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Feathers of birds of prey as indicators of mercury contamination in southern Finland

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Mercury levels in feathers of nestling (162 broods) and fully-grown individuals (n = 48) were studied. Within feather variation was considerable in many individual flight feathers. In juv. ospreys the mercury levels in distal parts of secondary coverts were significantly higher than those in proximal parts ($p<0.01$). In total feathers, the mercury levels were higher and their variations were larger in ad. than in juv. accipiters. Various irregularities in the mercury levels in different parts of the plumage of a bird seem to support the hypothesis that the mercury in the food eaten during feather growth considerably affects the mercury levels of the feathers, while the regular trends mainly support the hypothesis that the amount of mercury stored in body tissues is a determining factor of plumage levels. The importance of these factors seems to vary depending particularly on the age of the birds. From the result of this study, feathers as indicators of environmental mercury pollution should preferably be from nestlings. Small feathers are preferable to larger ones, and total feathers should be analysed rather than only parts of them.

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Introduction

Mercury levels in birds' feathers reflect the level circulating in the blood during the period of feather growth (e.g. Johnels and Westermark 1969, Westermark et al. 1975). Besides reflecting dietary intake at that time, the mercury level in the blood might be affected by the amount of mercury stored in other tissues of the body (see also Furness 1987). Recently it was suggested that the amount of mercury stored in body tissues is the main factor determining levels in plumage (Furness et al. 1986). Tejning (1967) found that ingested methyl mercury in domestic fowl *Gallus gallus* was deposited in the blood cells and internal organs and thereafter gradually transported to the growing feathers. During the growth of feathers, most of the mercury load not eliminated in excrement and eggs seems to accumulate in the plumage (cf. Furness 1987). Thus, feathers contain higher concentrations of mercury than generally found in the tissues of a bird (e.g. Westermark et al. 1975, Häkkinen and Häsänen 1980). As they have a higher trophic position, birds of prey in general accumulate greater concentrations of mercury than found in other species (e.g. Berg et al. 1966, Johnels and Westermark 1969, Jensen et al. 1972, Lindberg and Odsjö 1983, Solonen and Lodenius 1984, Frøslie et al. 1986).

The levels of mercury in feathers have been used to indicate the degree of mercury contamination of the environment (e.g. Berg et al. 1966, Jensen et al. 1972, Westermark et al. 1975, Solonen and Lodenius 1984, Applequist et al. 1985, Furness 1987). Feathers can easily be collected from moulting places or taken from live birds without harming them, as only a few small feathers are enough for analysis. In addition, trends may be examined by using museum specimens. However, as the growth of individual feathers takes several weeks, and that of the entire plumage several weeks, months or even years in young and adult birds, respectively, one can expect some variation in mercury levels in the feathers of an individual bird. This has been

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Tab. 1. Mercury levels (mg kg^{-1}) in different regions (d = distal, m = middle, p = proximal) of individual flight feathers (A-E) in some specimens of accipiters and one osprey in southern Finland. Feathers A-B were primaries, C secondaries, and D-E rectrices.

Specimen		Mercury levels (mg kg^{-1}) in feathers				
		A	B	C	D	E
A. gentilis ad. female	d	15	6.7	15.5	10	20.5
	m	11	8.1	14.5	17	14.5
	p	12	8.9	14	13	10
A. nisus ad. female	d	4.8	17	10	4.8	5.2
	m	3.9	14	7	2.7	3.7
	p	2.4	9	6.1	2.6	1.8
A. nisus ad. male	d	3.8	26	3.6	3.3	3.6
	m	4.4	19	3.5	4.4	5.2
	p	4	15	3.3	3.6	4.6
A. nisus juv. female	d	2.5	3.8	5	2.5	2.4
	m	2.7	3.7	3.8	3	3.4
	p	4	2.8	3	4.6	4.4
A. nisus juv. male	d	2.9	3.6	4	2.7	2.5
	m	3	3.1	3	3.4	2.9
	p	3.5	2.1	2.4	4.4	3.2
P. haliaetus juv.	d	4.7	4.7	5	4.6	4.7
	m	3.7	3.7	4.4	–	–
	p	2.7	2.8	3.3	2.4	3.0

demonstrated both between different parts of individual feathers (Berg et al. 1966, Johnels and Westermark 1969, Goede and de Bruin 1984) and between different parts of the plumage (Johnels et al. 1968, Johnels and Westermark 1969, Westermark et al. 1975, Bühler and Norheim 1981, Doi and Fukuyama 1983, Applequist et al. 1984, Furness et al. 1986).

In this paper, we examine the mercury levels in feathers of birds of prey using samples collected mainly from nestlings in four breeding seasons in southern Finland. Besides comparing the levels in different species showing the degree of mercury contamination of different food webs, we investigated how concentrations varied between different parts of the feathers and plumage, within and between broods, and annually. We have tried to determine which of the theories, relating plumage mercury level and the factors stated above, best fitted our data. The possible sources of mercury and suitability of feathers of birds of prey as indicators in monitoring the mercury levels in the environment were also considered.

