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Mercury load according to moulting area in primaries of the nominate race of the Lesser Black-backed Gull *Larus f. fuscus*

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The effects of environmental loading on the levels of mercury in primaries of the Lesser Black-backed Gull *Larus f. fuscus* were studied in the Gulf of Finland in 1979–91. The mercury levels in the shed primaries found at the birds' breeding ground differed according to the site of feather growth. In the primaries grown at the breeding ground by the Baltic Sea, the levels of mercury tended to increase all through the 80s, correlating with the mercury levels in the Baltic herring (*Clupea harengus*). No temporal trends could be discerned in the "African" feathers. It is suggested that the mercury load derived from the species' staple food in the Baltic nowadays contributes more to the mercury level in moulted primaries than the load derived from food in the African wintering grounds.

1. Introduction

Birds get their mercury load primarily via dietary intake (Tejning 1967). Formerly, it was commonly understood that the mercury level in a feather would chiefly reflect the level in the diet during feather growth (e.g. Johnels & Westermark 1969, Jensen et al. 1972, Lindberg & Odsjö 1983, Lindberg et al. 1983, Solonen & Lodenius 1984), as the bulk of the mercury is allocated to the feathers during their growth (Tejning 1967). However, mercury also builds up between the moults, and this load, stored in the body tissues, is mobilized for deposition in the newly developing feathers when the moult begins (Gochfeld 1980, Furness et al. 1986, Braune & Gaskin 1987a). An individual primary shows different levels of mercury, depending on where it occurs in the moulting sequence. The primaries shed first show higher levels than those shed last (Johnels et al. 1968, Gochfeld 1980, Bühler & Norheim 1982, Lindberg & Odsjö 1983, Appelquist et al. 1984, Furness et al. 1986, Lewis & Furness 1991), and this has been interpreted as a function of (i) varying mercury levels in the environment, and (ii) the extent to which stored mercury is eliminated from the bird's tissues to the feathers (for a review, see Furness et al. 1986, Furness 1987, Solonen & Lodenius 1990).

Analysis of feathers collected on the moulting grounds makes it possible to monitor the mercury loads in birds without having to kill them. This presupposes approximate knowledge of the ordinal numbers of the shed feathers.

We have employed this method for the Lesser Black-backed Gull of the nominate race (*Larus f. fuscus*), a form classified as "endangered" over most of its present range in the Baltic and Fennoscandia (Anon. 1992). It is the only true long-distance migrant among gulls in Fennoscandia and probably the only equatorial migrant gull in the Northwestern Palaearctic (see e.g. Schüz 1971, Glutz & Bauer 1982, Kilpi & Saurola 1984). This subspecies is also known as having a periodic stepwise moult (*periodische Staffelmauser*), a pattern typical of terns, Sternidae (Stresemann & Stresemann 1966). The stepwise moult involves simultaneous replacement of the remiges in two or three moult waves during the once-a-year remigal moult. The inner 1–3 primaries are moulted twice in the stepwise moult of *L. f. fuscus*, but only once in the normal descendent moult of other *Larus* gulls.

We aim to study two principal questions: (i) have the mercury levels in *L. f. fuscus* increased as a consequence of the overall pollution in the Baltic Sea, and (ii) do the differentially moulted primaries reflect any differences in mercury intake between moulting areas?

2. Material and methods

2.1. Collecting primaries

The study was conducted at the Söderskär Game Research Station in the central northern shore of the Gulf of Finland (60°07′N, 25°25′E) in 1980–83 and 1986–91. The study colony breeds on a treeless islet with dense grass vegetation, 1.3 ha in size. Every year during the brood-rearing period, the colony was visited at 1–3-day intervals and all the primaries found in the terrain were removed, labelled and stored in paper envelopes.

In an earlier study (Hario 1984), it was established that 12–34% of the *L. f. fuscus* specimens in this colony commenced their primary moult at the breeding site and that at least 20% of these had undergone the stepwise moult prior to spring migration. The moulting birds shed 1–3 of the innermost primaries at the breeding site, and after the growth of the new primaries was completed, the moult was arrested for the migratory period. The rest of the population (i.e. the majority) did not commence the moult at the breeding site at all and migrated with the old feathers. In the subsequent study years, 1985–91, the moulting cohort has remained roughly the same: 9–27% ($G = 1.21$, $P > 0.1$). The slight decrease in the proportion of moulting birds (for the calculation of the proportions, see Hario 1984) may be an artefact resulting from the increasing occurrence of early breeding failures in the colony. Failed breeders remove to "clubs" on the shoreline and on open rocks, where the wind and waves carry the feathers into the sea as soon as they are shed. Thus, although the searches were conducted systematically, the shedding sites must be considered more or less accidental, this giving rise to highly varying sample sizes.

