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CONCENTRATIONS OF MERCURY IN OTTERS (*LUTRA LUTRA* L.) IN SCOTLAND IN RELATION TO RAINFALL

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Abstract

Concentrations of mercury (Hg) were measured in 112 livers of otters from various areas in Scotland during 1986–1992. Mercury concentration varied from 0.3–44.7 ppm (dry). There was a significant positive correlation between Hg in otters and annual rainfall, consistent with an atmospheric origin of mercury pollution. Mercury concentration was higher in animals with lower body condition. Concentrations were shown to increase with the age of the animal, but not everywhere, and the correlation was weak. It appeared unlikely that during the study period otter numbers were affected by mercury. © 1997 Elsevier Science Ltd

INTRODUCTION

The natural range of the otter *Lutra lutra* L. includes almost all of Europe, but the species has disappeared from many areas and from several entire countries between 1950 and 1990 (Foster-Turley *et al.*, 1990). Pollution by organochlorines is considered to be a major factor behind this decline (Mason, 1989; Jefferies, 1989). The species has a diet consisting very largely of fish caught in fresh water habitats or along sea coasts (Mason and Macdonald, 1986; Chanin, 1991). The animals are, therefore, at the top of aquatic food pyramids, in a position where bioaccumulation of metals and organochlorines is likely.

Although organochlorines are assumed to be involved in the species' decline, the possibility cannot be discounted that metal pollution played a role (Kruuk and Conroy, 1991). Mercury (in its methylated form) is known for its potentially lethal effects on many wild carnivores, causing damage to the central nervous system leading to lassitude, loss of motor coordination and paralysis (Wren, 1985). Mercury occurs naturally in the environment but is very substantially augmented by agriculture, and by industrial sources, such as mining and smelting, fossil fuels, waste incineration and various production processes such as that of chlor-alkali. These industrial sources far outweigh the natural contribution, and a large proportion of the inorganic mercury is converted into methylmercury (Lindquist and Rohde, 1985).

In Britain there has been a decline in mercury in the environment over the last decades; for instance, Newton *et al.* (1993) show a substantial decrease since 1970 of mercury in heron (*Ardea cinerea*), but also in kestrel (*Falco tinnunculus*), sparrowhawk (*Accipter nisus*) and kingfisher (*Alcedo atthis*). The decline in mercury concentration over this period in these species was more pronounced than that of PCBs although there was circumstantial evidence that PCBs were the more important compounds. The reduction of the various contaminants coincided in England with a build-up of populations for the above birds, as well as for otters (Strachan and Jefferies, 1996).

It is not known at what concentrations mercury-contaminated prey becomes harmful to otters. In captivity, fish with 2.0 ppm (wet wt) methylmercury was lethal to an American river otter *Lutra canadensis* after 184 days (O'Connor and Nielsen, 1981). In Shetland the otter prey species contained mean levels of up to 0.14 ppm of total mercury wet wt (Kruuk and Conroy, 1991), and in England a main prey of otters, eel (*Anguilla anguilla*), contained mean concentrations of 0.29 ppm wet wt (Mason, 1989) in rivers where otters had disappeared, compared to 0.14 ppm in rivers where they were present. Hovens (1992) calculated mean levels of 0.1 ppm fresh weight of mercury in fish to be tolerable for otter food. Mason (1989) suggested that some sub-lethal effects on otters could occur when they ate fish contaminated with mercury at levels well below 1 ppm, and for management purposes he suggested that an arbitrary concentration of 0.3 ppm in fish should not be exceeded. For people, the World Health Organization (Anon., 1976) recommends a maximum weekly mercury intake of 0.2 mg for a person of 70 kg, or 0.15 $mg\,kg^{-1}\,yr^{-1}$; however, in Shetland in the 1980s, the mercury intake by otters was 4–7 $mg\,kg^{-1}\,yr^{-1}$ (Kruuk and Conroy, 1991), about 40 times higher than that recommended for people. This annual dose was still an order of magnitude below that demonstrated to be lethal for otters, but over the years such concentrations could accumulate.