Material and methods

To study the variation of the mercury levels in different parts of the plumage in ad. and juv. birds, we examined five fully-grown accipiters, one female goshawk *Accipiter gentilis* in ad. plumage and four sparrowhawks *A. nisus*, of both sexes in ad. and juv. plumages, found dead in the neighbourhood of the Lammi Biological Station, as well as one juv. osprey *Pandion haliaëtus* killed by an eagle owl *Bubo bubo* near Porvoo, on the southern coast of Finland. From each specimen, mantle and breast feathers, two primaries, one secondary, and two rectrices were analysed. Flight feathers (remiges and rectrices) were cut in 2–5 pieces to study the mercury levels in different parts of individual feathers. The distal and proximal parts of secondary coverts of 20 nestling ospreys were studied separately. Mercury levels in fully-grown birds were also studied from museum specimens of sparrowhawk (7 ad. and 31 juv. collected in southern Finland in 1930–80 (Zool. Mus., Univ. of Helsinki) (see Solonen and Lodenius 1984), and from five living ad. tawny owls *Strix aluco* of the same population as nine nestlings from nine broods were sampled in 1986.

Feather samples of nestlings were collected mainly in the Uusimaa province, of southern Finland, between 1984 and 1987 (details in Solonen 1988). Depending on the size of the feathers, 1–3 secondary coverts were taken from each half-grown to nearly fledged young of the broods studied. If the feathers available were small and little-developed, the samples of a brood were pooled, otherwise, generally, feathers of each individual were analysed separately. Seven species of diurnal birds of prey and six species of owls were included. The total number of broods studied was 162; 1–4 nestlings per brood were examined. The most intensively studied species were goshawk (34 broods), sparrowhawk (36), common buzzard *Buteo buteo* (18), osprey (32), and tawny owl (16).

The mercury analyses were performed at the Dept of Environ. Conserv., Univ. of Helsinki. The feather samples were oven dried at 50°C and digested in 10 ml of concentrated $H_2SO_4+HNO_3$ (4:1), using an aluminium hot bloc (+85°C; 4 h). The mercury contents were measured with an accuracy of 0.1–1 mg kg^{-1} (depending on the sample size) using cold-vapour atomic absorption spectrometry (Coleman MAS-50).

The first author was responsible for the design of the study, collecting samples, and preparing the draft. The second author performed the mercury analyses, and participated in writing the final draft.

Results

Variation in mercury levels within feathers

In flight feathers of adult accipiters studied, there seemed to be, on average, a more or less clear decreasing trend in mercury levels from the distal to proximal end of the feather but in individual feathers there were pronounced irregularities (Tab. 1). In the ad. male sparrowhawk, the seeming trend was due to a single feather (the second primary in descending order, the earliest one in the moulting sequence of the feathers examined; Stresemann and Stresemann 1966, Ginn and Melville 1983) with considerable differences in mercury level in different regions. The second primary also had the highest mercury level in the ad. female sparrowhawk, contrary to the situation in goshawk. The trend was more

Tab. 2. Mercury levels (mg kg^{-1}) in different regions of the plumage of some full-grown accipiters in southern Finland. Abbreviations: *Ag* = *A. gentilis*, *An* = *A. nisus*, a = adult, j = juvenile, ♀ = female, ♂ = male. Primaries are numbered (p 2, p 8) in descending order, secondaries (s 2) in ascending order, and rectrices (r 2, r 4) from the middle of the tail outwards according to their moulting sequence.

Feathers	Mercury levels (mg kg^{-1}) in birds examined				
	Aga♀	*Ana*♀	*Ana*♂	*Anj*♀	*Anj*♂
Mantle feathers	12	9.2	8.3	2.9	3.9
Breast feathers	16	5.2	5.0	3.0	3.0
Primaries (p 2)	7.9	13.3	20	3.4	2.9
Primaries (p 8)	12.2	3.7	4.1	3.1	3.1
Secondaries (s 2)	15	7.7	3.5	3.9	3.1
Secondary coverts	12	–	15	–	–
Rectrices (r 2)	15.6	4.0	4.2	3.1	2.8
Rectrices (r 4)	13.4	3.7	3.7	3.1	3.3

clear in feathers of young ospreys, while in juv. accipiters there was no decreasing trend (Tab. 1). In many individual feathers of juv. accipiters the trend was increasing, but on average the slight differences in low mercury levels in different parts of the feathers were obscured by this variation.

Within feather variation was, however, considerable in many individual flight feathers studied (CV up to 47.2%) the average coefficients of variation (CV) of the five corresponding feathers of the five accipiters examined ranging from 14.9 to 34.2%. As the number of samples was small, and there was high and irregular variation between different feathers, the median within feather differences were not significant in the accipiters (Mann-Whitney U-test) but in the 20 juv. ospreys (from 10 broods in 1987) the mercury levels in distal regions of secondary coverts were significantly higher than those in the proximal, the medians being 5.0 and 3.7 mg kg^{-1}, respectively ($U = 37.5$, $p<0.01$, Mann-Whitney U-test).

