Mercury in Finnish Sparrowhawks *Accipiter nisus*

Tapio Solonen & Martin Lodenius

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The mercury content of the Sparrowhawk *Accipiter nisus* was studied from feathers of museum specimens and from moulted feathers collected from nesting territories. The mercury contents of the samples dating from 1899 to the early 1980s varied from 1 to 42 µg/g, being most often about 2—5 µg/g. The mercury levels of some prey species of the Sparrowhawk were relatively high. In Sparrowhawks, significantly elevated mercury levels were recorded in the samples from the second half of the century, and high values predominated in the samples from the 1960s. These were followed by significantly lower values but the samples from the late 1970s and early 1980s also showed many high and some exceptionally high concentrations. The many interacting factors complicate assessment of the role of mercury in the breeding success and population changes of Finnish Sparrowhawks, but some sublethal effects are probable.

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Introduction

Mercury occurs naturally in many forms with various properties and toxicity. The most toxic form is considered to be monomethylmercury, which can be produced from mercury in other forms in both aquatic (Wood et al. 1968) and terrestrial environments (Beckert et al. 1974). Man's activities have raised the mercury levels in the environment (e.g. Johnels & Westermark 1969, Fimreite 1979), and it is difficult to assess the natural background levels (e.g. Johnels et al. 1979). The accumulation of mercury in food chains, however, is one of the best-known examples of environmental pollution (e.g. Johnels & Westermark 1969, Särkkä et al. 1978, Fimreite 1979).

The principal source of mercury pollution of terrestrial birds is seed dressed with the mercurial fungicides that came into common use after about 1940 (Fimreite 1979); for example, 5.6 tons of mercury (as methoxy ethyl mercury compounds) was used in Finnish agriculture in 1981 (Tiittanen & Blomqvist 1982). The consequence has been widespread contamination of seed-eating birds, especially those most associated with grain farming, and their predators. In many species the populations show an inverse relation to the pollution of their environment by mercury (see e.g. Borg et al. 1969, Westermark et al. 1975, Newton 1979, Thissen et al. 1982), but usually other pollutants than mercury have also been involved (see e.g. Koeman et al. 1972, Newton & Bogan 1978, Bogan & Newton 1979, Newton 1979, Cooke et al. 1982, Odsjö 1982, Dyck 1983).

In this paper we examine the mercury load throughout the present century in one of the most probable victims of mercury contamination in terrestrial food chains in Finland, the Sparrowhawk *Accipiter nisus*. The effects of elevated levels of mercury on the food chains, breeding success and population size are discussed.

Material and methods

The mercury content of Sparrowhawks was studied from feathers of museum specimens (mainly from the Zoological Museum of the University of Helsinki) and from moulted feathers (mainly those of females) collected from nesting territories. These two sample sets dated from 1899 to 1979 (N=44) and from 1959 to 1982 (N=71), respectively. Usually a mantle feather was analysed from each specimen studied, but in some cases only feathers from other parts of the plumage were available. The samples originated from various parts of Finland, from the southern coast to the districts of Oulu and Kuusamo in the north. A few recent feather samples from some prey species of the Sparrowhawk, and some other predatory birds from the southern part of the study area were also analysed. The feather samples were ovendried at +50°C and digested in 10 ml of concentrated H_2SO_4 + HNO_3 (4:1), using an aluminium hot bloc (+75°C; 4h). The mercury contents were measured with an accuracy of 0.1—1 µg/g, 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.

Table 1. The mercury content of feathers of the Sparrowhawk, some of its prey species, and some other predatory birds in southern Finland.

