MERCURY ACCUMULATION IN NATIVE MAMMALS OF THE SOUTHEAST

by

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ABSTRACT

Mercury levels in tissues of mammals collected in Georgia, Florida, and South Carolina were compared using hair mercury concentration as an index of total mercury content. Bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), opossum (*Didelphis marsupialis*) and gray fox (*Urocyon cinereoargenteus*) from the Lower Coastal Plain of Georgia had higher mercury levels than specimens from the Upper Coastal Plain of Piedmont. The highest individual mercury levels in raccoons and bobcats occurred in specimens from the Georgia Lower Coastal Plain flatwoods. Skeletal muscle and liver of individual raccoons and bobcats taken in the coastal flatwoods exceeded the 0.5 ppm limit for mercury in human foodstuffs. No pattern of mercury accumulation was detected in white-tailed deer (*Odocoileus virginianus*). Hair analysis revealed elevated mercury levels in mammals from a region exposed to mercury pollution. Mercury levels in wildlife exhibit a pattern similar to that of certain fallout radioisotopes such as 137Cs. These observations indicate that significant biomagnification of mercury may occur in native mammals in certain southeastern habitats.

INTRODUCTION

Release of mercury to the environment from industrial and agricultural sources has led to serious environmental problems in several parts of the world in recent years (International Atomic Energy Agency 1972). Mercury has entered the environment by numerous routes due to its use in paints, paper pulp manufacturing, the electrolytic generation of chlorine, manufacture of electrical apparatus, agricultural seed dressings and other products. Mercury tends to become adsorbed to soil particles or to humic acids and other proteinaceous materials in soils (Lambou 1972) and may in turn be incorporated by soil organisms and other animals, resulting in food chain concentration or biomagnification. Contamination of plant foliage, fruits or seeds would also lead to introduction of mercury into food chains.

Nelson et al. (1971) listed research objectives which would contribute to a better understanding of the distribution and cycling of mercury in ecosystems. These include identification of species which are prone to accumulate mercury, evaluation of the use of easily collected materials such as hair for field monitoring of mercury contamination, and identification of contaminated areas so that studies of reproduction and survival of affected species may be initiated.

Hair can be used as a biopsy specimen for assessment of exposure to trace metals (Birke et al. 1972, Skerfving 1972). However, relatively little use has been made of hair metal concentrations to evaluate exposure of native mammals to trace metals. Kennington and Ching (1966) and Huckabee et al. (1972) concluded that analysis of hair could be used to monitor trace metals in the environment. We have found that hair mercury levels are significantly correlated with mercury concentrations in skeletal muscle and liver (Cumbie, 1975) and have used hair mercury as an index of total mercury body burden.

Our study was undertaken to determine mercury concentrations which occur in terrestrial mammals in natural habitats of the Southeast. Additional objectives were to identify game species which may accumulate significant mercury body burdens, to evaluate the relative significance of mercury in food chains in the Southeast by comparison of mercury levels in indicator species, and to assess the human dietary hazard which might be posed by game mammals which are exposed to environmental mercury.

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MATERIALS AND METHODS

Mammals were captured with leg-hold steel traps and box-type live traps at various locations in Georgia and on the U. S. Atomic Energy Commission Savannah River Plant (SRP) in South Carolina. Specimens were also obtained from road-kills during travel to and from collecting areas. Furbearer hair specimens were obtained from pelts taken by trappers in Georgia during the 1973-1974 season, from Georgia Game and Fish Commission personnel and from individual hunters. White-tailed deer specimens were collected at game management area hunts and from deer taken by individual hunters in other areas. Raccoons from Florida were obtained through cooperation of the Florida Division of Health, Jacksonville.

Skeletal muscle and liver specimens were stored frozen until analyzed for mercury content. Hair specimens were removed with scissors, cutting so as to remove hair shafts as near the skin as possible, including both fur and guard hairs. Collection of hair contaminated by blood, soil, or feces was avoided. Deer hair was taken from the back of the neck, and specimens from fur pelts were taken from the posterior edges (upper hind leg) to minimize damage to hides or trophies. Hair specimens were generally taken from at least two locations to minimize the possible effect of point-to-point variation in hair mercury content. The samples from each animal were pooled, rinsed in acetone, dried, and clipped into lengths of approximately one cm with dissecting scissors.