Mercury levels in different regions of the plumage

In the total feathers estimation, the mercury levels were higher and their variations larger, in ad. than in juv. accipiters (Tab. 2). This was also the case with museum specimens of sparrowhawks as well as in the tawny owls studied. The median mercury level for sparrowhawks mantle feathers was significantly higher (9.6 mg kg^{-1}) in ad. ($n = 7$) than in juv. (4.2 mg kg^{-1}) ($n = 31$) ($U = 33$, $p<0.01$, Mann-Whitney U-test). The median mercury level in secondary coverts was significantly higher (1.1 mg kg^{-1}) in five ad. tawny owls than in nine nestlings (0.5 mg kg^{-1}) (from nine broods) ($U = 0.5$, $p<0.01$, Mann-Whitney U-test). The mercury levels in feather samples from corresponding parts of the plumage of the four sparrowhawks were significantly higher in ad. than in juv., both in males (medians 4.0 vs. 3.0 mg kg^{-1}; $n = 18$) and in females (medians 5.2 vs. 3.0 mg kg^{-1}; $n = 19$) ($U = 39.5$ and 79.5, respectively; $p<0.01$, Mann-Whitney U-test).

There was a significant correlation between the mercury levels in different regions of the plumage in both ad. and juv. specimens ($r = 0.687$, $p<0.01$, $df = 16$, and $r = 0.656$, $p<0.01$, $df = 17$, respectively; log-transformed data). In the two ad. sparrowhawks, there was a significant correlation between the mercury levels in the total feathers examined ($r_s = 0.786$, $p = 0.05$, $df = 5$), and in the female the levels correlated negatively with the general moulting sequence of the feathers (according to Stresemann and Stresemann 1966, Ginn and Melville 1983) ($r_s = -0.866$, $p<0.05$, $df = 5$). In the goshawk examined there was no such correlation ($r_s = 0.429$, ns). In the specimens studied, the mercury levels in 17–24 feather samples from different regions of the plumage of each individual varied 19.4–89.0% (CV), and the width of the range within an individual was 2.3–22.8 mg kg^{-1} (Tab. 3).

Variation within and between broods

Within broods of 2–3 nestlings examined the coefficients of variation of the mercury levels in feathers averaged 10.1–17.7% ranging from zero to 64.6% in different species (Tab. 4). The variance was significantly greater in sparrowhawk than in goshawk ($F = 4.517$, $p<0.01$, F-test), and in osprey than in both of the accipiters ($F = 3.244$, $p<0.05$, and $F = 14.655$, $p<0.01$, respectively). The variance within broods was significantly less than that between broods in goshawk, sparrowhawk and osprey ($F = 27.862$, $p<0.001$; $F = 2.885$, $p<0.05$; $F = 5.727$, $p<0.001$, respectively). The coefficients of variation between broods (including those with only one nestling analysed) ranged from 30.2 to 64.3% in the different species (Tab. 4). The variance between broods was significantly greater in osprey than in the other species studied ($F = 3.012$, $p<0.01$; $F = 6.439$, $p<0.01$; $F = 9.255$, $p<0.01$), and in goshawk than in sparrowhawk and common buzzard ($F = 2.138$, $p<0.05$, and $F = 3.072$, $p<0.01$, respectively). In different spe-

Tab. 3. Variation of the mercury levels in different regions of the plumage of some individual birds of prey. Medians (Md), means ± standard deviations ($\bar{x}$ ± SD), ranges, coefficients of variation (CV%), and numbers of samples investigated (n) are given. Feather samples included mantle and breast feathers, and different regions of some remiges and rectrices.

Specimen	Mercury levels (mg kg^{-1})					
	Md	$\bar{x}$	SD	Range	CV%	n
A. gentilis ad. female	12.5	13.2	3.7	6.7–21	28.0	24
A. nisus ad. female	5.2	6.3	4.0	1.8–17	63.5	19
A. nisus ad. male	4.2	7.3	6.5	3.2–26	89.0	19
A. nisus juv. female	3.0	3.3	0.8	2.2–5.0	24.2	19
A. nisus juv. male	3.0	3.1	0.6	2.1–4.4	19.4	19
P. haliaetus juv.	4.4	4.1	1.0	2.4–5.7	24.4	17

Tab. 4. Variation in mercury levels in feathers of nestling birds of prey in southern Finland within and between broods (n = the number of broods). Within broods 2–3 nestlings from each brood were examined.

Species	Coefficients of variation (%)				
	Range within	Mean ±SD within	(n)	Between	(n)
Accipiter gentilis	0–21.9	10.5 6.4	(14)	64.3	(34)
Accipiter nisus	0–37.7	10.1 12.8	(10)	30.2	(36)
Buteo buteo	6.8–31.9	15.5 11.2	(4)	44.2	(18)
Pandion haliaëtus	0–64.6	17.7 18.9	(23)	39.4	(32)

cies, within brood variances were 3.6–34.7% of the variances between broods.

Annual variations and long-term trends

In accipiters, the mercury levels in feathers of broods were generally relatively similar in different years (Fig. 1). However, for goshawk, the level in 1987 was significantly lower than before ($U = 14$, $p<0.01$, Mann-Whitney U-test). In osprey, the annual variations were significant between all the successive years ($U = 0–2$, $p<0.01$). The short study period does not, of course, reliably reveal any long-term trends, but the results suggest that there might be a decreasing trend in the mercury levels of goshawks. The museum specimens of juv. sparrowhawks showed no significant differences in the mercury levels of feathers between the decades from the 1930s to the 1950s and 1970s (Fig. 2). In the 1960s, however, the median level was significantly higher than in the 1970s ($U = 11.5$, $p<0.05$, Mann-Whitney U-test) (cf. Solonen and Lodenius 1984).