	Hg µg/g		
	Mean	Range	N
Predatory birds			
Accipiter nisus (1899—1950)	3.7	2.1—5.8	16
" (1951—1982)	8.4	1.0—42	99
Accipiter gentilis	2.7	1.3—5.3	3
Buteo buteo	5.3	2.3—7.3	3
Pandion haliaëtus	11.6	1.7—20	3
Bubo bubo	0.7	0.1—1.1	3
Prey species			
Fringilla coelebs	2.5	0.8—4.2	5
Parus montanus	2.2	1.3—2.7	3
Garrulus glandarius	1.5	1.2—1.8	2
Emberiza citrinella	1.4	0.2—3.8	3
Turdus merula	1.2	0.4—1.7	3
Sturnus vulgaris	1.0	0.6—1.4	2
Turdus iliacus	0.7	0.5—0.8	3
Turdus pilaris	0.7		2
Parus major	0.7	0.5—0.8	3
Bonasa bonasia	<0.2		2
Chlethrionomus glareolus	<0.2		2

Results

The mercury content of the feathers of Finnish Sparrowhawks varied widely, averaging 7.8 (median 5.6) µg/g dry weight (N=115) (Table 1). It was generally in the range 1.0—42 µg/g, being most often about 2—5 µg/g (Fig. 1). Because of probable external contamination of some museum specimens (cf. Berg et al. 1966) from the first few decades (up to the 1930s), exceptionally high values from that period (up to 130 µg/g) were excluded from the analysis of the results.

Between the 1950s and 1960s the mercury concentrations in Finnish Sparrowhawks rose significantly (Mann-Whitney U-test; $P<0.01$) (Fig. 2). High levels predominated in the samples of the 1960s, and these were followed by significantly lower ones in the 1970s ($P<0.05$), though many high and some exceptionally high concentrations were also recorded for the samples from the late 1970s and early 1980s. Although the mercury level in the early 1980s was significantly ($P<0.01$) lower than in the 1960s, it was still significantly ($P<0.05$) higher than the mercury levels of the first half of the century. High concentrations were recorded for the samples from western and northern Finland (Fig. 3), but only the difference between southern and northern Finland after 1970 was significant ($P<0.05$). On the other hand, large differences could occur between nearby territories.

The mercury levels of some prey species of the Sparrowhawk were relatively high (Table 1). The results suggest that among the species analysed, the most probable sources of mercury for the

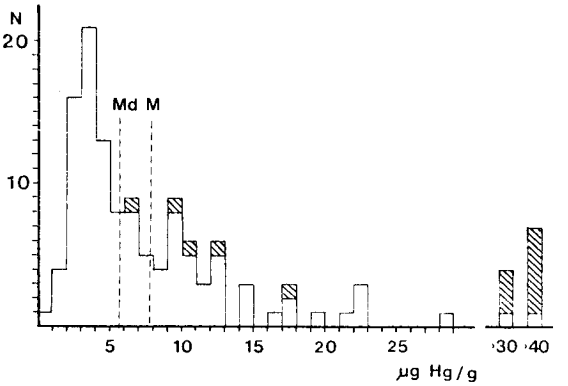

Fig. 1. Frequency distribution of mercury levels in feathers of Finnish Sparrowhawks in 1875—1982 (N=129). Hatching indicates the samples probably contaminated externally, and therefore excluded from the analysis of the results. M = mean, Md = median.

Sparrowhawk were some granivores, omnivores and soil invertebrate feeders (the Chaffinch *Fringilla coelebs*, the Willow Tit *Parus montanus*, the Jay *Garrulus glandarius*, the Yellowhammer *Emberiza citrinella*, the Blackbird *Turdus merula* and