Thus, mercury intake by otters is not likely to cause mortality in the short term, but it could have subtle effects at the population level, especially since it has been suggested that the concentration in animals accumulates with age (Wren, 1985; Kruuk and Conroy, 1991). It is important, therefore, to assess its presence in otters in different areas, and to address hypotheses regarding the origin of mercury in these regions. There is evidence that a major mechanism of dispersion of mercury is atmospheric, with mercury compounds amongst others entering the ecosystem in precipitation (Lindquist and Rodhe, 1985). This suggests the hypothesis that in regions exposed to the same atmospheric air currents, mercury concentrations would be higher in high rainfall areas.

In this paper, we describe the concentration of mercury in the tissues of otters *Lutra lutra* from Scotland in relation to the animals' age and physical condition, and to area of occurrence and precipitation, during 1986–1993. The aim of the analysis was to assess how mercury levels are distributed within Scotland and whether otter populations are at present likely to be affected by mercury.

Otters have remained common in most areas of Scotland throughout the periods of population crashes elsewhere (Green and Green, 1987), occurring at varying densities. They can be aged accurately (Heggberget, 1984), and the availability of tissues from numbers of dead otters provided the opportunity to study the rate at which mercury accumulated in individuals (Kruuk and Conroy, 1991). It is possible also to assess their relative body condition K (Kruuk *et al.*, 1987; Kruuk and Conroy, 1991), and to compare K for different concentrations of mercury.

Here we address the following hypotheses:

1. The tissue concentration of mercury accumulates with the age of the otter.
2. The body condition of otters is lower in animals with high burdens of mercury.
3. Mercury concentrations in some Scottish otter populations are high enough to have sub-lethal effects.
4. Otters in areas with high precipitation carry higher concentrations of mercury.

METHODS

The carcasses of otters reported on in this paper were collected from June 1987 until July 1992. The large majority of these animals were killed by traffic, deep frozen after collection, then sent to the Institute of Terrestrial Ecology laboratory in Banchory where they would be measured, autopsied and dissected in batches.

The age of each otter was estimated by counting incremental growth rings in the dentine of one of the canine or incisor teeth (Heggberget, 1984). The body condition index (K) was calculated as $K = W / \text{a}.L^{\text{n}}$, in which W = body mass in kg, L = total length in m, the constants a = 5.02 and n = 2.33 for females, and a = 5.87 and n = 2.39 for males (Kruuk *et al.*, 1987).

Samples of liver from each otter were weighed (wet wt) and analyzed in the Institute of Terrestrial Ecology at Monks Wood. The method used was atomic absorption spectrophotometry with the cold-vapour technique (Thermo-electron 151, background corrected), after drying to constant weight at 85°C and digestion in concentrated nitric acid (Hatch and Ott, 1968). With every 25 tissue samples, a spiked sample with known mercury content (supplied by the National Bureau of Standards) was analysed. Recovery of mercury was generally within the range of 95–105% and no correction was made. Limits of detection were about 0.01 ppm. Residues are generally expressed as ppm dry wt, and average values are given as geometric means (Newton, 1988; Newton *et al.*, 1993; Smit *et al.*, 1994) which were close to median values. All statistical manipulations were carried out on log-transformed data.

The Institute of Hydrology provided interpolated monthly precipitation data on a 1-km grid scale, derived from Metereological Office measuring stations. These data were for the period January 1986 to December 1993 for the Scottish mainland, and for the period January 1992 to December 1993 for Orkney and Shetland. From this the mean annual precipitation was calculated for 1986–1993 and 1992–1993, for those 1-km National Grid squares from which otter carcasses had been obtained, using Arc/Info GIS software.

To compare annual rainfall data from 1986–1993 with 1992–1993, we correlated the two sets of information from grid squares where otter carcasses had been collected. There was a very strong and highly significant linear correlation (r = 0.997, r^2 = 0.993, N = 83, $p < 0.0001$). For some purposes, therefore, we used 1992–1993 data to represent rainfall for the whole study period when including Orkney and Shetland in analyses.