Mercury levels in different species

The median and mean levels of mercury in the feathers of nestlings of the species studied were strikingly highest

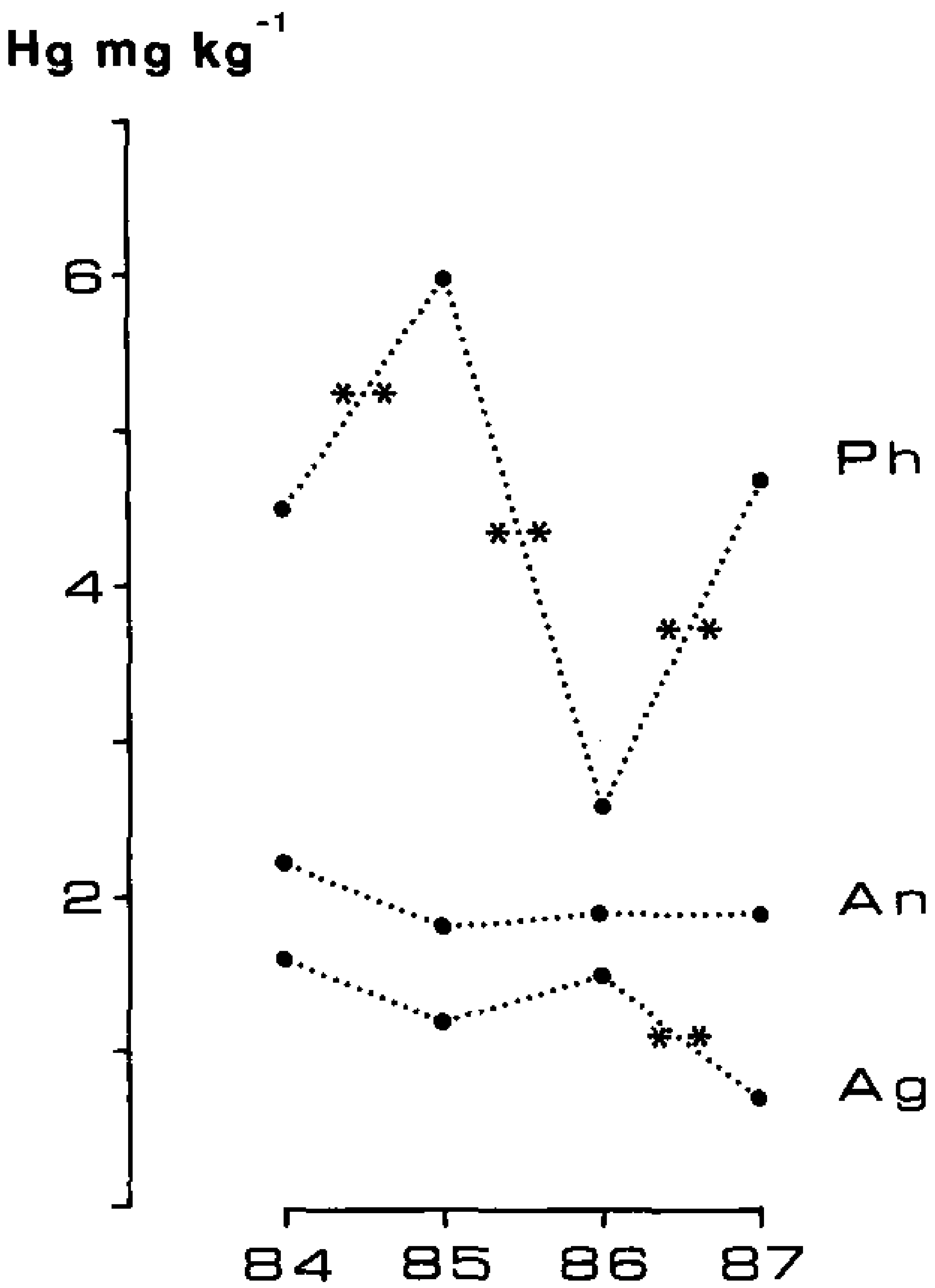

Fig. 1. Annual variation in median mercury levels (Hg mg kg^{-1}) in feathers of broods of some species of birds of prey in southern Finland between 1984 and 1987: goshawk (A g), sparrowhawk (A n), and osprey (P h). Significant differences between years ($P<0.01$, U-test) are indicated by asterisks.

