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# Mercury Concentrations in Seabirds from Colonies in the Northeast Atlantic

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**Abstract.** Total mercury concentrations were determined in samples of body feathers from a range of common seabird species breeding at Låtrabjarg, northwest Iceland, St. Kilda, Foula and the Firth of Forth, Scotland and Bleiksøy, Syltefjord, and Hornøy, Norway. Seabirds from Låtrabjarg generally exhibited the highest mercury concentrations, with a trend of decreasing mercury concentrations in a southwest to northeast direction in seabirds at the other colonies; seabirds at Hornøy were generally found to have the lowest mercury concentrations. Some species at the Firth of Forth exhibited relatively elevated mercury concentrations compared to those at Foula and Norwegian sites. Inter-colony differences in diet were thought to be relatively small for most species and unlikely to account for the range of mercury concentrations measured in the seabirds (Låtrabjarg: lowest arithmetic mean mercury concentration in common guillemots *Uria aalge,* 1.6 μg/g, s.d. = 0.6, n = 45; highest arithmetic mean mercury concentration in kittiwakes *Rissa tridactyla,* 5.5 μg/g, s.d. = 1.7, n = 36). The oceanic transport of mercury, together with the effects of anthropogenic inputs of mercury to the northeast Atlantic, and the removal of mercury from the water column via biological activity are discussed as influential factors determining the observed patterns of mercury concentration in seabirds.

Birds have been used extensively as monitors of contaminants in a range of environments. Their position at or near the apex of many food webs results in their exhibiting relatively high concentrations of many pollutant residues, including organochlorines and some non-essential heavy metals, as the result of bio-magnification of lipid-soluble toxins up food chains. In particular, birds offer great potential for the elucidation of trends in environmental contamination with mercury. Analysis of eggs provides a measure of exposure of an individual bird to environmental mercury over a short period during egg formation (Fimreite *et al.* 1974, 1980; Barrett *et al.* 1985; Becker *et al.* 1985, 1989, Lewis *et al.* in press). Because mercury binds strongly to feather keratins (Crewther *et al.* 1965) during feather growth and concentrations in feathers are unaffected by various rigorous treatments (Appelquist *et al.* 1984), the mercury concentration in a sample of feathers provides an easily-obtainable, relatively non-invasive measure of the mercury burden of a given individual. The use of feathers in this way is enhanced by the fact that mercury concentrations of feathers have been shown to correlate positively with those of internal tissues (for example, Furness and Hutton 1979; Ohlendorf *et al.* 1985; Thompson *et al.* 1991), providing an "index" of the mercury contamination of an individual without the need to sacrifice large numbers of birds. Mercury concentrations in feathers reflect also the uptake and storage of mercury over the period between moults (Furness *et al.* 1986; Honda *et al.* 1986; Braune 1987; Braune and Gaskin 1987a), rather than short-term uptake, but consideration of timing of moult, relative to time of feather sampling, should be made when using feathers to monitor mercury concentrations.

The suitability with which birds lend themselves to assessments of environmental mercury contamination has led to many aspects of avian mercury dynamics being investigated. Prominent amongst these have been those of geographical variations in mercury burdens of birds, covering a diverse group of environments. Mercury concentrations in some birds of prey have been determined in order, in part, to investigate spatial variations in mercury burdens of terrestrial and coastal systems (Lindberg and Odsjö 1983; Newton and Haas 1988; Furness *et al.* 1989; Newton *et al.* 1989). Seabirds have often been examined since mercury concentrations tend to be higher within marine ecosystems. Geographical variation in the mercury burden of seabirds has been studied in Hawaii and the north Pacific Ocean (Ohlendorf and Harrison 1986; Honda *et al.* 1990; Burger *et al.* 1992), in the Mediterranean Sea and eastern Atlantic Ocean (Renzoni *et al.* 1986), along the German North Sea coast (Becker *et al.* 1985; Becker 1989), around the coast of Britain (Parslow and Jefferies 1975, 1977; Walsh 1988), in Greenland (Nielson and Dietz 1989) and in Norway (Fimreite *et al.* 1974; Barrett *et al.* 1985). Explanations for the observed patterns in mercury concentrations in the above studies have included variations in environmental concentrations of mercury at the base of the food chain, localised pollution effects and inter- and intra-specific dietary variation. The extent to which inter-species differences in avian mercury concentrations are due to diet can be difficult to assess (Norheim and Kjos-Hanssen 1984; Muirhead and Furness 1988). However, those species feeding at the highest trophic levels within a given food chain have been shown to exhibit relatively high mercury concentrations compared to those species of lower trophic status (for example, Fimreite 1974; Delbeke *et al.* 1984; Braune