RESULTS

A total of 112 otter carcasses were analysed, and their sites of origin are shown in Fig. 1. Table 1 summarizes the main results. The animals varied widely in age, starting with six-month old cubs and with the oldest animal, at 15 years, also the oldest wild *Lutra lutra* on record. The condition of the otters ranged from extremely poor (index K = 0.48) to very fat (K = 1.41), with a mean K of almost exactly one, which was defined as 'normal' (Kruuk *et al.*, 1987). The overall geometric mean Hg concentration was 9.44 ppm, and the highest concentration in this sample was 44.7 ppm, found in Argyll.

For a preliminary analysis of differences in mercury concentrations between areas of Scotland, we grouped carcasses into seven regions (Table 2). This showed substantial variation, with highest mean values in the mid-western area Argyll and in Orkney, much lower values in the north-east (Grampian), and other areas intermediate.

There are large climatic differences between these areas of Scotland, of which rainfall is probably the most important factor. We found about five-fold variation in mean annual precipitation across the country (Fig. 1), with a minimum of 646 mm yr^{-1} (1986–1993, East Grampian), and a maximum of 3266 mm yr^{-1} (West Argyll). To test whether climate could be responsible for

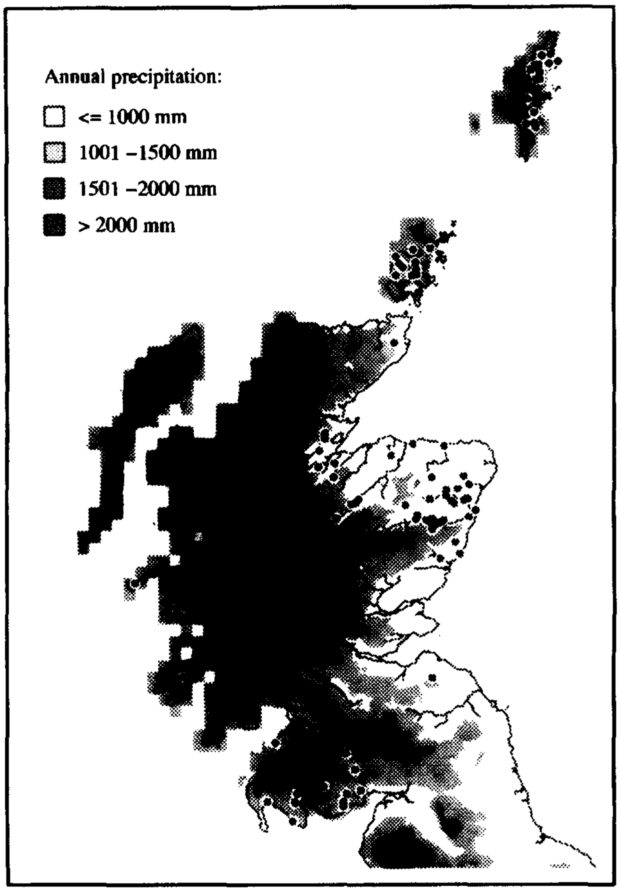

Fig. 1. Map of Scotland with the origin of otter carcasses. Annual precipitation, shown as shading, based on data copyright Institute of Hydrology.

at least part of the regional variation in mercury contamination, we correlated mercury in each otter carcass with the estimated mean annual rainfall (1992–1993) for that particular site. This was highly significant ($r = 0.33$, $r^2 = 0.11$; $N = 109$; $p < 0.001$).

We calculated a similar correlation for otter carcasses and rainfall from 1986–1993 for the Scottish mainland only (thereby excluding Orkney and Shetland), on the assumption that the ecology of the island otters was not strictly comparable with the mainland sample. The Orkney and Shetland otters feed on marine fish (Herfst, 1984; Kruuk and Moorhouse, 1990; Kruuk, 1995), and the mainland otters mostly or only on fresh water species (e.g. Jenkins and Harper, 1980; Kruuk *et al.*, 1993; Durbin, 1993). A linear regression of mercury concentration on mean annual rainfall 1986–1993 in mainland otters showed (Fig. 2):

Table 2. Concentrations of mercury (ppm dry wt) in otter livers; geometric means and standard deviations

Area	N	Mean ppm Mercury	S.d.
Shetland	14	11.1	1.6
Orkney	14	13.2	1.8
North/NW	10	9.9	3.1
Argyll	18	14.1	2.3
South-West	13	12.1	2.0
North-Central	10	9.6	2.8
Grampian	33	5.9	2.6