2.2. Moulting pattern of shed primaries

The collected primaries could be grouped into three different categories according to the wear of the feather (as evaluated by eye): fresh, intermediate and worn. The differences stem from the age of the feather and can be related to the moulting pattern:

"Worn" primaries were produced by individuals that had undergone the normal descendent moult, starting it in the previous summer on the breeding grounds, interrupting it for the autumn migration period and ending it on the wintering grounds. The "worn" primaries had thus been used for two migration flights (autumn and subsequent spring), i.e. both-ways trip to equatorial Africa, totalling 12 000–16 000 kilometres. The age of the "worn" primaries was about one year.

"Fresh" primaries had been grown on the wintering grounds prior to the spring migration, to replace the innermost worn primaries in individuals that had undergone the periodic stepwise moult. According to the examination of museum collections (see later), their age was about 3–4 months.

"Intermediates" were slightly more worn than the "fresh" ones, with a less glossy surface and the terminal band shading into dirty white instead of pure white. On the other hand, they lacked the ragged appearance of the "worn" primaries. They were in seemingly "good condition", but it was difficult to place them in either of the two previous categories. The reason for this is that they had been used for only one migration journey (spring) by individuals that had not commenced the moult on the breeding grounds (unlike those with "worn" primaries) and had not undergone the stepwise moult (unlike those with "fresh" primaries). They had been formed in the previous autumn upon arrival at the wintering grounds, from October on (Stresemann & Stresemann 1966) and were thus roughly six months older than the "fresh" ones and three months younger that the "worn" ones.

In the following text, the worn primaries are named "Baltic" primaries, the intermediates are named "African autumn" primaries and the fresh ones "African stepwise" primaries.

Primaries of subadult birds, recognizable by their colouring, were discarded. The numbers of primaries collected are shown in Table 1, ranked according to the year of growth. In addition, all the primaries were analysed in one wing from each of six individuals found dead in 1990–91 in the easternmost part of the Gulf of Finland (60°19′N, 27°35′E).

2.3. Mercury analyses

The mercury analyses were made at the Department of Environmental Conservation of the University of Helsinki. Total mercury in the feathers was determined by cold vapour atomic absorption spectrophotometry (Coleman MAS-50), by the method described in Solonen & Lodenius (1990). The results are expressed as mg total Hg/kg dry weight.

2.4. Studies on museum skins

The moulting patterns were verified using skin collections at the Zoological Museums of Helsinki, Stockholm and Copenhagen and at the British Museum (Natural History), Tring. Of the 31 specimens of adult *L. f. fuscus* taken from non-wintering grounds in the breeding and post-breeding seasons, 9 were at the wing-moulting

Table 1. Mercury levels in *Larus f. fuscus* primaries of three different moulting patterns (see footnote). Means ± standard deviation based on untransformed data. n = number of analysed feathers.

	"Baltic"			"African autumn"			"African stepwise"		
	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD	Range	n
1979	3.7 ± 2.2	0.7 – 11.7	21	4.6 ± 1.7	3.0 – 7.5	5			..
1980	4.8 ± 1.3	3.6 – 6.5	4	6.8 ± 6.0	2.5 – 11.0	2	4.8 ± 2.3	2.7 – 8.5	6
1981	5.5 ± 2.5	2.8 – 10.5	15	3.4 ± 0.9	2.0 – 4.3	5	2.7 ± 1.3	1.9 – 4.9	5
1982	5.0 ± 1.8	2.7 – 8.6	10	3.7 ± 0.8	2.8 – 4.7	5	4.1 ± 1.1	2.8 – 5.3	4
1983			..			..	4.0 ± 1.3	2.7 – 6.2	6
1985	5.6 ± 0.6	4.8 – 6.2	6	4.5 ± 2.1	1.2 – 7.0	7			..
1986	6.3 ± 3.0	2.6 – 11.6	10	3.7 ± 2.0	2.2 – 6.6	4	3.7 ± 3.7	1.3 – 10.1	5
1987	7.5 ± 2.0	5.2 – 9.8	5	6.3 ± 2.0	4.0 – 9.1	9	5.7 ± 4.9	1.7 – 12.8	4
1988			..	4.7 ± 2.1	2.9 – 7.0	3	5.6 ± 1.4	4.1 – 8.0	6
1989	4.8 ± 2.1	1.8 – 8.5	12	2.4 ± 2.8	1.2 – 8.1	6	4.8 ± 0.7	4.1 – 5.6	3
1990	7.8 ± 4.6	1.7 – 15.2	7	6.7 ± 3.3	1.8 – 12.3	8	4.1 ± 2.5	1.1 – 7.4	9
1991			..			..	4.5 ± 1.4	2.4 – 5.8	6
All years	5.3 ± 2.7	0.7 – 15.2	90	4.7 ± 2.6	1.2 – 12.3	53	4.4 ± 2.3	1.1 – 12.8	54

