series 125, 3-11.