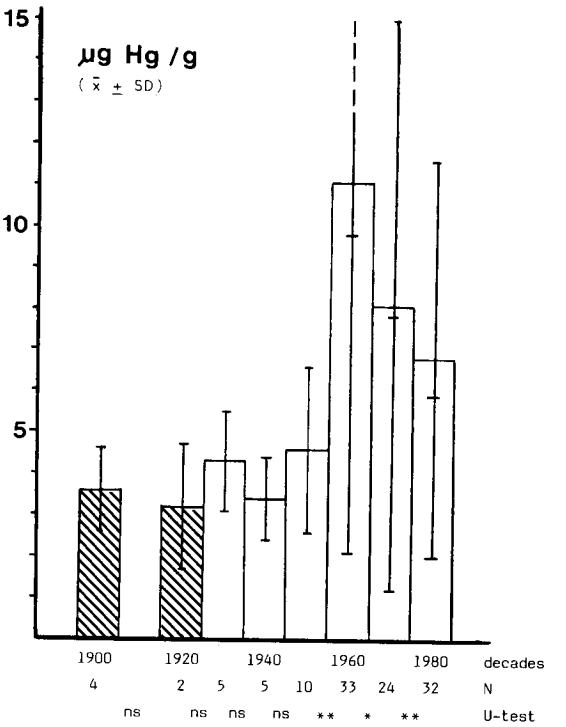

Fig. 2. Mercury levels in feathers of Finnish Sparrowhawks from the turn of the century up to the early 1980s (N=115). The data from the earliest decades (hatched bars) have been arbitrarily reduced by excluding samples that were probably externally contaminated (cf. Fig. 1). Significance of differences: Mann-Whitney U-test.

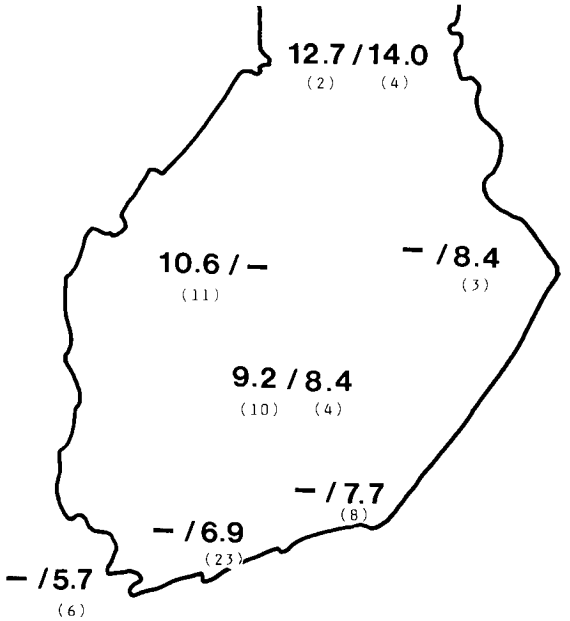

Fig. 3. Mercury levels (μg/g) in moulted feathers of the Sparrowhawk collected from nesting territories in various parts of Finland in 1959—1970 (left) and 1971—1982 (right). The number of the samples in parentheses.

the Starling *Sturnus vulgaris)*. Among some other diurnal raptors of the study area the mean mercury content was highest (11.6 μg/g; N=3) in the fish-eating Osprey *Pandion haliaëtus,* fairly high (5.3 μg/g; N=3) in the mainly rodent-eating Common Buzzard *Buteo buteo,* and relatively low (2.7 μg/g; N=3) in the Goshawk *Accipiter gentilis,* which feeds mostly on medium-sized birds (Table 1). In the Eagle Owl *Bubo bubo,* the terrestrial bird predator that is highest in the food web of the area, the mercury content averaged only 0.7 μg/g (N=3).

Discussion

Accumulation of mercury in feathers. Feathers are formed during a fairly short period of juvenile life and during the moult in full-grown birds. The levels of mercury in the feathers reflect the amount of mercury present in the blood when the individual feathers were formed (Johnels & Westermark 1969, Westermark et al. 1975). Most of the mercury in feathers consists of methyl mercury, which is eliminated slowly from the animal body and thus readily accumulates in ecosystems (see Westermark et al. 1975). The levels of mercury in feathers have been found to be about 7–8 times that in fresh breast muscle tissues (Berg et al. 1966, Johnels & Westermark 1969, Westermark et al. 1975), but this ratio may vary (see Häkkinen & Häsänen 1980). The feather content thus roughly corresponds to the dry-weight content of muscle. In the liver the mercury content is about 2—3 fold that in the muscle (Westermark et al. 1975, Häkkinen & Häsänen 1980). The variation in the mercury content within a feather is not greater than a factor of 2 (Berg et al. 1966, Johnels & Westermark 1969), but in adult birds, the variation between the feathers of different parts of the plumage may be wide (Johnels & Westermark 1969, Westermark et al. 1975, Bühler & Norheim 1981).

