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Mercury in eggs and nestlings of the osprey (Pandion haliaetus) in Finland and its bioaccumulation from fish

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In 1972—80 total mercury concentration was determined by activation analysis in 16 addled osprey eggs, in samples of 137 mantle feathers from nestlings, and in tissues of three osprey nestlings that were found dead. The mercury concentration in the addled eggs varied between 0.1 and 0.4 ppm and was probably not the cause of their failure to hatch. High mercury concentrations were found in fish and in osprey nestlings in the same areas of Finland. In Lapland and in the SW archipelago of Finland the mantle feathers contained averages of 3.4 and 4.5 ppm of mercury, whereas by the mercury-polluted rivers Kymijoki and Kokemäenjoki and Lake Päijänne the corresponding values were 24.7, 23.8 and 18.3 ppm of mercury, respectively. In 1972 at most 5 % of the Finnish osprey population lived in the mercury-contaminated areas.

In the moderately polluted Hämeenkyrö area, one young osprey found dead had a highly elevated mercury content. Most of its mercury load was in the plumage, which seems to act as a safety valve against mercury poisoning.

In 1970—78 the reproductive success of ospreys in the mercury-contaminated areas was about the same (1.4 nestlings per occupied nest) as the average for the whole country.

After the mercury ban the contamination of nestlings in this area underwent a significant decrease between 1972 and 1978, but there was no resulting improvement in reproductive success.

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1. Introduction

For several decades during this century human activities raised the level of mercury locally in the environment. As a result, both terrestrial and aquatic food chains showed signs of mercury contamination (e. g. Johnels et al. 1967; Häsänen & Sjöblom 1968; Borg et al. 1969). In areas with high levels of mercury in fish fish-eating birds readily bioaccumulate mercury (Johnels et al. 1968; Fimreite et al. 1971; Fimreite 1974; Särkkä et al. 1974). Thus they form important indicators of mercury contamination in the aquatic environment.

In Finland the discharge waters of the pulp and paper industry and also air pollution through chlorine factories brought the mercury problem to such a point that legal restrictions were applied in 1968 (Häsänen 1973). The fish in the water areas affected had high contents of mercury (Häsänen & Sjöblom 1968) and coincidentally white-tailed eagles, *Haliaetus albicilla*, in the SW archipelago of Finland were found dead because of mercury poisoning (Henriksson et al. 1966). In birds mercury exerts its harmful effects on reproduction, and the poor reproductive success of the white-tailed eagles was assumed to be connected not only with chlorinated hydrocarbons but also with mercury (Koivusaari et al. 1976). Ospreys have not been reported to have died of mercury poisoning, but both in Finland and Sweden the populations have diminished for reasons that are not well understood (Saurola 1976; Odsjö & Sondell 1976).

This paper reports on total mercury in osprey eggs and nestlings and discusses osprey reproduction in the light of the concentrations

observed.Activation analysis made it possible to assay mercury in small samples of feathers collected from living nestlings, and to investigate the exposure of Finnish osprey nestlings to mercury contamination. An attempt was also made to estimate the uptake of mercury from fish by osprey nestlings on the basis of data on their diet (Häkkinen 1978) and the amount of fish consumed (Häkkinen 1977).

The first author was responsible for collecting the study material and preparing the draft, and second author performed mercury assays. However, both authors answer for the findings of the study.

2. Material and Methods

In June and July 1970—72, addled osprey eggs were collected for assays of mercury. Of the 16 eggs, 15 were from nests near the city of Tampere (61° 30′ N, 23° 50′ E) in central Finland and one from Inari (69° 00′ N, 27° 20′ E) in northern Lapland. The eggs contained liquid matter or dead embryos and some were partially dried. All the eggs were collected the same year as they were laid. The eggs were wrapped in aluminium foil in the field to prevent external contamination, transferred to the laboratory and stored at —20° C until the mercury assay. The contents of each egg were mixed before sampling.