Specimens were analyzed for total mercury content by the flameless atomic absorption technique using a Coleman MAS-50 mercury analyzer. Procedures were based on those described by Hatch and Ott (1968) and the U. S. Environmental Protection Agency (1972). Alternatively, total mercury content was determined by non-destructive neutron activation analysis (Westermark and Sjostrand 1960). Specimens were exposed to thermal neutrons in the Georgia Tech nuclear research reactor, held for at least one week to permit decay of short-lived isotopes, and counted using a 55-cc lithium-drifted germanium (Ge-Li) detector coupled with a 4000-channel pulse height analyzer or a 5-inch NaI crystal detector coupled with a 400-channel pulse height analyzer. All mercury concentrations are expressed in parts per million (ppm).

Hair mercury levels of mammals were compared between different physiographic regions in Georgia. Georgia specimens were also compared to specimens from the SRP in the Upper Coastal Plain of South Carolina and to specimens from northern Florida (north of a line between Citrus and St. Johns counties) and southern Florida (south of a line between Lee and Brevard counties). Georgia specimens were divided into those taken from the Piedmont, Upper Coastal Plain or Lower Coastal Plain counties. All Florida animals were considered to be Lower Coastal Plain specimens.

Data were analyzed using statistical techniques described by Sokal and Rohlf (1969). Homogeneity of variances was determined by Bartlett's method or by the Fmax method. When variances were found to be heterogeneous, mean mercury levels of groups were compared using Snedecor's approximate test of equality of means, or by an approximate t-test of the difference between means.

RESULTS

The lower limit of detection of the atomic absorption technique was 0.02 ug mercury, or 0.04 ppm in a 0.5 g sample. Recovery of mercury added to typical specimens of skeletal muscle or hair as inorganic mercury ($HgCl_2$) or as methylmercury (CH_3HgCl) was consistently found to be in the range of 85 to 100 percent. Analyses of total mercury content by atomic absorption techniques performed at the Southeast Environmental Research Laboratory and at the Savannah River Ecology Laboratory were in agreement with our results. Typical standard errors of measurement for determinations of mercury concentration in hair, skeletal muscle, and liver specimens were 10, 6, and 5 percent, respectively.

The lover limit of detection of the nondestructive neutron activation technique was 0.1 ug mercury, or 0.2 ppm in a 0.5 g tissue specimen. Determinations of mercury levels in hair by the atomic absorption and neutron activation techniques were in agreement, and the mercury data for hair was pooled for further analysis. However, data reported below for muscle and liver were obtained by atomic absorption spectroscopy except where otherwise noted. Mercury concentrations below the limits of detection are reported as nondetectable (N. D.).

Washing of hair specimens in our laboratory with distilled water, acetone, detergent and ethylenediaminetetraacetic acid was not effective in removing naturally occurring or artificially applied mercury from hair (Cumbie 1975). Other investigators have also found that washing is not effective in removing mercury from hair (Huckabee et al. 1972). Therefore, hair specimens in our study were not routinely washed except for a rinse in reagent grade acetone, which removed dust and aided in drying.

We have found that juvenile raccoons have lower hair mercury concentrations than adults from the same areas (Cumbie 1975). Therefore only data from mammals judged to be adults are reported here.

Table 1. Mercury concentrations (ppm) in hair of bobcats from the Piedmont, Upper Coastal Plain and Lower Coastal Plain of Georgia, and from the Savannah River Plant in South Carolina.

Origin	Sample Size	Mean	Standard Deviation	Range
Piedmont and Upper Coastal Plain	9	0.93	0.59	0.22-2.31
Lower Coastal Plain	28	7.44	8.40	0.44-32.4
Savannah River Plant	6	8.61	6.17	1.97-19.1

Mercury concentrations detected in hair of bobcats are presented in Table 1. Bobcats from the Upper Coastal Plain and Piedmont of Georgia were grouped together due to small sample size and the similar ranges of mercury concentration observed in these animals. Comparison of variances of these groups by Bartlett's method indicated that the variances differed significantly ($X^2=33.6$, p 0.01). Comparison of hair mercury levels between regions by Snedecor's approximate test of equality of means showed that the group means differed significantly ($Fs= 12.06$, $F0.01= 7.21$). Pairwise comparisons of mean mercury levels in t-tests indicated that the Lower Coastal Plain bobcats were significantly higher in mercury content than the Upper Coastal Plain and Piedmont bobcats ($t= 4.07$, $t0.01=2.76$, $df=28$). Bobcats from the SRP were also significantly higher in mercury content than the Upper Coastal Plain and Piedmont Georgia animals ($t=3.04$, $t0.05=2.57$, $df=5$). However, the mercury levels of Lower Coastal Plain Georgia bobcats did not differ significantly from those of SRP bobcats ($t=0.39$, $t0.05=2.10$, $df=11$).