In juvenile Sparrowhawks the mercury content of feathers reflects the situation in the surroundings of their birthplace. In adults the mercury of moulted feathers reflects the situation either in the area of their birth or in their breeding locality in the preceding year. During the growth of feathers, most of the mercury load seems to be accumulated in the plumage, which evidently acts as a safety valve against mercury poisoning (Häkkinen & Häsänen 1980). In males, moulted feathers are the main route by which mercury is eliminated, whereas in females a considerable proportion is eliminated in eggs, the methylated forms primarily in the albumen (see Fimreite 1979). Thus, similar levels of mercury in the feathers reflect different levels in other tissues in males and females. Individually varying rates of accumulation and elimination of mercury also bring about variations in the ratio between the feather and other tissue levels (e.g. Westermark et al. 1975).

Mercury levels. It was difficult to assess the natural background level of mercury in the Sparrowhawk, but general levels in the samples from the 1930s and 1940s suggest that it might be about 3—4 μg/g (Fig. 2), i.e. roughly similar to those reported for Swedish Goshawks and Peregrines *Falco peregrinus* (Berg et al. 1966).

The mercury levels in Finnish Sparrowhawks were relatively high, but only a few comparable data on the species were available (Table 2). The high variation in the mercury levels resembled that noted in many other species (e.g. Westermark et al. 1975). The levels were fairly high compared with those in some other birds of prey in the study area (Table 1) and elsewhere in Finland (e.g. Henriksson et al. 1966, Häkkinen & Häsänen 1980, Lindberg et al. 1983) and in Sweden (e.g. Berg et al. 1966, Borg et al. 1969, Johnels & Westermark 1969, Jensen et al. 1972, Westermark et al. 1975, Lindberg & Odsjö 1983; cf. also Bednarek et al. 1975)). As our sample feathers from the Osprey were from adults, they may have grown in the wintering areas in Africa (see e.g. Johnels & Westermark 1969, Jensen et al. 1972), in which case they are not comparable with our

Table 2. Mercury levels of the Sparrowhawk in samples from different countries. According to studies of Westermark et al. (1975) and Häkkinen & Häsänen (1980), the ratio feather:muscle:liver is roughly 8:1:3 on a wet weight basis and 1:1:3 on a dry weight basis.

Tissue	Hg µg/g Mean/ Median (md)	Range	N	Country	Reference
Feathers (dry weight)	4.1	2.1—7.7	26	Finland 1899—1960	This study
"	11.1	2.3—42	33	" 1961—1970	"
"	7.4	1.0—29	56	" 1971—1982	"
"	4.9	0.4—20.3	52	Germany 1972—1973	Bednarek et al. 1975
"		2 —20	18/3	Norway 1976	Bühler & Norheim 1981
Liver (dry)	6.4		150	England 1970—1975	Cooke et al. 1982
Liver (wet)	9.2	8.3—10	2	Holland 1969	Koeman et al. 1969
"	md 0.8	0.1—5.7	36	Norway 1965—1976	Holt et al. 1979
"	md 1.9	0.4—5.7	11	" 1972—1977	Norheim & Frøslie 1978
Liver/kidney (wet)	18.4	0.2—55	6	Sweden 1963	Borg et al. 1969
Kidney (wet)	md 1.5	0.4—12	31	Norway 1965—1976	Holt et al. 1979
"	md 1.6	0.4—4.4	11	" 1972—1977	Norheim & Frøslie 1978
Muscle (wet)	2.8	0.2—6.7	4	Switzerland 1972	Veluz et al. 1976
"	md 0.6	<0.1—1.4	15	Norway 1965—1976	Holt et al. 1979
"	md 0.8	0.2—1.4	11	" 1972—1977	Norheim & Frøslie 1978
Brain (wet)	md 0.3	<0.1—0.7	4	" 1965—1976	Holt et al. 1979
Eggs (wet)	0.7	0.4—1.1	3	Holland 1969	Koeman et al. 1972
"	0.4	0.2—0.6	10	" 1970	"