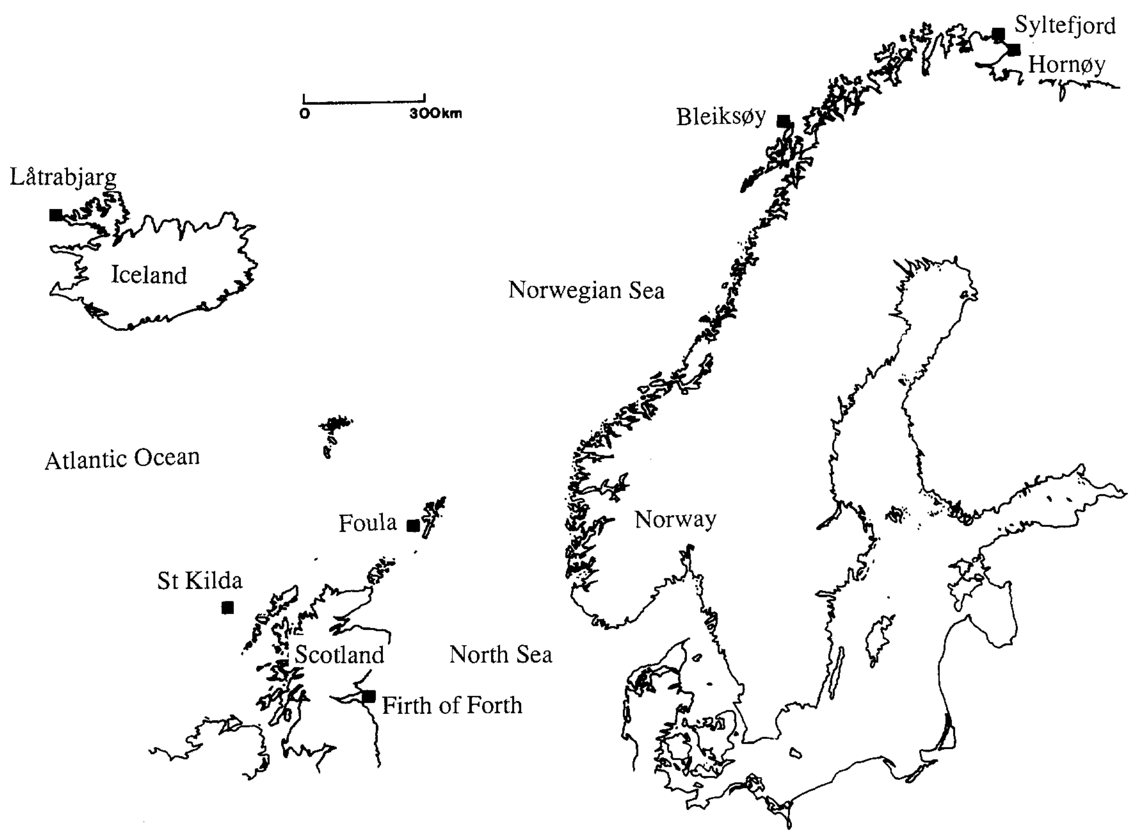


**Fig. 1.** Map showing the location of the seven study sites

1987; Lee *et al.* 1989; Honda *et al.* 1990). In addition, however, confounding factors such as the ability of long-lived, slow-moulting seabirds (for example, some large albatrosses) to bio-transform ingested mercury and store inorganic mercury (Thompson and Furness 1989a; Honda *et al.* 1990; Lock *et al.* 1992) add to the problem of linking observed mercury concentrations with diet.

In this paper, we present data on mercury concentrations for a range of common species of Atlantic seabirds from north-west Iceland, three Scottish and three Norwegian sites. The trends in mercury concentrations are discussed in relation to both interspecific and inter-colony differences.