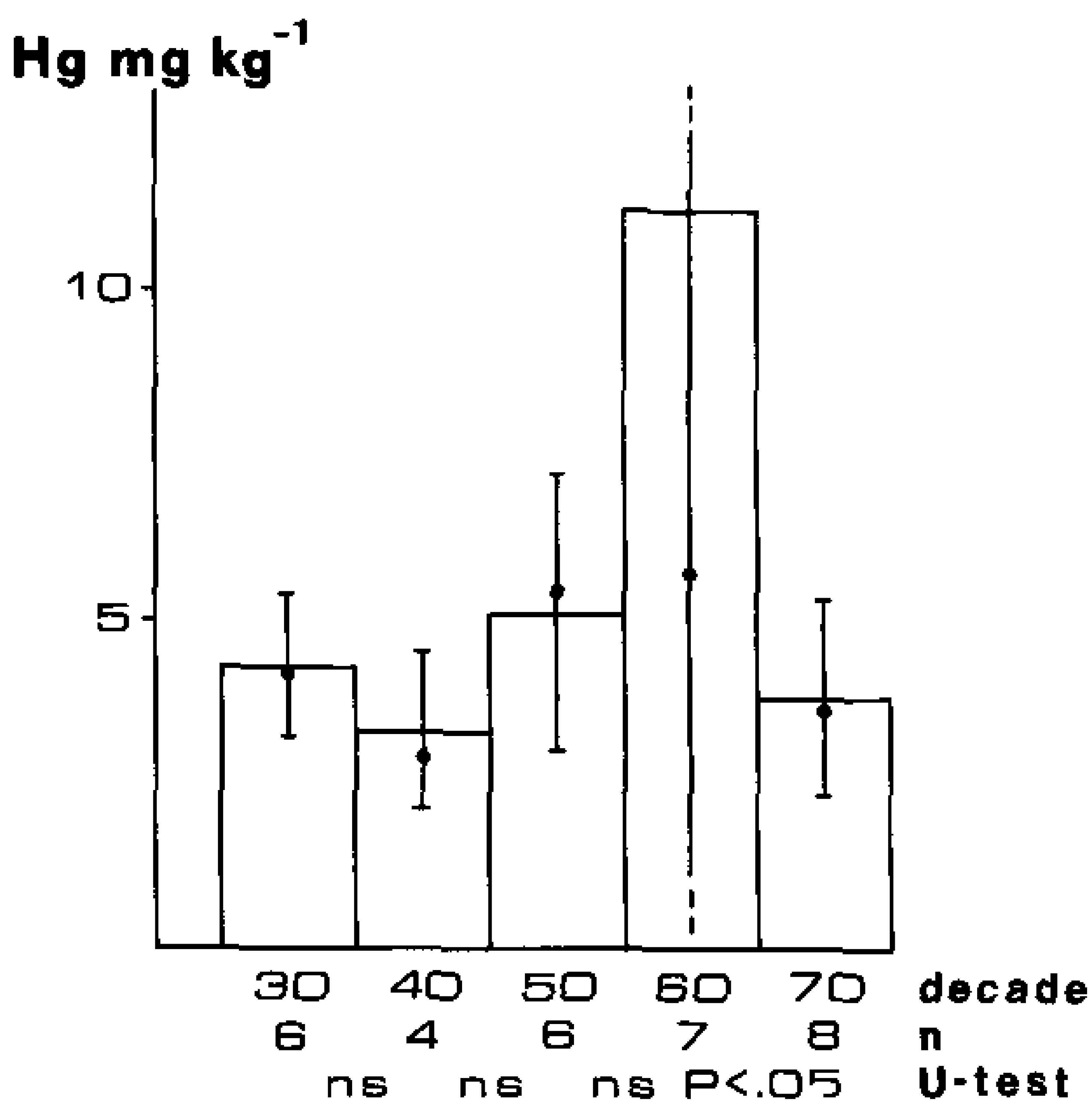

Fig. 2. Median (dots) and mean (blocks with bars indicating standard deviations) mercury levels (Hg mg kg^{-1}) in mantle feathers of museum specimens of juv. sparrowhawks from southern Finland in 1930–80 (SD of the 1960s is ±11.5) (cf. Solonen and Lodenius 1984).

Tab. 5. Mercury levels (mg kg^{-1} dry weight) in feathers (secondary coverts) of bird of prey nestlings in southern Finland in 1984–87. Medians (Md), means ± standard deviations ($\bar{x}$ ± SD), ranges, and numbers of broods examined (n) are given. Samples analysed were from 1–4 nestlings per brood.

Species	Mercury levels (mg kg^{-1})				n
	Md	$\bar{x}$	SD	Range	
Pernis apivorus	0.4	0.5	0.2	0.3–0.7	3
Circus aeruginosus	2.3	2.5	0.5	2.0–3.4	7
Accipiter gentilis	1.2	1.4	0.9	0.5–5.5	34
Accipiter nisus	2.0	2.0	0.6	0.9–3.7	36
Buteo buteo	1.2	1.2	0.5	0.3–2.1	18
Pandion haliaëtus	4.0	4.0	1.6	0.8–7.6	32
Falco subbuteo	4.2	4.2	–	–	1
Bubo bubo	0.7	0.7	0.5	0.3–1.4	4
Strix aluco	0.4	0.5	0.2	0.2–0.9	16
Strix uralensis	0.4	0.6	0.5	0.2–1.3	4
Strix nebulosa	0.6	0.6	–	–	1
Asio otus	0.2	0.3	0.2	0.2–0.5	3
Aegolius funereus	0.4	1.5	2.0	0.4–3.8	3

in osprey (4.0 mg kg^{-1}, both) as was the upper limit of the range (7.6) (Tab.5). The levels in marsh harrier *Circus aeruginosus*, another species with primarily aquatic food chains, were also relatively high. Additional samples for hobby *Falco subbuteo* should be analysed, as the single brood examined in this study exhibited a considerably high value as compared to the range of levels in other species. In species which prey mainly upon terrestrial vertebrates, the mercury levels were quite high in the bird-eating accipiters, especially in sparrowhawk, while in the vole-eaters, including mainly species of owls, the levels were generally low, less than 1 mg kg^{-1}. In many cases, the median and mean were similar suggesting the normal-like distribution of the values (Fig. 3). The shapes of distribution were fairly similar for the species with terrestrial food chains. They differed markedly from that of osprey. A single brood of goshawk that differed strikingly from the others was from a territory near a eutrophic coastal bay which suggests that the brood was largely fed with prey from aquatic habitats.