In 1972 bird ringers helped to collect mantle feathers of living osprey nestlings from 103 nests in different parts of Finland. Feathers were obtained both in areas were mercury contamination of fish had already been discovered and in uncontaminated areas (see Häsänen & Sjöblom 1968). In 1978 another set of samples was collected from 14 nests to ascertain whether mercury concentrations had changed. From each nestling two or three mantle feathers were pulled out. On the basis of their wing length nestlings were judged to be 25—35 days old (Häkkinen 1977). Within a brood the variation in mercury concentration among the nestlings was relatively small, the mean and SD being 1.3 ± 0.8 ppm (nestlings, N =36 nests, N=16). Thus only one feather sample per nest was needed. If more than one nestling was sampled at the same nest the highest concentration of mercury was used in later calculations.

The finding of dead nestlings in three nests made it possible to study the distribution of mercury in the body tissues. The collection data for these nestlings were as follows:

1) Inari, 24. VII.1972. The three nestlings starved to death because an eagle owl, *Bubo bubo*, had killed the female parent. The oldest nestling was taken for mercury analysis; it was 20 days old and weighed 695 g.

2) Ranua, 2.VII.1974. The nestlings was found dead for an unknown cause at the age of 25 days; it weighed 648 g.

3) Hämeenkyrö, 22.VII.1974. One of the two nestlings was found dead at the age of 25 days; it weighed 755 g. According to Nuorteva et al. (1975), fish in the Hämeenkyrö area are moderately polluted with mercury.

Table 1. Mean wet and dry weights (g) of various tissues in three osprey nestlings aged 20 to 25 days.

Tissue	Wet weight	Dry weight
Liver	23.4	5.9
Kidney	1.5	0.3
Breast muscles	21.5	4.4
Brain	3.8	0.4
Plumage	161.8	65.8
Rest of body	294.2	60.6
Total weight	718.2	137.4

The three nestlings were wrapped in aluminium foil and stored at —20°C. The wet weights of liver, kidney, breast muscles, brain, plumage and the rest of the body were measured (Table 1) and mercury was analysed in each tissue. Tissue samples from one nestling (3) were dried at +80°C for 24 h to obtain the relation of dry weight to wet weight.

Total mercury was determined by neutron activation analysis at the Technical Research Centre of Finland (see Häsänen 1970). A chemical separation method (Häsänen 1970) was applied to the egg samples and to all other tissues except plumage. Mercury in the plumage was analysed by activation analysis, using entire mantle feathers and the middle vanes from primaries and rectrices. Duplicate analyses of each sample gave results of high consistency. The mercury values are expressed in parts per million (ppm), mg or μg Hg on both a wet weight and a dry weight basis. Depending on the mercury concentrations, there is a 5—10 % variation in the accuracy of the determinations. Mercury concentrations were calculated on the air-dry weight of the feathers, there being a 12 % difference between the dry weight and air-dry weight.

3. Results

3.1. Mercury in eggs

The mercury concentrations in the addled eggs varied considerably among nest sites (Table 2), the range being 0.1-0.4 ppm of mercury on a wet weight basis. In five cases only a dry weight was available. On a dry weight basis three eggs had mercury levels extending 1.0 ppm; no nestlings were present at these nests. Many eggs from central Finland had as low a mercury concentration as the egg from Lapland. Three nests contained two addled eggs; in one case there was a great difference in concentration between the eggs.

3.2. Mercury in feathers of nestlings

High concentration of mercury were found in the mantle feathers of osprey nestlings in some areas of Finland (Fig. 1). Feathers from the nests

Table 2. Mercury in addled eggs of the osprey. The eggs were collected from central Finland and Lapland in 1970—72.