## Materials and Methods

### *Sample Collection and Storage*

In all cases, four to ten body feathers (Furness *et al.* 1986) were taken from apparently healthy adult birds during the breeding season and placed in mercury-free polythene bags prior to mercury analysis.

Species and sites (Figure 1) sampled were as follows: northern fulmar *Fulmarus glacialis* from Låtrabjarg (northwest Iceland), St. Kilda (Outer Hebrides), Foula (Shetland) and the Bass Rock (Firth of Forth, eastern Scotland); kittiwake *Rissa tridactyla* from Låtrabjarg, Foula, the Bass Rock and the Isle of May (Firth of Forth), Bleiksøy (northwest Norway) and Syltefjord and Hornøy (northeast Norway); razorbill *Alca torda* from Låtrabjarg, St. Kilda, Foula, the Bass Rock and the Isle of May; Brünnich's guillemot *Uria lomvia* from Låtrabjarg and Hornøy; common guillemot *Uria aalge* from Låtrabjarg, Foula, the Bass Rock and the Isle of May and both north-eastern Norwegian sites; Atlantic puffin *Fratercula arctica* from Låtrabjarg, St. Kilda, Foula, the Isle of May, Bleiksøy and Hornøy; shag *Phalacrocorax aristotelis* from Foula, the Isle of May and Hornøy. Sampling years ranged from 1986 to 1991, but the majority of samples were obtained during the period 1989–1991.

### *Mercury Analysis*

All feather samples were analyzed for total mercury using a cold vapor technique following standard acid digestion (Furness *et al.* 1986). Mercury concentrations are expressed on a fresh weight basis, since it is impossible to obtain consistent or meaningful "dry" weights (Thompson 1989). The accuracy of mercury determinations was assessed by analyzing International Atomic Energy Agency horse kidney Reference Material H-8; results obtained fell well within the 95% confidence limits of the mean of published and accepted values (Thompson and Furness 1989b). The limit of detection was 0.01 μg/g, although this concentration was never approached in any sample analyzed in the present study.

### *Statistical Analyses*

Initially, feather mercury concentrations for each species at each locality were tested for goodness of fit to a normal distribution using Kolmogorov-Smirnov one-sample tests. Where appropriate, one-way ANOVA with Student-Newman-Keuls range tests or, for comparisons involving two samples only, t-tests were employed to assess inter-colony and inter-species differences in mercury concentrations. Alternatively, Kruskal-Wallis one-way ANOVA and Mann-Whitney U-tests were used for data which deviated significantly from a normal

**Table 1.** Total mercury concentrations (μg/g fresh weight) in body feathers from adult seabirds sampled at Látrabjarg, Iceland; St. Kilda, Outer Hebrides; the Firth of Forth, eastern Scotland (Isle of May and Bass Rock); Foula (Shetland Isles); and northwest (Bleiksøy) and northeast (Syltefjord and Hornøy) Norway. Values are arithmetic means ± 1 standard deviation, geometric means in parentheses, number sampled and ranges