Discussion

Distribution of mercury within an individual

Most of the mercury in the feathers is in the form of methyl mercury, which readily accumulates in ecosystems and is eliminated slowly from the animal body (see Westermark et al. 1975). The levels of mercury in feathers have been found to be c. 7–8 times that in fresh breast muscle tissues (Berg et al. 1966, Johnels and Westermark 1969, Westermark et al. 1975), however, this ratio may vary (see Häkkinen and Häsänen 1980). The feather content thus roughly corresponds to the dry-weight content of muscle. In the liver the mercury content is c. 2–3 fold that in muscle (Westermark et al. 1975, Häkkinen and Häsänen 1980). In British sparrowhawks and some other predatory birds, the mean mercury concentrations in the liver rose at the onset of the moult and fell again rapidly (Cooke at al. 1982, see also Braune and Gaskin 1987b). This suggests seasonal fluctuations in the mercury levels of the body.

The present results indicate that the variation in the mercury content within a feather may be considerable (see also Berg et al. 1966, Johnels and Westermark 1969, Goede and de Bruin 1984). Lower levels in juv. compared with ad. have been reported (e.g. Koivusaari et al. 1976, Stanley and Elliot 1976, Särkkä et al. 1978a, Broo and Odsjö 1981, Lindberg 1983, see also Wiemeyer et al. 1987), and they are, rather intuitively, suggested to be due to the birds' brief exposure to mercury contamination (e.g. Lindberg and Odsjö 1983, Lindberg et al. 1983, Solonen and Lodenius 1984). The implicit assumption is that mercury levels in feathers reflect both the levels in food and the levels of mercury accumulated in other tissues of the body.

The declining trends with growth of individual feathers (the decrease in the levels from the distal to the proximal regions of the feathers) in the three ad. accipiters and 20 young ospreys probably reflect the reduction in the mercury load of the body due to elimination of accumulated mercury into the feathers (cf. Furness et al. 1986, Braune and Gaskin 1987a). In young ospreys, the trend in that case reflects a decline from the levels of mercury originally found in eggs. Probably due to the generally much lower mercury levels in accipiters, a similar trend was not demonstrable in the juv. sparrowhawks examined.