other data. The low mercury levels in the Eagle Owls may be partly due to the fact that the feathers were from juveniles, with fairly brief exposure to mercury contamination (cf. e.g. Lindberg & Odsjö 1983, Lindberg et al. 1983), and partly to the local feeding habits of the parents. Fairly low and declining levels of mercury have recently been reported from an inland population of the species in Sweden, but in coastal regions the birds were much more contaminated (Odsjö & Olsson 1975, Broo & Odsjö 1981).

In Swedish Goshawks, the mercury content of the feathers paralleled the use of methyl mercury in agriculture (see Johnels & Westermark 1969, Jensen et al. 1972, Westermark et al. 1975, Fimreite 1979, Johnels et al. 1979). A roughly similar trend appeared to exist in Finnish Sparrowhawks and the same seems to be true of many other species (see e.g. Tejning 1967, Borg et al. 1969, Johnels & Westermark 1969, Odsjö & Olsson 1975, Westermark et al. 1975, Odsjö & Sondell 1977, Johnels et al. 1979). The general level of mercury in the Sparrowhawk seemed to be higher than in many other species. The peak was not so pronounced as in the Swedish Goshawk, which may be due to the fact that the methoxy ethyl mercury compounds used in Finnish agriculture do not accumulate as readily in the food-chains as methyl mercury compounds. Nevertheless, our results suggest that mercury contamination of the terrestrial food web in southern Finland is an actual problem (cf. Odsjö & Olsson 1975).

Although the material was scanty, this study, like many others (see e.g. Berg et al. 1966, Borg et al. 1969, Johnels & Westermark 1969, Fimreite et al. 1970, Westermark et al. 1975, Fimreite 1979, Johnels et al. 1979), suggests that granivorous birds are the main link in the accumulation of mercury in raptors feeding on terrestrial birds. In the Sparrowhawk granivores form a considerable proportion (about 20 % on a fresh weight basis) of the prey during the breeding and moulting season in Finland (Sulkava 1964). In winter and early spring the proportion of granivorous birds (especially Yellowhammers, House Sparrows and Chaffinches) is evidently larger, but the mercury accumulated at that time can not be quantified from feather samples. 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 et al. 1982). This suggests seasonal fluctuations in the mercury levels of the body.

Effects of mercury on birds. From feeding experiments with methyl mercury, it appears that the liver levels associated with death are about 30—130 µg Hg/g in Pheasants *Phasianus colchicus,* 50—200 µg/g in Magpies *Pica pica,* and 70—115 µg/g in Jackdaws *Corvus monedula* (Borg et al. 1969). Koeman et al. (1971) fed mice with a total body content of 13.3 µg Hg/g to Kestrels *Falco tinnunculus* and reported 49—122 µg/g in the liver of the birds at death. In the Red-tailed Hawk *Buteo jamaicensis,* Fimreite & Karstad (1971) found that Hg residues were lethal at levels as low as 17 µg/g. The extremely high mercury levels reported in some fish-eating birds apparently suffering no ill effects (Fimreite 1974) may be related to physiological factors, as fish is normally high

in selenium, which is known to antagonize the metabolic effects of mercury (Fimreite 1979). The effects of mercury and other contaminants are usually additive, but may sometimes be synergistic. It is often difficult to separate the specific effect of one contaminant without an experimental approach (cf. Fimreite 1979), and sublethal effects are usually difficult to demonstrate (e.g. Jensen et al. 1972).