| Species | Months at colony/year | Iceland | Scotland: St. Kilda | Scotland: Firth of Forth | Scotland: Foula | Norway: Northwest | Norway: Northeast |
|---|---|---|---|---|---|---|---|
| Northern fulmar | 10 | $3.8^{A} \pm 1.5$[a] | $3.3^{B} \pm 1.6$[b] | $2.3^{C} \pm 0.8$ | $1.6^{D} \pm 0.6$ | — | — |
| *Fulmarus glacialis* | | (3.5) 25 | (3.0) 85 | (2.2) 12 | (1.5) 32 | | |
| | | 0.8–8.0 | 1.2–11.5 | 1.0–3.4 | 0.9–3.9 | | |
| Kittiwake | 7 | $5.5^{A} \pm 1.7$ | — | $3.8^{B} \pm 1.7$ | $2.9^{C} \pm 0.9$ | $4.2^{B} \pm 1.3$ | $3.1^{C} \pm 1.2$ |
| *Rissa tridactyla* | | (5.1) 36 | | (3.4) 46 | (2.8) 42 | (4.0) 34 | (2.9) 60 |
| | | 1.6–10.1 | | 0.7–9.5 | 1.6–5.2 | 2.9–9.4 | 1.4–6.8 |
| Razorbill | 6 | $2.7^{A} \pm 1.1$ | $2.1^{AB} \pm 0.6$ | $2.2^{B} \pm 0.8$ | $1.9^{B} \pm 1.1$ | — | $1.7^{B} \pm 0.6$ |
| *Alca torda* | | (2.4) 37 | (2.0) 15 | (2.0) 33 | (1.7) 52 | | (1.6) 30 |
| | | 0.8–5.8 | 1.0–3.3 | 1.2–4.6 | 0.7–5.3 | | 0.8–2.9 |
| Brünnich's guillemot | 6 | $2.1^{A} \pm 0.7$ | — | — | — | — | $1.2^{B} \pm 0.2$ |
| *Uria lomvia* | | (2.0) 38 | | | | | (1.1) 25 |
| | | 1.0–3.4 | | | | | 0.8–1.7 |
| Common guillemot | 7 | $1.6^{A} \pm 0.6$ | — | $3.8^{B} \pm 3.2$ | $1.2^{C} \pm 0.4$ | — | $1.2^{C} \pm 0.3$ |
| *U. aalge* | | (1.5) 45 | | (3.0) 44 | (1.1) 56 | | (1.2) 45 |
| | | 0.7–3.7 | | 1.1–15.4 | 0.3–2.4 | | 0.5–2.2 |
| Atlantic puffin | 6 | $4.8^{A} \pm 1.4$ | $5.1^{A} \pm 1.5$ | $3.2^{B} \pm 2.1$ | $3.7^{B} \pm 1.8$ | $3.0^{B} \pm 0.7$ | $1.0^{C} \pm 0.4$ |
| *Fratercula arctica* | | (4.6) 37 | (4.8) 24 | (2.5) 30 | (3.4) 46 | (3.0) 16 | (0.9) 31 |
| | | 2.3–7.9 | 2.7–8.3 | 0.2–7.6 | 1.5–11.4 | 2.2–4.2 | 0.2–2.3 |
| Shag | 12 | — | — | $2.3^{A} \pm 0.6$ | $1.9^{B} \pm 0.6$ | — | $1.9^{B} \pm 0.6$ |
| *Phalacrocorax aristotelis* | | | | (2.2) 33 | (1.8) 40 | | (1.8) 24 |
| | | | | 1.5–4.4 | 0.8–3.8 | | 1.2–3.4 |

[a]Within each species, arithmetic mean mercury concentrations with different upper case superscripts (A–D) are significantly different.
[b]Data from Thompson *et al.* (1992)

distribution. The word 'significant' has been used in the statistical context only, indicating a probability of chance occurrence of less than 5%.

## Results

There was no significant difference between mercury concentrations in body feathers of kittiwakes from Syltefjord (median = 3.2 μg/g, range = 1.7–6.8 μg/g, n = 30) and from Hornøy (median = 2.6 μg/g, range = 1.4–5.8 μg/g, n = 30; U = 320, z = −1.92, P > 0.05, Mann-Whitney U-test). Similarly, mercury concentrations in common guillemots from these two locations were not significantly different (Syltefjord: arithmetic mean = 1.2 μg/g, range = 0.5–1.6 μg/g, n = 17. Hornøy: arithmetic mean = 1.2 μg/g, range = 0.6–2.2 μg/g, n = 28. t = −0.28, 43 d.f., P > 0.05, t-test). Data from these two north-eastern Norwegian sites have been combined in these species.

Data on mercury concentrations for all species and from all locations are presented in Table 1. Mercury concentrations in body feathers were found to be generally higher in birds sampled from Látrabjarg and St. Kilda when compared to birds from Foula, the Firth of Forth and Norway. Similarly, birds sampled from the Firth of Forth tended to have significantly higher mercury concentrations than those from Foula (Table 1). Kittiwakes and puffins from Bleiksøy had significantly higher mercury concentrations in feathers than those from Syltefjord and Hornøy (Table 1).

Mercury concentrations tended to be highest in feather samples from puffins and kittiwakes, regardless of location (Figure 2). Of the other species studied, guillemots (common and Brünnich's) usually had uniformly low mercury concentrations in feathers with intermediate values being found in razorbills and fulmars (Figure 2). Notable exceptions to this pattern were the relatively high mean mercury concentration exhibited by common guillemots sampled from the Firth of Forth colonies and the relatively low mean mercury concentration exhibited by puffins from northeast Norway (Table 1 and Figure 2).