Sample	Nest locality	Nest code	Collection date	Hg, ppm wet weight	Hg, ppm dry weight	Egg contents	Young at nest N
1	Hämeenkyrö	A	7.VII.1971	0.4	1.5	liquid mass	0
2	»	B	11.VII.1972	0.2	0.8	»	1
3	Suodenniemi	A	7.VII.1971	0.3	0.6	embryo	0
4	»	A	11.VII.1972	—	0.5	dried	0
5	»	A	11.VII.1972	0.2	0.7	embryo	0
6	»	B	9.VII.1970	0.3	0.9	embryo	0
7	Ruovesi	A	10.VII.1971	0.1	0.5	liquid mass	0
8	»	A	10.VII.1971	—	1.9	dried	0
9	»	B	27.VI. 1972	0.2	0.7	embryo	2
10	Orivesi		9.VII.1972	0.1	0.3	liquid mass	2
11	Eräjärvi		11.VII.1971	0.1	0.5	liquid mass	0
12	Kangasala	A	18.VII.1972	—	0.3	dried	0
13	»	A	18.VII.1972	—	0.3	dried	0
14	Viljakkala		6.VII.1971	0.1	0.4	liquid mass	2
15	Vesilahti		7.VII.1972	0.3	1.3	embryo	0
16	Inari (Lapland)		26.VII.1972	—	0.4	dried	2

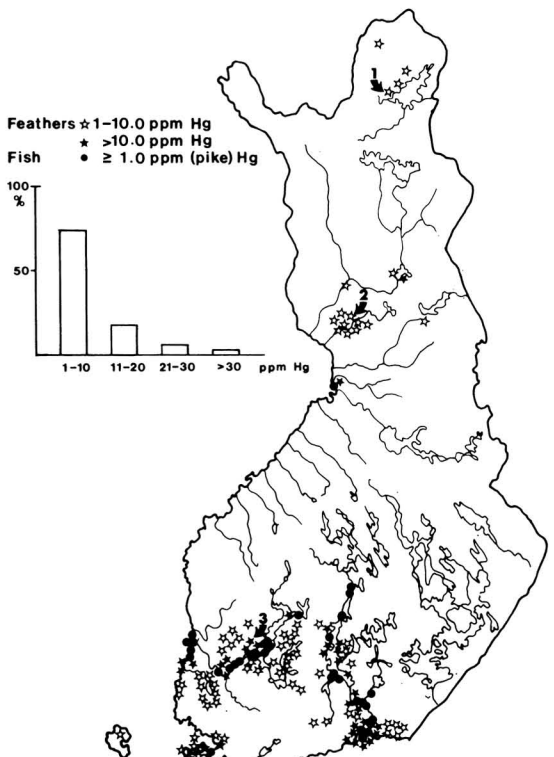

Fig. 1. Mercury in mantle feathers of young Finnish ospreys in 1972. The map shows the positions of the nests ($N = 103$), the mercury concentrations in the young, and the areas where mercury concentrations in pike were high (≥ 1.0 ppm) in 1967 (Häsänen & Sjöblom 1968). The bar diagram shows the frequency distribution of the feather material with respect to mercury concentration. The numbers (1—3) refer to the nests where dead osprey nestlings were collected for mercury analysis.

along the river Kymijoki, the river Kokemäenjoki, Lake Päijänne and the coastal area of Rauma contained more than 10.0 ppm of mercury. For comparison, the lake and river systems in which Häsänen & Sjöblom (1968) found high mercury concentrations (≥ 1.0 ppm) in pike in 1972 are included in Fig. 1. The concentrations were highest in the samples from nests along the lower part of the river Kymijoki and the adjoining coastal area, where the mean ± S D was 24.7± 11.2 (N=9). Along the river Kokemäenjoki osprey nestlings had a mean concentration of 23.8±13.3 ppm (N=6) in feathers and on Lake Päijänne 18.3±3.7 (N=6). In the SW archipelago, Åland Islands and northern Lapland the concentrations were much lower; the mean ± S D for the two SW areas being 4.5±1.7 ppm (N=11) and for Lapland 3.4±1.8 (N=4). Thus, five- to seven-fold differences in the mercury concentrations in feathers were found between the areas. In the nests studied, mercury in feathers exceeded 10.0 ppm in 26.6 % and 30.0 ppm in 2.5 %.