The material is arranged according to the year of feather growth. Hence, the 1979 "Baltic" and "African autumn" primaries were actually shed (and collected) in 1980, and the 1979 material does not include any "African stepwise" primaries grown and shed in 1979. The same applies to the 1985 material, collected in 1986, after a two-year pause in sampling (see Material and methods). In 1991, only "African stepwise" primaries were available, for the same reason: "Baltic" and "African autumn" primaries for 1991 were not shed till 1992. The percentage of the total material accounted for by "African stepwise" primaries has not changed from 1980–83 (26%) to 1986–91 (30%) ($G = 0.46$, $P > 0.1$).

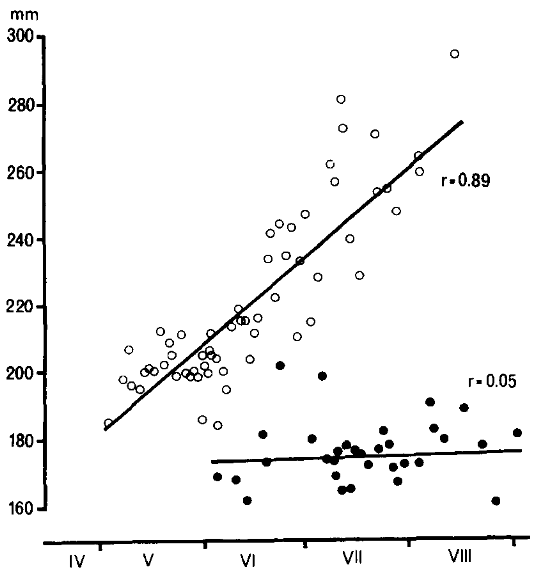

Fig. 1. The lengths of primaries shed by *L. f. fuscus* (filled circles) and *L. argentatus* (open circles) during the breeding periods of 1980–83. Daily means of a total of 137 *L. f. fuscus* and 337 *L. argentatus* feathers (from Hario 1984).

stage (29%) and none had shed more than the three innermost primaries. The stepwise moult was established in four adults from the African wintering grounds (see later).

3. Results

3.1. Sequence of primaries

On the breeding grounds, *L. f. fuscus* adults shed only the short innermost primaries. Their sequence (ordinal number) could not be worked out, but a comparison with the shed primaries of neighbouring Herring Gulls (*L. argentatus*) clearly demonstrates that only the uniformly coloured inner 1–3 (rarely 4?) primaries of about equal size were shed, whereas *L. argentatus* extended the moult to the longer outer primaries (with different colouration) (Fig. 1). Had the moult of *L. f. fuscus* adults also extended to the longer outer primaries during the 3-month period of wing moult at the breeding site, then the size distribution of the collected primaries would have approached that of *L. argentatus* adults.

3.2. Mercury levels in "Baltic" and "African" feathers

The mean annual levels of mercury in "Baltic", "African autumn" and "African stepwise" primaries are shown in Table 1. There was no overall difference between the groups (Kruskall-Wallis test, $H = 4.50$, $P = 0.1$), but the "African stepwise" primaries tended to have higher levels than the "Baltic" ones ($H = 3.91$, $P = 0.04$).

There seemed to be a temporal trend, approaching significance, in the mercury levels of the "Baltic" primaries, the readings increasing from 1979 to 1990 ($r_s = 0.69$, $n = 9$, $P = 0.05$), but not in the levels of either "African" group ("African autumn": $r_s = 0.01$, $n = 10$ $P = 0.98$ and "African stepwise": $r_s = 0.10$, $n = 10$, $P = 0.76$) (data from Table 1).