Statistical significance: Kruskal-Wallace $\chi^2 = 17.5$, $df = 6$, $p < 0.01$

$$\begin{aligned} &\text{Hg} = 0.006(\text{rain}) + 5.503 \\ &(r = 0.36, r^2 = 0.13; N = 82, p < 0.001) \end{aligned} \qquad (1)$$

There was a significant negative correlation between body condition index K and the concentration of mercury in the liver (Fig. 3):

$$\begin{aligned} &\text{Hg(ppm)} = 26.9 - 12.4K \\ &(r = -0.26, r^2 = 0.07, N = 104; p < 0.003) \end{aligned} \qquad (2)$$

This negative correlation also obtained for all areas analysed separately. A similar relationship was found for body condition and PCBs in this sample (Kruuk and Conroy, 1996), but there was no significant correlation between concentrations of mercury and PCBs ($r = 0.15$, $N = 104$, $p < 0.2$).

When comparing the mercury load of animals of different age, we found a weak but significant positive correlation over all samples combined (Fig. 4):

$$\begin{aligned} &\text{Hg(ppm)} = 9.81 + 0.84(\text{age}) \\ &(r = 0.23, r^2 = 0.052, p < 0.02; N = 109) \end{aligned} \qquad (3)$$

To incorporate simultaneously the effects of age, body condition and rainfall, a stepwise multiple regression showed

$$\text{Hg} = 0.0001R - 0.5982K + 0.0336A \qquad (4)$$

(see Table 3) in which Hg = mercury concentration in the liver in ppm dry, R = mean annual rainfall 1986–1993 in mm, K = body condition index and A = age in years.

Table 1. Summary of values of the main variables analysed in 112 carcasses (Age in years; Condition index, see text; Hg in ppm livers, wet wt and dry wt)

	N	Mean, arith	s.d., arith	Mean, geom	s.d., geom	Min	Max
Age	109	4.21	2.72	3.27	2.22	0.5	15
Condition	97	1.01	0.21	0.98	1.26	0.48	1.41
Mercury wet	112	4.04	3.01	2.86	2.60	0.11	13.43
Mercury dry	112	13.28	10.05	9.44	2.55	0.33	44.71

DISCUSSION

The results showed that Scottish otters may have concentrations of up to 45 ppm (dry wt) of mercury in their livers, with a geometric mean of 9.4 ± 2.5 ppm. The arithmetic mean of 13.3 ppm compares with, for instance, 8.1 ppm for otters in USA ($N = 192$; Wren, 1985); concentrations in Scotland are somewhat higher, but still far below the level of 110 ppm in otters which died after being fed mercury-contaminated fish over up to six months (O'Connor and Nielsen, 1981). Only 15% of the otters in our sample had levels above 20 ppm. Thus, just a few individual otters in Scotland may possibly have accumulated enough mercury to affect their survival, e.g. during times of food-stress. However, it appeared unlikely that populations would be suppressed by such contamination, even in the worst affected area (Argyll) where 11% had more than 40 ppm, and 28% more than 20 ppm ($N = 18$).

Elsewhere, selenium has been found to counteract the toxicity of mercury, with good correlations between concentrations of selenium and mercury in the liver of several marine and freshwater mammals (Koeman *et al.*, 1975; Smith and Armstrong, 1978; Wren, 1984). In Shetland otters, however, no such relationship was present (Kruuk and Conroy, 1991).