3.3. Mercury in nestlings

Three osprey nestlings which perished at 20 to 21 days of age, were analysed in detail for mercury (Table 3). Two of them (1,2) came from northern Finland and one (3) from the moderately polluted Hämeenkyrö area (Fig.1). The nestling from Inari showed a low concentration of mercury in all tissues. Somewhat higher concentrations were present in another nestling from northern Finland. In the nestling from Hämeenkyrö manyfold concentrations were recorded in all tissues studied, the difference being especially pronounced in the plumage. Of the

Table 3. Mercury in various tissues of three dead osprey nestlings. The numbers (1—3) refer to the collection sites as illustrated in Fig. 1.

Tissue	Hg, ppm wet weight (dry weight)		
	Inari (1)	Ranua (2)	Hämeenkyrö (3)
Liver	0.2 (0.8)	—	1.8 (7.1)
Kidney	0.2 (0.8)	0.4 (2.2)	1.4 (6.8)
Breast muscle	0.1 (0.5)	0.2 (0.8)	0.7 (3.4)
Brain	0.1 (0.4)	0.1 (1.2)	0.3 (2.9)
Plumage[1]			
mantle feathers	0.3	0.4	5.7
primaries	0.4	0.1	8.3
rectrices	0.2	0.4	6.8

[1] air-dry weight

body tissues, liver and kidney contained the highest concentrations of mercury in each nestling. Breast muscle and brain had on average half of that concentration. When a low level of mercury was present in the body tissues the plumage values were also low. However, when body tissues were rich in mercury a relatively higher proportion of the mercury was bound to plumage. No general conclusion could be drawn about the distribution of mercury within the plumage in the three nestlings. Calculations from the data given in Tables 1 and 3 showed that the mercury contents of two osprey nestlings, one from an uncontaminated and the other from a contaminated area, differed greatly (Table 4), the difference being in general more than 10-fold. The total mercury contents of these nestlings were 0.08 and 1.0 mg Hg/kg. In the nestlings from the mercury-contaminated area the bulk of the mercury burden was bound to the plumage.

3.4. Changes in concentrations of mercury

Fourteen nests in which a heavy mercury contamination (> 10. ppm) in feathers of nestlings was found in 1972 were resampled in 1978 (Table 5). There was a significant decrease in the mercury concentrations between the years ($t = 3.07$, $P < 0.01$). The decrease was 55 % on Lake Päijänne, and 50 % on the river Kymijoki, but only 27 % on the river Kokemäenjoki. One nest in Ruovesi showed an increased mercury concentration. Even in 1978, however, feather samples still showed levels exceeding 10.0 ppm in many of the nests studied.

Table 4. Mercury content of various organs and tissues (μg Hg and (%)) of two osprey nestlings, one from an uncontaminated (Inari) and the other from a mercury-contaminated (Hämeenkyrö) area.

	Inari	Hämeenkyrö
Liver	4.7 (7.8)	41.9 (5.4)
Kidney	0.2 (0.3)	2.0 (0.3)
Breast muscles	2.4 (4.0)	15.0 (1.9)
Brain	0.2 (0.3)	1.2 (0.2)
Plumage	19.7 (32.6)	506.7 (65.5)
Rest of body	33.3 (55.0)	206.0 (26.7)
Total	60.5	772.8

3.5. Reproductive success

In 1970—78 the productivity, expressed as the mean number of nestlings (25 to 35 days of age) per occupied nest, was studied at ten nests where assays in 1972 showed heavy mercury contamination (> 10.0 ppm) in feathers of nestlings (Table 6). In 1970—78 the mean annual productivity was 1.47±0.3 nestlings per occupied nest. Productivity, which was low in 1973—75, had risen since 1975 to the pre-1973 level. However, no clear relation could be shown between the decrease in the mercury concentrations in 1972—78 and the mean productivity of the nests. Nor was there a significant correlation between the mean annual productivity at each nest and the mercury concentration in 1972.