3.3. Mercury levels in the whole wings

Of the six wings in which all the primaries were analysed, two had "worn", two "intermediate" and two "fresh" innermost primaries. These are referred to as "Baltic", "African autumn" and "African stepwise" wings in Fig. 2. In the two former groups, the mercury levels decreased gradually from the innermost to the outermost primaries (Kendall rank correlation: $\tau = 0.78$, $P = 0.004$ and $\tau = 0.86$, $P = 0.0009$). In the "African stepwise" group, however, the low levels in primaries nos. 1 and 2 interfere with the serial correlation analysis, resulting in a non-significant distribution ($\tau = 0.33$, $P = 0.25$).

4. Discussion

4.1. Validity of the material

A possible source of error in our material is our inability to identify the ordinal number of each primary. One could argue that even though the sampling units (the primaries) have been drawn from the population quite randomly (see Methods), there is still a possibility that the "Baltic" material contains more, say, primaries no. 1 (with the highest mercury level, Fig. 2) and the "African autumn" material more primaries no. 3 (lower

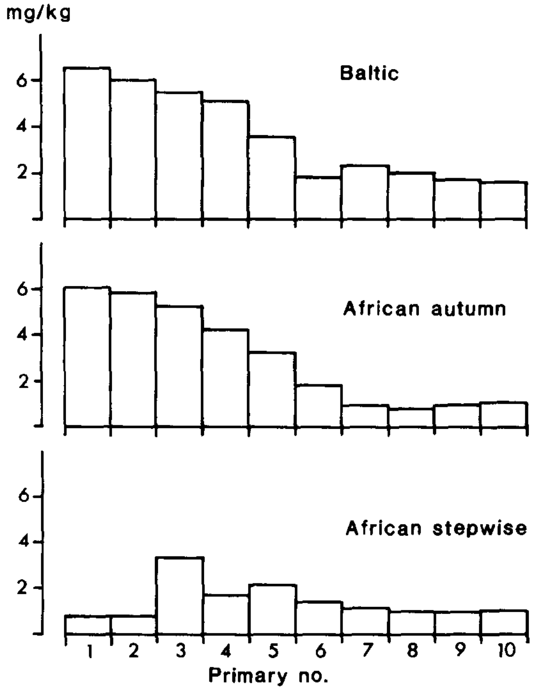

Fig. 2. Examples of mercury levels in primaries of the three moulting patterns of *L. f. fuscus*. The values in each group are the mean mercury concentrations (mg/kg dry weight) of the individual primary feathers (nos. 1–10) of two adult gulls found dead in the easternmost part of the Gulf of Finland in 1990–91.

mercury level than in no. 1). If so, the distributions need not be skewed despite the bias in the means. However, this would mean that we systematically, year after year (see the annual differences in mercury levels among groups in Table 1), missed more of the first shed 1—2 primaries in the "African autumn" group than in the "Baltic" group, and vice versa (more "Baltic" primaries nos. 2–3 missed than "African autumn" ones). We consider this sampling error very improbable, although we are not able to exclude its possibility. However, with a mixture of first, second and third primaries from different birds, we feel that the variation in the mercury load within birds could partially cancel out the effects of the hypothesized skewed composition in primary groups.

Assuming that this sort of sampling error does, nevertheless, exist, we feel that it should appear at a constant rate over the years. We will therefore confine our further discussion to the changes in mercury levels between years instead of trying to establish how close our sample means are to the population means. We also assume that the sexes are loaded in a constant manner from year to year (for differential loading in sexes, see Braune & Gaskin 1987a).

4.2. Mercury levels in the stepwise moulted primaries

Our result that the mercury concentrations decrease progressively from the innermost to the outermost primaries in "Baltic" and "African autumn" wings (Fig. 2) is in accordance with the findings for a variety of species of Gochfeld (1980), Furness et al. (1986) and Braune & Gaskin (1987a, b), who considered this sequential decrease to result from decreasing loadings from body tissues during the current mobilisation.

In the stepwise moult of *L. f. fuscus*, however, the growth of "fresh" inner primaries coincides with completion of the outermost primaries of the first moulting wave. This results in a lower mercury load in the inner primaries, because the primaries of the first moulting wave have received the highest mercury load from stores in the body tissues. This is why the "African stepwise" group in our material shows lower mercury levels than the two other groups. This has less to do with differences in the dietary intake during feather growth between the Baltic and Africa.