## Discussion

There are few published data on mercury concentrations in feather samples from seabirds from the north and northeast Atlantic. To our knowledge, there have been no studies of mercury concentrations in Icelandic seabirds of the same species as those analyzed in the present investigation. Similarly, there are no data available on mercury concentrations of feather samples from Norwegian seabirds of the species analyzed here, although the findings of some of the studies of mercury concentrations in eggs of Norwegian seabirds (Fimreite *et al.* 1974; Holt *et al.* 1979; Barrett *et al.* 1985) will be discussed later. Osborn *et al.* (1979) reported mercury concentrations in feather samples from Atlantic puffins (mean = 7.94 μg/g, n = 10) and northern fulmars (mean = 3.34 μg/g, n = 5) from St. Kilda which are similar to those concentrations described here (Table 1), although the analysis of primary feathers on a dry mass basis (about 90% of the fresh mass) in that study differs from the use of body feathers in the present study. The mercury concentrations of feather samples from seabirds from Foula

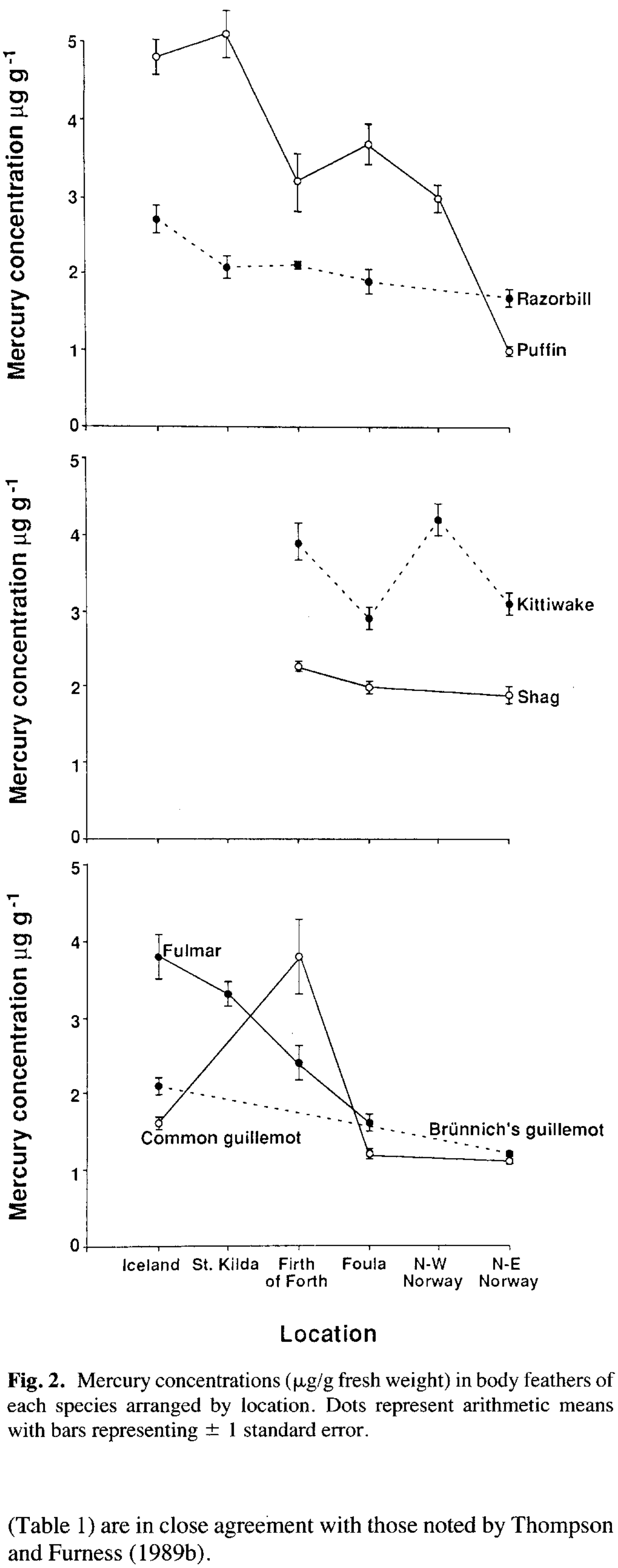


**Fig. 2.** Mercury concentrations (µg/g fresh weight) in body feathers of each species arranged by location. Dots represent arithmetic means with bars representing ± 1 standard error.