4. Discussion

4.1. Significance of mercury in eggs and nestlings

For purposes of conservation it is important to establish the general significance of mercury concentrations found in osprey eggs and nestlings. For comparison, data from a number of studies dealing with mercury in eggs of fish-eating birds are presented in Table 7. The mean or range of total mercury in whole eggs (yolk and white) is given. As the bulk (78 to 90 %) of the total mercury in eggs of fish-eating birds occurs in the form of the poisonous methyl mercury (Wahlberg et al. 1971; Fimreite et al. 1974; Särkkä et al. 1978), relatively low concentrations are fatal to the embryos.

In the Quarken area of the Gulf of Bothnia addled osprey eggs contained the same level of mercury as found in this study (Koivusaari et al. 1972a). The reproductive success was normal, although eggshell thickness had decreased by some 15 % in the population since the beginning of the century (Koivusaari et al. 1972b). In Sweden fresh osprey eggs had concentrations of mercury similar to those found in the addled eggs in Finland. All expect one egg with 0.4 ppm (wet weight) of mercury were considered normal by Westermark (1965).

Table 5. Mercury (ppm) in the mantle feathers of osprey nestlings in 1972 and 1978. Fourteen nests which showed heavy mercury contamination (> 10.0 ppm) in feathers of the young in 1972 were selected for the comparison.

Lake or river system, nest locality	Nest code	1972	1978	Change %
The river Kymijoki and its coastal area				
Ruotsinpyhtää	A	21.6	13.5	— 37.5
»	B	17.6	10.6	— 39.8
Pyhtää	A	27.0	17.4	— 35.6
»	B	51.2	17.4	— 66.1
Pernaja		28.3	7.9	— 72.1
Lake Päijänne				
Jämsä		19.9	9.1	— 54.3
Padasjoki		23.4	14.9	— 36.4
Jaala		13.1	4.2	— 68.0
Iitti		14.9	5.7	— 61.8
The river Kokemäenjoki				
Nokia		15.9	10.7	— 32.8
Kokemäki	A	26.5	20.9	— 21.2
»	B	20.2	16.1	— 20.3
Keikyä		13.6	9.1	— 32.4
The upper part of the river Kokemäenjoki				
Ruovesi		11.8	18.2	+ 35.2

In fish-eating birds the first suspicion of hatching failure has been reported at the level of 0.5 ppm in eggs and hatchability is cleary affected when the level reaches 1.0 ppm (see Table 7). Hence we conclude that mercury was probably not the cause of the hatching failure of the addled osprey eggs under study. However, the mercury threshold at which birds' eggs fail to hatch varies with the species. Under experimental conditions hatchability of pheasants' eggs was significantly lower in eggs containing 0.5—1.5 ppm of mercury than in controls (Fimreite 1971). In the herring gull, *Larus argentatus*, in sharp contrast, mercury in the eggs at concentrations as high as 2—26.0 ppm did not affect the hatching success.

Like Berg et al. (1966), we regard the mercury concentrations in the feathers as an acceptable indicator of the mercury load in living birds. In mammals, including man, hair samples have been used in the same way (e.g. Birke et al. 1972; Cumbie 1975; Nuorteva et al. 1975). In Lapland and in the SW archipelago of Finland osprey nestlings probably had a natural background level of mercury in their feathers. For adult ospreys Johnels et al. (1968) suggested 4.0 ppm of mercury in feathers as the upper limit under natural conditions. In southern Finland, however, nestlings at many nests had 5 to 10.0 ppm of mercury in their feathers. This finding may be explained by diffuse contamination from industrial areas (Soveri 1973). To exclude this type of general mercury contamination we set the lower limit for contamination of feathers at 10.0 ppm. High mercury concentrations were found in fish and in osprey nestlings in the same, relatively restricted areas of Finland.