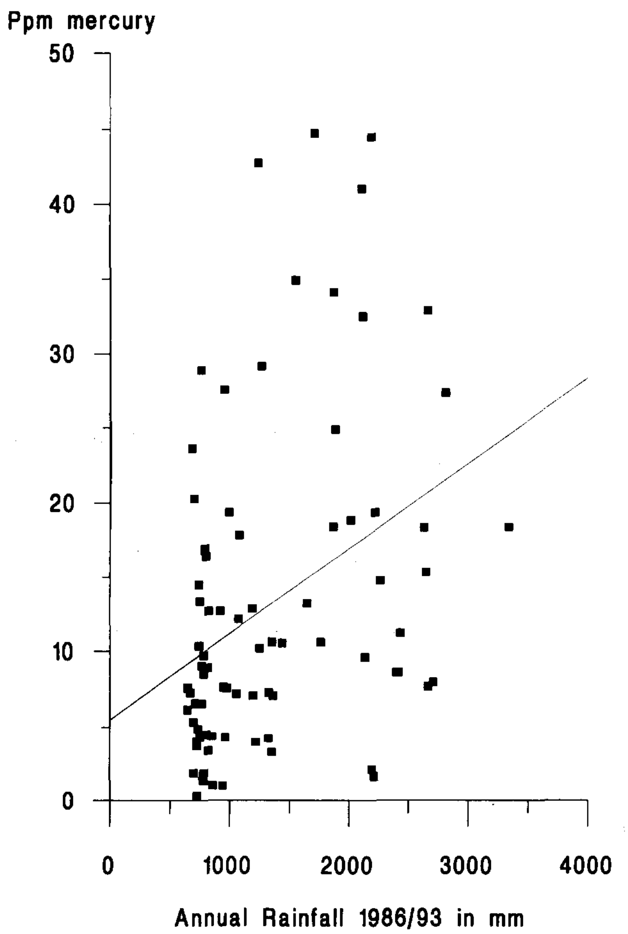

Fig. 2. The concentration of mercury in livers of otters, in relation to mean annual rainfall over 1986–1993, on the Scottish mainland. Regression: ppm Hg = 5.503 + 0.006*(rain), $r = 0.36$, $r^2 = 0.13$, $N = 82$, $p < 0.001$.

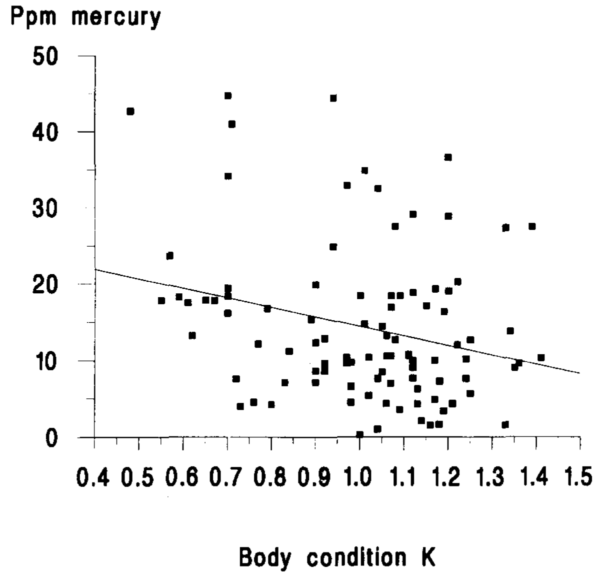

Fig. 3. The relation between body condition K and mercury concentration in the liver of otters. Regression: ppm Hg = 26.86 − 12.396K, $r = 0.26$, $r^2 = 0.07$, $N = 97$, $p < 0.01$.

The observations supported the hypothesis that mercury in otters accumulates with age. However, the age of the otters explained only 6% of the variation in Hg concentration over the whole sample, and in some areas the relationship was absent, or even negative. As yet we have no satisfactory possible hypothesis for these differences; it seems likely that otters are able to excrete some of the absorbed mercury with age, but the mechanism is unclear.

There are several possible explanations for the high negative correlation between relative body-mass, i.e. body condition K and mercury concentration: a low K could be either cause or consequence of mercury contamination. As mercury levels were generally rather low, we suggest that it was likely that otters with low body