(Table 1) are in close agreement with those noted by Thompson and Furness (1989b).

There are no published data on the diets of Icelandic seabirds, although sandeels *Ammodytes marinus* and capelin *Mallotus villosus* were seen to predominate in food items brought back to the colony at Låtrabjarg (R.W. Furness and R.T. Barrett pers. obs.), and fish of this type and size predominate in the diet of Brünnich's guillemots from a wide range of locations (Bradstreet and Brown 1985). Seabirds on Foula were found to feed extensively on sandeels while breeding (Furness 1983; Furness and Todd 1984), the same prey species predominated in the diets of puffins and razorbills at St. Kilda (Harris 1984; Leaper *et al.* 1988). In contrast to Foula, fulmars at St. Kilda fed largely on pelagic zooplankton (Furness and Todd 1984). Seabirds breeding at the Firth of Forth colonies fed predominantly upon sandeels, with clupeid and gadoid species of lesser importance (Harris and Hislop 1978; Galbraith 1983; Harris and Wanless 1986, 1989, 1990, 1991). In north-west Norway (Bleiksøy), puffins fed on sandeels, herring *Clupea harengus* and saithe *Pollachius virens* (Barrett *et al.* 1987), whilst kittiwakes were found to take deep-water lanternfishes (Myctophidae) to some extent (R.T. Barrett pers. obs.). At north-east Norway (dietary data from Hornøy) capelin predominated in the diet of both guillemot species and kittiwakes, with a considerable proportion (25% by weight) of euphausiids in the diet of the latter (Barrett and Furness 1990). Shags fed entirely on sandeels in 1983 (Furness and Barrett 1985), but by 1989, gadoids accounted for 40% (by number) of the diet (Barrett and Furness 1990).

The seabirds studied in this investigation tended to feed largely upon the same prey species, namely small shoaling fish, with fulmars at St. Kilda and kittiwakes at Hornøy taking varying proportions of zooplankton. There is little evidence to suggest that the inter-colony differences in mercury concentrations of a particular seabird species (Table 1) are due to marked variations in diet, with the possible exceptions of fulmars at St. Kilda and Foula and kittiwakes at northwest and northeast Norway. Mercury concentrations in the fish species taken by seabirds in this study were generally low (< 0.1 µg/g wet weight), although this conclusion is based on relatively few studies which do not provide data for all of the regions covered in the present investigation (Portmann 1972; Greig *et al.* 1975; Perttila *et al.* 1982; Clark and Topping 1989; Thompson *et al.* 1992). There have been even fewer studies of mercury concentrations in zooplankton, but published data indicate these to be at least an order of magnitude lower than those reported for marine fish (Knauer and Martin 1972; Braune and Gaskin 1987b). Such a contrast could be a possible explanation of the significant difference in mean mercury concentrations between kittiwakes from northwest and northeast Norway (Table 1), but one might have predicted mercury concentrations to be lower in fulmars from St. Kilda, which feed largely on zooplankton, compared to those in fulmars from Foula which prey upon sandeels and discarded whitefish (Furness and Todd 1984). However, the reverse was found in this study (Table 1).

Given that, for most species, differences in breeding-season diet between colonies are slight, the possibility should be considered that differences in mercury concentrations exist between prey in different areas.