In 1975 Saurola (1976) estimated the Finnish osprey population at 900—1000 nesting pairs. At most 5 % of the population lived in the mercury-contaminated areas in 1972, and our further discussion deals with this part of the population.

Very few data are available on mercury concertrations in feathers of nestlings. On a mercury-contaminated water system in Uppland, central Sweden, Johnels et al. (1968) reported 17.0—20.2 ppm of mercury in primaries of a young osprey and 13.7 and 20.0 ppm in primaries of two adult birds.In the same area of Sweden Westermark (1965) found 10.0—17.0 ppm of mercury in feathers of adult ospreys. Mr. Lars Ölander kindly collected feather material for the study from five Swedish osprey nestlings at three nests in the Jönköping area. The feathers contained 1.2 to 3.5 ppm of mercury, a level about

Table 6. Annual productivity of ten osprey nests where the feathers of the young showed heavy mercury contamination (> 10.0 ppm) in 1972. Mean productivity is expressed as the number of nestlings per occupied nest.

Nest locality	Nest code	Hg, ppm in feathers of the young in 1972	Years 1970	71	72	73	74	75	76	77	78	Productivity/year Mean	*SD*
Ruotsinpyhtää	A	21.6	3	1	3	0	0	0	1	1	1	1.11	1.16
Ruotsinpyhtää	B	17.6	—	—	1	3	0	2	3	2	3	2.00	1.15
Pyhtää	A	27.0	2	0	3	2	2	2	3	1	3	1.77	1.20
Pyhtää	B	51.2	1	3	3	2	0	0	0	2	2	1.44	1.23
Pernaja		28.3	3	2	2	0	1	2	3	3	1	1.88	1.05
Nokia		15.9	—	—	2	2	2	2	2	0	1	1.57	0.78
Kokemäki	A	26.5	3	1	1	0	2	2	1	3	1	1.55	1.01
Kokemäki	B	20.2	3	1	1	1	1	0	0	0	0	0.87	0.99
Keikyä		13.6	0	1	1	0	1	0	0	2	2	0.77	0.83
Ruovesi		11.8	0	2	2	2	3	2	2	1	3	1.70	1.05
Mean annual productivity			1.87	1.37	1.90	1.20	1.00	1.20	1.50	1.50	1.70		

Table 7. Mercury (ppm wet weight) in eggs of some fish-eating birds and the significance of the observed concentrations for reproduction.

	Mean or range	N	Significance for reproduction	Reference
Osprey, *Pandion haliaetus*	0.1—0.4[1]	16	Reproduction normal	This study
»	0.0—0.3[1]	6	Reproduction normal	Koivusaari et al. 1972 a
»	0.1—0.4	5	—	Westermark 1965
Bald eagle, *Haliaetus leucocephalus*	0.2—0.4	14	Reproduction normal	Postulpalsky 1971
White pelican, *Pelecanus erythrorhynchos*	0.3	30	Reproduction normal	Vermeer 1971
»	0.5[1]	21		
Gannet, *Sula bassana*	0.5[1]	10	Hatching possibly impaired	Fimreite et al. 1974
Common tern, *Sterna hirundo*	0.6	4	Reproduction possibly affected	» 1971
Red-breaster merganser, *Mergus serrator*	0.8	8	Reproduction possibly affected	» 1971
Common tern, *Sterna hirundo*	1.0—3.6	35	Hatching rate low	Fimreite 1974
White-tailed eagle, *Haliaetus albicilla*	1.0[1]	2	Reproduction low	Koivusaari et al. 1972 a
»	3.5—11.0[1]	6	Sterility	Borg et al. 1965

[1]Addled eggs.

the same as was found in uncontaminated areas of Finland. The present data do not imply that ospreys have died of mercury poisoning either in Finland or in Sweden. However, indirect effects may be expected in ospreys living in areas with heavy mercury contamination.