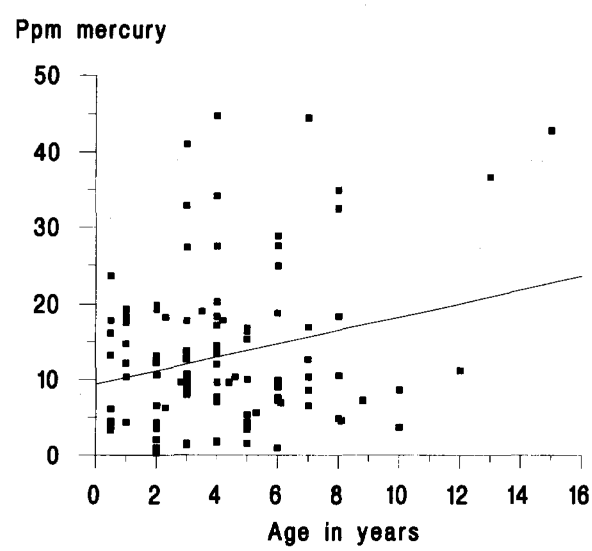

Fig. 4. The relation between age of otters and mercury in their livers (ppm dry wt). (ppm Hg) = 9.81 + 0.84(age), $r \doteq 0.22$, $r^2 = 0.05$, $p < 0.02$.

Table 3. Stepwise multiple regression, mercury versus rainfall (total over 1986–1993), body condition and age. $r^2 = 0.23$

Variable	Estimate	S.e.	F	Prob.
Rainfall	0.000141	0.000065	4.69	0.0341
K	–0.598248	0.232693	6.61	0.0125
Age	0.033594	0.016221	4.29	0.0424
Intercept	1.263252	0.265000	22.72	0.0001

condition accumulated Hg in the liver through remobilization of fat and associated methylmercury, and subsequent transfer to the liver.

Our results support the hypothesis that regional differences in Hg concentration are partly caused by differences in precipitation. Alternative explanations are differences in underlying geology, presence of point sources of mercury contamination or differences in acidification of water systems (Wren and MacCrimmon, 1983). We have been unable to find a likely cause in patterns in the geology of Scotland. Differences in acidification would also not explain mercury distribution, as suggested by Wren *et al.* (1986). The only significant acidification of Scottish lakes has been documented in the South-west, Galloway, and areas elsewhere do not appear to be affected (Maitland *et al.*, 1987).

As regards point sources from anthropogenic activities, which may affect areas with a radius of up to 50km, mercury is generated especially by mining, industrial production, burning of fossil fuels and waste incineration (Lindquist and Rohde, 1985). In Scotland, all these activities are concentrated in the Central Belt (Glasgow-Edinburgh), well away from almost all our collecting areas. It is possible, of course, that such pollution caused otters to be largely absent from this central area and, therefore, from our samples.

The correlation between rainfall and mercury in mainland otters is quite strong (eqn 1, $r = 0.36$) and explains 13% of the variation. Together with age and body condition *K*, it accounts for 23% of the variation (eqn 4), but clearly other factors (presently unknown) are, if anything, more important. It would be useful to compare these findings with data on mercury in otters elsewhere.

Otters are likely to acquire mercury through their prey. This consists very largely of fish, of which the fresh water species most important to otters in Scotland are eel (*Anguilla anguilla*) and salmonids (mostly *Salmo trutta*, but also *S. salar*) (Jenkins *et al.*, 1979; Jenkins and Harper, 1980; Green *et al.*, 1984). Eels could be especially important accumulating agents for various contaminants (Hider *et al.*, 1982), partly because of their high lipid content (Boetius and Boetius, 1985), and partly because they may live to over 15 years before migrating or being consumed by otters (Moriarty, 1978). In a sample of 88 eels from Scotland, Kruuk *et al.*, (1993) found a mean dry wt value of 0.45 ppm Hg, with 0.91ppm in Shetland (individual maximum of 1.34 ppm) and 0.18 ppm in Grampian. These values are high for animals such as otters with an exclusive fish diet (for instance compared with the recommended maximum concentration in fish for human consumption of 0.96 ppm (Anon., 1976).

In conclusion, there is no direct evidence for any one area that present-day mercury intake by otters affects populations. There is evidence for accumulation with age, but it is also likely that some mercury is excreted again in time. However, mercury concentrations in otters and their food are relatively high, and it remains possible that even a small increase in environmental mercury would have a significant effect on survival. With the evidence that mercury has substantially decreased in British wildlife over the last two decades and before the present survey (Newton *et al.*, 1993), its role as a possible contributing factor for the large-scale decline in otters in the 1960s and 1970s remains a possibility.

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