The results (Table 1) indicate a general decline in avian mercury concentrations from St. Kilda; through Foula and northwards along the Norwegian coast in a southwest to northeast direction, with somewhat higher mercury concentrations in some species from the Firth of Forth. These colonies are exposed to the north Atlantic drift current which flows northwards along the west coasts of Britain and Ireland, splitting at the north of Scotland to continue in a northeasterly direction as the Norwegian current, and to flow southwards into the North Sea along the east coast of Britain, then turning northwards up the west coast of continental Europe and subsequently joining the

Norwegian current. Mercury, from natural and anthropogenic sources, entering this system in the southwest via, for example, pluvial deposition (Gardner 1975), could be depleted from the water column by biological activity or by sequestration by particulate matter. Several studies have noted reduced mercury concentrations in sea water in association with biological activity (Chester *et al.* 1973; Gardner 1975; Gill and Fitzgerald 1987). The stripping of mercury from the water column from the southwest to the northeast would tend to result in a gradient of mercury concentrations in biota in a similar direction, and could account for the observed pattern of seabird mercury concentrations at St. Kilda, Foula and Norway. Walsh (1988) noted highest mercury concentrations in gannets *Sula bassana* from the southwest of Britain and Ireland and lower concentrations to the north and east. Similarly, mercury concentrations in eggs of seabirds from northern Norway have been shown to be generally lower than those in eggs of seabirds from more southerly locations within Norway (Fimreite *et al.* 1974; Holt *et al.* 1979), although this trend of decreasing mercury burdens with latitude at Norwegian colonies was not found by Barrett *et al.* 1985). The relatively high mean mercury concentrations found in some species from the Firth of Forth in this study (Table 1), differ from the finding of Walsh (1988) in gannets, and may be indicative of an increased exposure to mercury pollution in species which spend some or all of the nonbreeding period within the North Sea. This relatively shallow sea receives considerable industrial discharges via major continental river systems, and elevated mercury burdens have been reported in seabirds breeding along the German North Sea coast (Becker *et al.* 1985; Becker 1989). Common guillemots, for example, breeding at the Firth of Forth are thought to spend at least part of the remainder of the year along continental European coasts in the southern North Sea (Mead 1974; Blake *et al.* 1984).

The fact that mercury concentrations in this study were found to be generally highest in seabirds from Låtrabjarg, northwest Iceland (Table 1) is noteworthy, but cannot be fully explained at this time. Seabirds at that location were observed to be feeding in an area to the northwest of Låtrabjarg (Figure 1) (R.W. Furness and R.T. Barrett pers. obs.), and as such were exposed to an essentially different current system, the east Greenland current, than those seabirds at British and Norwegian colonies. This water mass flows in a southwesterly direction off the northwest coast of Iceland. Several studies have reported somewhat elevated mercury concentrations in sea water samples taken from this region (Carr *et al.* 1972; Gardner and Riley 1974; Gardner 1975), but more recently, however, Olafsson (1983) found considerably lower mercury concentrations than those previously reported. Despite the variations in mercury concentrations measured in seawater from this area, it is difficult to explain the consistent, relatively high mercury concentrations in seabirds from northwest Iceland other than by considering the possibility of somewhat higher mercury concentrations in the marine system in which they feed, especially since the diets of the Icelandic seabirds are likely to be very similar to those of seabirds from the other locations in this study. Furthermore, it is interesting to note that in contrast to the results found here, Thompson *et al.* (1992) found no difference between mercury concentrations in great skuas *Catharacta skua* from colonies in southern Iceland and those in skuas from Foula, both of which are exposed to the north Atlantic drift current.

The significant inter-specific differences in mercury concentrations of seabirds at a given colony reveal that puffins and kittiwakes had relatively high mercury concentrations, with lower mercury concentrations being found in guillemots (Figure 2). There is little evidence to support the suggestion that dietary variation alone could account for the significant differences in mercury concentrations measured in feather samples. For example, arithmetic mean mercury concentrations increase by a factor of over three in the seabird species at Foula (Table 1), this in species which have remarkably similar diets (Furness 1983). The winter distribution and exposure to mercury of particular species might influence mercury burden, but very little is known of the winter diets of seabirds. However, most of the seabirds studied here attend their breeding area for considerably more than half of the year and are thought to have a far higher daily food intake while breeding. Indeed, the resident shag and the fulmar (present for ten months per year; Table 1) show the same geographical pattern of mercury concentrations as the most mobile of the study species, the puffin (Table 1), suggesting that breeding season intake is largely responsible for mercury concentrations in seabirds. Analysis of mercury concentrations in feathers from Icelandic seabirds in museum collections (Thompson *et al.* 1992) might help to determine whether the high concentrations of mercury in seabirds from northwest Iceland are a consequence of aerial transport of pollution or a natural feature of that ecosystem.

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