Adult white-tailed eagles found dead in the archipelago of Sweden had 25, 35, 49 and 51 ppm of mercury in their feathers (Jensen et al. 1972). In the SW archipelago of Finland adult white-tailed eagles which were assumed to have died of mercury poisoning had 8 to 28 ppm of mercury in their feathers (Henriksson et al. 1966). However, adult and young birds may react differently to the exposure.

When attempting to relate mercury concentration in feathers to that in body tissues, Johnels & Westermark (1969) found concentrations 7 to 8 times higher in feathers than in breast muscle. Vermeer & Armstrong (1972) reported a good correlation between the breast muscle and the primaries (a ratio of 1:12) in adult pintails, *Anas acuta*, but not in immatures. In two osprey nestlings from northern Finland the concentrations in feathers and in breast muscle were of the same order. In the moderately exposed nestlings from Hämeenkyrö mercury showed a breast muscle/feather ratio of about 1:10 (Table 3). Further studies on bioaccumulation are needed before the feather mercury values of nestlings can be used for estimation of mercury in other tissues.

In terrestrial animals concentrations of mercury are higher in liver and in kidney than in skeletal muscles (Ackefors et al. 1970). This conclusion was supported by the few data of this study. High mortality was demonstrated by Fimreite (1970) in White Leghorn chicks having 10.0 ppm of mercury in the liver (wet weight) and a concentration of 3.9 ppm caused retardation of growth. If we consider the osprey nestling from Hämeenkyrö to represent the general exposure of osprey nestlings to mercury in the mercury-contaminated areas of Finland the results are not alarming.

In 1954—67 the pulp and chlorine industries released 8.6 tons of mercury annually into certain Finnish water systems, and with the restriction in 1968 the value fell to only 0.8 tons (Häsänen 1973). As a result the mercury concentrations in fish have decreased, particularly in the lower parts of the rivers Kymijoki and Kokemäenjoki and on the coast of Oulu, and to a lesser extent in the inland waters (Häsänen 1973). Several other studies have confirmed this decrease (Nuorteva et al. 1975; Paasivirta et al. 1975; Lind & Hanski 1976; Mankki unpublished). The present study shows that mercury in feathers of osprey nestlings decreased significantly between 1972 and 1978, the decrease being less marked on the river Kokemäenjoki than in the other areas. This may be due to the chlorine factory at Äetsä, which is still releasing some mercury through the air into the river.

Since the mercury ban in 1968, decreasing concentrations of mercury have also been found in seals (Häsänen 1973), terns and gulls (Paasivirta et al. 1975) and snails (Lindgren 1976) in the mercury-contaminated areas of Finland. In Sweden a dramatic decrease in mercury level was seen in feathers of the goshawk, *Accipiter gentilis*, after the banning of alkyl mercury compounds as seed dressing agents in 1966 (Jenssen et al. 1972).

According to Saurola (1976), the annual reproductive success of the Finnish osprey

population was 1.4 nestlings per occupied nest in 1971—75. In certain areas of W and SW Finland the reproductive success was much lower than in other parts of the country. However, there is no evidence that this difference is due to mercury load, for in the mercury-contaminated area of Finland the reproductive success of the osprey was much the same as the average for the whole country. Moreover, the decrease in mercury contamination did not increase the osprey's reproductive success during the study. Hence the decrease in the Finnish osprey population must be due to factors other than mercury.

Table 8. Transfer of mercury from fish food to two osprey nestlings, one from an uncontaminated (Inari) and the other from a mercury-contaminated (Hämeenkyrö) area.