We have confirmed this concurrent growth of the two primary groups in the stepwise moult in our examination of the museum skins in the Stockholm, Copenhagen and Tring collections: four *L. f. fuscus* adults from Central African countries (Zaire, Nigeria, Tanzania, Ethiopia) had the new innermost 1–3 primaries growing simultaneously with the outermost ones in January–February.

In museum collections, the skins of moulting adults of *L. f. fuscus* originating from the wintering grounds are comparatively rare. The Stresemanns (1966) were able to find only two such specimens in their vast material.

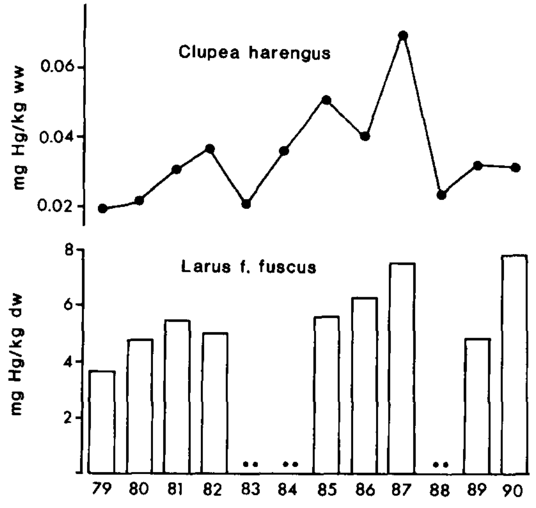

Fig. 3. Annual mean concentrations of mercury in *Larus f. fuscus* "Baltic" primaries (columns) and in *Clupea harengus* muscle (line). The results for *Clupea harengus* are from Haahti (1991) and from the Finnish Institute of Marine Research (unpubl.).

4.3. Temporal trends in mercury levels of the "Baltic" and "African" primaries

Apart from the two first study years, there was a tendency for the "Baltic" primaries to show higher mercury levels than the "African autumn" ones, although not statistically significantly. More interestingly, there was also a suggestive upward trend in the mercury levels of the "Baltic" primaries from 1979 to 1990, the mean level in 1990 being on average twice as high as that in 1979. No such trend was seen in either of the "African" groups.

The increasing levels in "Baltic" primaries fit what is known about the gross occurrence of mercury in the Finnish environment all through the 80s. The mercury emission into air, water and soil increased markedly during the 80s, as measured from the emissions from different kinds of industrial sources (Mukherjee 1989).

The increasing levels in the "Baltic" primaries also correlate with the trend of the mercury concentrations in the Baltic herring (*Clupea harengus*) in the Gulf of Finland (Fig. 3, Kendall rank correlation, $\tau = 0.54$, $n = 9$, $P = 0.040$). As herring is the staple food of *L. f. fuscus* in the study area (Hario 1990), acquisition via dietary intake is evidently responsible for the current increase in the mercury levels of the "Baltic" primaries.

4.4. Secondary effects of mercury

The mercury accumulated in the tissues of seabirds is predominantly in organic form, the most lethal of the compounds being methylmercury (for reviews, see e.g. Dale et. al. 1973, Furness 1987). The digested mercury entering the blood circulation ends up in the emerging feather, which after having been keratinized becomes physiologically isolated from the rest of the body (Voitkevich 1966), thus forming a resistant depot for mercury (Appelquist et al. 1984, Goede & de Bruin 1986). During a complete moult, as much as 93% of the total body burden of mercury in adult Bonaparte's Gulls (*Larus philadelphia*) is distributed to the feathers (Braune & Gaskin 1987a). In domestic hens, the corresponding figure ranged from 40 to 95% (Tejning 1967).

Unlike several other heavy metals, which deposit in bird feathers via atmospheric fallout as well (Hahn et al. 1989, 1990), mercury is believed to deposit almost exclusively via dietary intake (e.g. Tejning 1967, Westermark et al. 1975). Excretion is possible during the moult, when the feather is shed, and via the excreta, and, in females, as a loss into the eggs.