The smaller variation within feathers as well as within

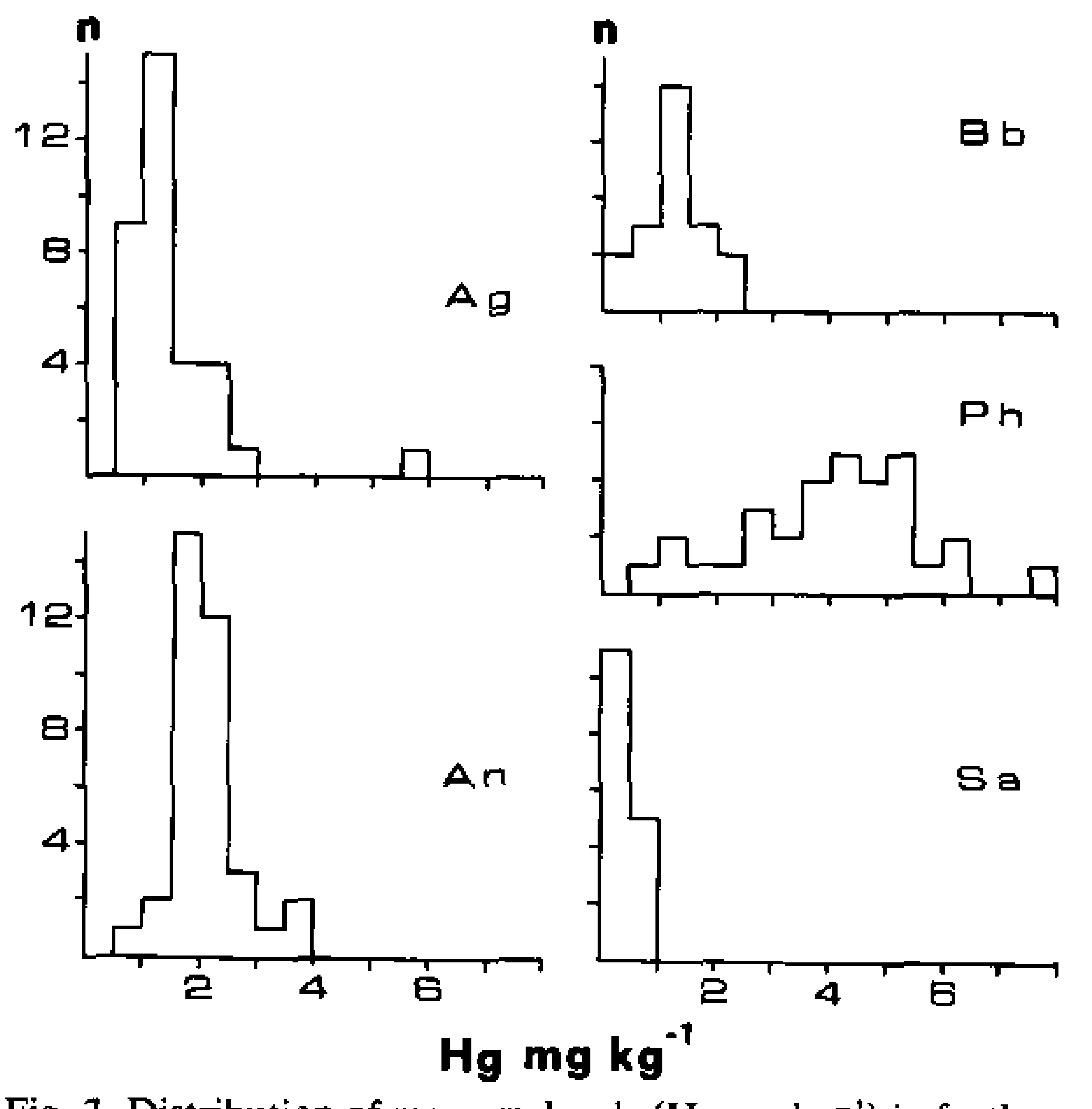

Fig. 3. Distribution of mercury levels (Hg mg kg^{-1}) in feathers of broods of birds studied in southern Finland between 1984 and 1987: goshawk (A g), sparrowhawk (A n), common buzzard (B b), osprey (P h) and tawny owl (S a).

the entire plumage in juv. as compared to ad. is clearly seen by the present results. This is something which has not been given much consideration in other studies (e.g. Bühler and Norheim 1981, Furness at al. 1986). The variation in ad. may be quite large, as noted above (see also Johnels and Westermark 1969, Westermark et al. 1975, Bühler and Norheim 1981). The ad. accipiters of this study had mercury concentrations in the most heavily contaminated parts of the plumage up to nine times higher than in the least contaminated parts (cf. Bühler and Norheim 1981).

The present results do not unambiguously support the hypothesis of a general decline in mercury levels in later moulted feathers, due mainly to the elimination of mercury accumulated in body tissues (Furness et al. 1986). A similar trend has been demonstrated in various (at least 14) species (see Furness et al. 1986) including some birds of prey (Johnels et al. 1968, Bühler and Norheim 1981, Lindberg and Odsjö 1983). Most often the pattern has been interpreted as evidence that dietary intake changed over the period of feather growth. Our samples may not have been quite representative due to their small numbers and some uncertainty in the moulting sequence of the various feathers analysed. However, the results show that in the mercury levels between feathers there are irregularities that might be due to factors other than irregularities in the moulting sequence (cf. Furness et al. 1986). Differences in the growth rate of individual feathers in different parts of the plumage evidently produce some variation in the mercury levels of full-grown feathers. Within feather variations may obscure any patterns which may be present.

Our result, that there are no general clear trends or pronounced variations in the mercury levels of the feathers in juv. birds, might explain the lack of any trend in the mercury levels of the primaries in some specimens of skuas studied by Furness et al. (1986). Their mysterious individual variations might be either due to irregularities in the moulting sequence in ad. birds or variations in the mercury intake during feather growth. The latter idea is supported by the irregular variations between nestlings within a brood found in this study. Presumably there is some variation between the mercury levels of prey species of different food chains (see also Furness 1987, cf. Odsjö and Olsson 1975, Häkkinen and Häsänen 1980, Lindberg et al. 1983) and every food item brought to the nest is probably not divided evenly between the nestlings. These variations in young birds would be hard to explain in any other way. Great physiological differences between siblings seem improbable. On the other hand, in a similar manner to the first feathers, the first eggs laid in a clutch might be more contaminated than later ones (see e.g. Lindberg 1983, but see also Gilbertson 1974, Newton 1979, Mineau 1982). This might also explain some of the within brood differences.

To summarize, the various irregularities in the mercury levels in different parts of the plumage of a bird seem to support the hypothesis that the mercury in the food ingested during the growth of the feathers considerably affects the levels of mercury in the feathers. On the other hand, the regular trends mainly support the hypothesis that amount of mercury stored in body tissues is another determining factor of the levels in plumage (Furness et al. 1986). The relative importance of these factors, however, seems to vary, depending on, among other things, the age of the birds considered.

Mercury levels and sources

The results of this study indicate, not surprisingly, that the mercury contamination was most heavy in aquatic environments (e.g. Häkkinen and Häsänen 1980, Lambertini 1982, Odsjö 1982, Lindberg 1983, Lindberg and Odsjö 1983, Frøslie et al. 1986). This mercury is mainly from industrial waste (see e.g. Särkkä et al. 1978a, b) but other sources may also be involved (see e.g. Lodenius et al. 1983a, b). The present levels in osprey were, however, relatively low. Häkkinen and Häsänen (1980) showed large regional variation in mercury levels in osprey nestlings. In 1972, the mean levels in contaminated areas varied between 18.3 and 24.7 mg kg^{-1}, being 5–7 fold those in unpolluted areas. The levels had decreased significantly in 1978, but in most nests they still exceeded 10.0 mg kg^{-1}.