Nest locality	Total fish intake,[1] kg	Estim.av. mercury[2] level in fish, mg/kg	Estim.total intake of mercury, mg Hg	Total mercury content of the young, mg Hg
Inari	4.8	0.15	0.72	0.06
Hämeenkyrö	6.5	0.50	3.25	0.77

[1] Data from Häkkinen (1977).
[2] Data from Häkkinen (1978); Häsänen & Sjöblom (1968); Nuorteva et al. (1975).

4.2. Bioaccumulation of mercury in ospreys

Finnish ospreys feed exclusively on fish (Häkkinen 1978; Linkola unpublished) and fish mercury values can be used to predict the bioaccumulation of mercury in ospreys. In central Finland and on the SW coast of Finland the osprey's diet consist mainly of bream-like fishes, their average size being 300 g (Häkkinen 1978). The mercury content of such fish is about half that in 1 kg pike in the same water areas (Nuorteva et al. 1975; Paasivirta et al. 1975). It was estimated that in northern Finland the osprey's fish food contained 0.1—0.2 ppm of mercury (modified from Häsänen & Sjöblom 1968; Häsänen unpublished). The same concentration was present in the breast muscles of the two osprey nestlings analysed. In the moderately contaminated area of Hämeenkyrö ospreys fed on fish containing 0.5 ppm of mercury (see Nuorteva et al. 1975) The accumulation coefficient (mercury in food/mercury in breast muscles) for the osprey nestling which grew up in the same area was 1.4, which indicates a slight bioaccumulation. Similar evidence has been present by Nuorteva & Häsänen (1972) for sarcosaprophagous larvae and by Johnels et al. (1967) for pike.

It was also possible to make quantitative comparisons of transfer of mercury from fish to osprey nestlings in uncontaminated and contaminated areas (Table 8). The total mercury intake and the mercury content of nestlings were estimated for both situations. The calculations revealed that in the contaminated area the nestlings assimilated relatively more mercury, most of which accumulated in the plumage. Probabaly the rate of excretion via the faeces remains constant (Tejning 1967; Svensson & Ulfvarson 1968). Excrection via growing feathers is a most important, and perhaps even life-saving, factor for osprey nestlings. In young ospreys the development of plumage takes about a month (Johnels et al.1968). While growing, the feathers bind mercury from the circulation and so act as a safety valve. However, the ability of plumage to bind mercury is restricted to the time of growth, and the chemical properties of plumage are also important. Evidence for these arguments is given in Fig. 2. Increase of mercury in fish used as food was reflected in feather mercury concentrations up to a certain level, 20—30 ppm. Beyond that level there was practically no further accumulation.

Many papers already cited in the discussion have demonstrated the difference between the osprey and the white-tailed eagle with respect to mercury contamination. Koivusaari et al. (1972a; 1976) proposed the following two explanations:

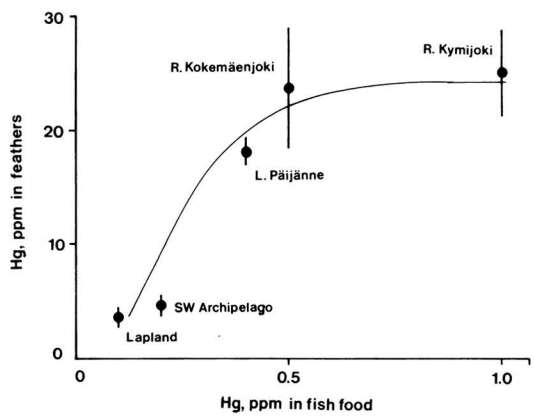

Fig. 2. Accumulation of mercury from fish eaten to feathers of osprey nestlings. Five areas in which fish showed different degrees of mercury contamination are compared. Fish mercury data are from Häsänen & Sjöblom (1968), Paasivirta et al. (1975), and Linko & Terho (1977).

the lifetime of the eagle is longer than that of the osprey and the eagle occupies a higher position in the ecological food chain. Future research will show whether dietary differences between these birds can account for the phenomenon.

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