The reproductive system in birds seems to be the most prominent target of many environmental pollutants, including mercury (e.g. Fimreite 1979). It has been suggested that the mercury level in the body causing sterility corresponds to a level in the feathers of about 40 µg/g or even lower (Berg et al. 1966, Westermark et al. 1975). Unhatched eggs with high levels of mercury have been found in many studies (e.g. Henriksson et al. 1966, Borg et al. 1969, Fimreite 1974), and the bulk of the mercury in eggs occurs in the methylated form (Fimreite et al. 1974, Särkkä et al. 1978). Reduced hatchability seems to be largely due to increased embryonic mortality during the first days of incubation, and the survival rate of chicks from contaminated eggs may also be reduced (see Fimreite 1979; cf. also Häkkinen & Häsänen 1980). Eggs were not analysed in this study, but no correlation has been found between the mercury levels of the parent birds and the number of unhatched eggs, or the breeding success measured as the number of fledglings (T. Solonen, unpubl.). Among Sparrowhawks in Germany, differences in breeding success between two areas were related to difference in the mercury levels in eggs, but as organochlorines were also present, the results were hard to interpret (Bednarek et al. 1975, see also Newton 1979). In Central Europe, DDE seems to be the main factor responsible for impaired breeding success of the Sparrowhawk and other birds of prey (Koeman et al. 1972, Newton 1974, Newton & Bogan 1978, Bogan & Newton 1979).

Effects of environmental pollution on birds are finally reflected in changes in their populations (see e.g. Borg et al. 1969, Newton 1979, Cooke et al. 1982, Dyck 1983). Migrating and ringing statistics suggest that the Finnish Sparrowhawk population has increased in the last few years (see Saurola 1981, 1983, Solonen 1984), and this seems to agree with the general trend in the mercury content of the birds. The existence of many interacting factors (see above) obscure the role of mercury in the population changes of Finnish Sparrowhawks, but some sublethal effects are probable. It has been suggested that high levels of mercury in the eggs of some accipiters have contributed to documented organochlorine-related declines in the populations (Fimreite et al. 1970), and that these contaminants accumulate almost in parallel in the food chains (Holt et al. 1979). The demethylation of mercury is, however, a significant detoxication route for methyl mercury in birds of prey, enabling them to tolerate methyl mercury better than has been believed (Norheim & Frøslie 1978). A detailed study on the combined effects of various environmental pollutants possibly affecting Sparrowhawks (heavy metals, and DDT- and PCB- compounds) would be desirable.

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Selostus: **Varpushaukan höyhenten elohopeapitoisuus Suomessa**

Suomalaisten varpushaukkojen elohopeapitoisuuksia tutkittiin sekä museonäytteistä että pesimäpaikoilta kerätyistä höyhenistä. Vuosisadan vaihteen ja 1980-luvun alun väliltä peräisin olevien näytteiden elohopeapitoisuudet vaihtelivat välillä 1—42 µg/g (kuva 1) ja olivat keskimäärin 7.8 (mediaani 5.6) µg/g (N=115). Vuosisadan puolivälin jälkeen pitoisuudet kohosivat merkitsevästi ja 1960-luvulla korkeat arvot olivat vallitsevia (kuva 2). Myöhemmin seurasi lasku, mutta vielä 1970-luvun lopulla ja 1980-luvun alussa tavattiin huomattavan korkeita elohopeapitoisuuksia. Vaikka nykyisin elohopeaa on varpushaukan höyhenissä merkitsevästi vähemmän kuin 1960-luvulla, ovat pitoisuudet edelleen selvästi vuosisadan alkupuolen tason yläpuolella. Varpushaukan höyhenten elohopeapitoisuudet olivat korkeita erityisesti Länsi- ja Pohjois-Suomessa, vaikkakaan alueelliset erot eivät pienestä aineistosta johtuen yleensä olleet merkitseviä (kuva 3). Joidenkin varpushaukan saalislajien elohopeapitoisuudet olivat suhteellisen korkeita ja varpushaukan pitoisuudet vaikuttivat huomattavilta eräisiin muihin petolintuihin verrattuna (taul. 1). Suomalaisten varpushaukkojen elohopeapitoisuudet näyttivät olleen kohtalaisia joihinkin ulkomaisiin tuloksiin verrattuna (taul. 2), mutta monista tekijöistä johtuen elohopean merkityksestä lajin menestymiselle on vaikeaa saada selvää kuvaa.

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