The effects of the moult on the levels of mercury in feathers and body tissues in Bonaparte's Gull were studied by Braune & Gaskin (1987a). Their study, based on 222 shot specimens, revealed significant differences between sexes in mercury in primaries nos. 1–5, males having higher concentrations than females. Adult females did not differ from second-year birds (sexes pooled) in any of the comparisons, whereas juveniles (first-autumn) had the lowest mercury concentrations of all cohorts in primaries nos. 1–5. This gives strong support for the interpretation that the mercury loading in primaries is derived both from stores in body tissues (female allocating a part of it to the egg) and from dietary intake (juveniles having been exposed for a shorter time than older age classes).

We measured the mercury levels in a small sample of eggs of *L. f. fuscus* from the study area in 1984 (detailes in Uuksulainen 1992). The levels ranged from 0.11 mg/kg (wet weight) to 0.51 mg/kg, averaging 0.22±0.15 (SD, n = 11). The mercury levels in fresh breast muscle tissues, liver and feathers have shown the ratio 1:3:7 (Westermark et al. 1975), and the content in eggs is about 10–20% of that in the liver (Ohlendorf et al. 1978). With the mean annual levels of the "Baltic" primaries (5.3), the liver would score 2.27 mg/kg and the eggs 0.22–0.44 mg/kg. The latter values agree rather well with the levels in our small egg sample, suggesting that the acquisition of nutrients for egg formation takes place on the breeding grounds in the Baltic. Little is known, however, about the secondary effects of mercury on fish-feeding birds. According to Dale et al. (1973), reproduction in pelagic birds is not affected at levels below 10 mg/kg (dry weight) in the liver, whereas signs of poisoning might be expected to appear at levels over 25 mg/kg. Converted into dry weight (see Dale et al. 1973), our estimated concentration in the liver is 10.4 mg/kg, which is well below the concentrations at which symptoms of reduced reproduction should appear. The corresponding value based solely on the 1990 levels in the "Baltic" primaries (7.8) is 15.4.

As was noted, the mercury levels in the Baltic environment are increasing, and the crude amount of mercury allocated from the female gull's body to the eggs is probably also increasing. Our readings of mercury in the primaries may be minimum figures, as part of the "Baltic" material stems from females that had recently allocated some of their mercury burden to eggs, prior to feather growth (in 1984, the mean mercury concentration for a complete clutch of three eggs amounted to 0.68 mg/kg).

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Selostus: **Suomenlahden selkälokkien käsisulkien elohopeapitoisuus — saanto muuttomatkan ääripäissä**

Nimirodun selkälokki aloittaa käsisulkasatonsa joko pesimäpaikoilla kesällä tai vasta saavuttuaan talvehtimisalueilleen Afrikkaan samana syksynä. Pesimäpaikoilla kasvatetut sulat (n. 1–3 sisintä käsisulkaa) ovat seuraavana vuonna raskaasti kuluneita ja useimmat helposti erotettavissa afrikkalaisista sulista, jotka ovat joko aivan tuoreita (porrastuneesti keväällä ennen paluumuutolle lähtöä uusitut) tai lievästi kuluneita (edellisenä syksynä normaalissa, ns. laskevassa järjestyksessä sulitut).

Söderskärin pesimäyhdyskunnista talteen poimituissa Afrikassa ja toisaalta Itämeren alueella kasvatetuissa käsisulissa oli erilaiset elohopeapitoisuudet vuosina 1979–91: Itämeren alueella kasvatetuissa sulissa oli lievästi korkeammat elohopeapitoisuudet kuin Afrikassa kasvatetuissa ja lisäksi Itämeren sulissa pitoisuuksien suuntaus oli nouseva läpi koko tutkimusjakson. Afrikkalaisten sulkien elohopeapitoisuuksissa ei ollut merkitsevää ajallista muutosta. Itämeren alueella kasvatettujen sulkien pitoisuudet korreloivat merkitsevästi silakan elohopeapitoisuuksien vuosivaihteluiden kanssa Suomenlahdella. On ilmeistä, että yhä suurempi osuus selkälokin sulkasadon aikaisesta elohopeakuormituksesta on peräisin sen pääravinnosta pesimäalueilla.

Sulkien elohopeapitoisuuksista lasketut rintalihaksen ja rasvan elohopeapitoisuudet olivat vajaa puolet niistä pitoisuuksista, joissa elohopealla otaksutaan olevan vaikutusta kalaravintoa käyttävien merilintujen lisääntymiseen. Pitoisuuksien kasvu läpi 1980-luvun on kuitenkin huomionarvoinen asia.

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