In terrestrial habitats, food chains via small passerines to sparrowhawk, carried considerable concentrations of mercury. At present, insectivorous birds probably play a major role in this transport (e.g. Särkkä et al. 1978a, Lindberg et al. 1983, Delbeke and Joiris 1987). It has, however, also been suggested that granivorous birds are the main link in the accumulation of mercury in raptors feeding on terrestrial birds (see e.g. Berg et al. 1966, Borg et al. 1969, Johnels and Westermark 1969, Fimreite et al. 1970, Westermark et al. 1975, Fimreite 1979, Johnels et al. 1979, Solonen and Lodenius 1984). This mainly concerns methyl mercury used in agriculture (see Solonen 1985a). Mercurial fungicides were used in Finland as seed dressings as early as the 1920s, but their use did not increase significantly until the 1950s. Methyl mercury compounds (a total of 3.8 tonnes) were used only in 1956–1969, mainly in southwestern Finland. In 1981, sales of mercury-containing seed dressings were 241 tonnes, containing 5.4 tonnes of active ingredients, and there were enough dressed seeds to sow nearly 20% of the total arable land in Finland (Tiittanen and Blomqvist 1982).

Granivores form a considerable proportion (about 20% on a fresh weight basis) of the prey of sparrowhawks during the breeding and moulting season in Finland (Sulkava 1964). In winter and early spring the proportion of granivorous birds (especially yellowhammers *Emberiza citrinella,* house sparrows *Passer domesticus* and chaffinches *Fringilla coelebs*) is evidently larger, but the mercury accumulated at that time can not be quantified directly from feather samples (cf. Solonen and Lodenius 1984). As suggested above, it can, however, affect the levels of new feathers growing in the next moult of the full-grown birds, and in the case of females, also in the levels found later in eggs and subsequently possibly in the feathers of the young (see also Lambertini 1982).

Feathers of birds of prey as environmental indicators

From the results of this study, feathers to be used as indicators of environmental mercury pollution should preferably be from nestlings, but full-grown birds in juv. plumage can also be used. Breeding ad. serve for comparison, but their indicator value depends on the additional information being available (age, locality of feather formation, etc.). Small feathers are preferred to larger ones (see also Furness et al. 1986), and total feathers should be analysed rather than only some sections of them (see also Goede and de Bruin 1984). Because of the considerable variation within individuals, the mercury levels in feathers must be interpreted cautiously, especially when the number of samples is small. Only corresponding regions of the plumage should be used when comparing levels in different birds. As within brood variations seemed to be rare, and usually relatively minor, it may be sufficient to sample one nestling per brood. Pooled samples of nestlings from total broods are, however, preferable as indicators of mercury accumulation in local food webs. This is often also a practical necessity because individual feathers may not be mature enough to obtain samples large enough for analysis.

Birds in general, and birds of prey in particular, have been put forward as sensitive environmental indicators (see e.g. Ellenberg 1981a, Solonen 1985b). Many species respond quickly to various environmental changes. As they have a high position in food chains, birds of prey have a well-known potential for indicating the accumulation of various pollutants in the environment (e.g. Newton 1979, Ellenberg 1981a, Cooke et al. 1982, Frøslie et al. 1986). In practice, however, not all species have similar indicator potential. Species used to monitor environmental pollution should, among other things, be preferably sedentary, easily available and widely distributed, large enough for analytical purposes and should show relatively high contamination patterns (Moore 1966, Stanley and Elliot 1976, Ellenberg 1981b, see also Pinowska et al. 1981).

As demonstrated in this study, different food webs need their own indicator species. On the basis of the present results, a set of avian mercury indicators in southern Finland should include at least 4–5 species. The osprey feeds exclusively on fish and it seems to be especially suitable for monitoring of persistent contaminants in aquatic ecosystems (see also Häkkinen and Häsänen 1980, Wiemeyer et al. 1987). Both of the accipiters studied have their merits and disadvantages in monitoring terrestrial environments. The sparrowhawk is more strictly a species of terrestrial food chains while goshawk may, at least locally, use considerable amounts of prey from aquatic habitats (waterfowl, larids, waders). The tawny owl is a particularly suitable indicator for monitoring urban and rural environments (see also Ellenberg 1981b, Hahn 1981, Weiss 1981). The distribution and density of its populations can be manipulated with nest boxes, and also adult birds are relatively easy to catch repeatedly for feather sampling. Unlike sparrowhawk in Finland, goshawk and tawny owl are highly sedentary, long-lived, and large; these characteristics are well suited to their being good biological indicators (see also Ellenberg 1981b).

The five species studied most intensively in this study (goshawk, sparrowhawk, common buzzard, osprey, and tawny owl) comprise a set of indicator species that cover various environments from urban and rural areas to forests and waters. They all are common and accessible enough for representative annual sampling. Mercury levels in the feathers of nestlings probably reflect quite accurately the levels of their parents' foraging areas in the neighbourhood of the nest-site (see also Lindberg and Odsjö 1983), indicating the degree of mercury contamination of local food webs. Comparative studies on the prey (see e.g. Fimreite et al. 1970, Koivusaari et al. 1976, Häkkinen and Häsänen 1980, Lindberg and Odsjö 1983, Solonen and Lodenius 1984, Braune and Gaskin 1987a, Delbeke and Joiris 1987) of the species considered here (various birds, small mammals, and fish) and on other indicator organisms, for instance, mosses and lichens (e.g. Lodenius and Laaksovirta 1979, Lodenius 1981, Lodenius and Tulisalo 1984) and mushrooms (e.g. Lodenius and Herranen 1981, Liukkonen-Lilja et al. 1983) from the same areas would be particularly enlightening.

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