Table 2. Mercury concentrations (ppm) in hair of raccoons from Georgia, Florida and South Carolina.

Origin	Sample Size	Mean	Standard Deviation	Range
Georgia				
Piedmont	53	2.09	1.72	0.22-8.80
Upper Coastal Plain	17	4.15	3.66	0.31-12.0
Lower Coastal Plain	76	6.12	7.47	0.23-50.6
Florida				
North	23	7.50	7.48	0.52-35.7
South	11	4.35	3.24	0.84-10.1
South Carolina				
Savannah River Plant	5	9.86	3.87	5.70-15.2

Meal hair mercury levels of raccoons were highest in SRP specimens, followed by Lower Coastal Plain, Upper Coastal Plain and Piedmont Georgia raccoons, in that order (Table 2). Variances of these groups were heterogeneous (Fmax=18.9, F0.01=2.3) and mean mercury levels of the groups differed significantly (Fs=12.9, F0.01=5.3). Lower Coastal Plain and SRP raccoons had significantly higher mean mercury levels than Piedmont raccoons (t=4.53, t0.01=2.6, df=86; and t=4.45, t0.02=**3.75,** df=4; respectively). Upper Coastal Plain raccoons also had significantly higher mercury levels than Piedmont raccoons (t=2.24, t0.05=2.09, df=19). Lower Coastal Plain Georgia and SRP raccoons did not differ in mercury content (t=**1.94,** t0.05=2.36, df=7), but SRP raccoon mercury levels were significantly higher than those of the Georgia Upper Coastal Plain Raccoons (t=2.94, t0.05=2.36, df=7). Mercury levels of Florida raccoons were similar to those observed in Lower Coastal Plain raccoons from Georgia. It is interesting to note that raccoons from northern Florida, nearer the Lower Coastal Plain Georgia habitats, had higher mercury concentrations than raccoons from southern Florida. However, this difference was not significant (t=1.71, t0.05=2.03, df=34).

Opossum hair mercury levels (Table 3) were highest in Lower Coastal Plain and SRP specimens, as observed in bobcats and raccoons. Variances of mercury levels in specimens from the four regions differed significantly (Fmax=64.2, F0.01=8.8), but mean mercury levels did not (Fs=2.28, F0.05=3.65).

Table 3. Mercury concentrations (ppm) in hair of opossum from the Piedmont, Upper Coastal Plain and Lower Coastal Plain of Georgia, and from the Savannah River Plant in South Carolina.

Origin	Sample Size	Mean	Standard Deviation	Range
Piedmont	65	1.30	0.60	0.39-3.31
Upper Coastal Plain	33	1.55	1.03	0.28-3.81
Lower Coastal Plain	29	2.39	4.16	0.39-23.4
Savannah River Plant	9	4.44	4.84	1.14-17.1

Hair mercury data for gray fox and red fox *(Vulpes fulva)* are presented in Table 4. Red foxes collected from the Lower Coastal Plain and Piedmont of Georgia did not differ in mercury content. Variances of the different groups of gray foxes were heterogeneous (Fmax=64.7, F0.01=12.9), and differences between mean mercury levels of gray foxes from the four regions were significant (Fs=6.89, F0.01=6.03). Since the

SRP foxes exhibited a much higher mean mercury level than the other three groups, the SRP foxes were eliminated and the comparison of means repeated, with the result indicating that the Piedmont, Upper Coastal Plain and Lower Coastal Plain foxes also differed in mercury content (Fs=8.62, F0.01=6.2). However, pairwise comparisons of mean mercury levels failed to demonstrate significant differences between Piedmont and Lower Coastal Plain (t=1.49, t0.05=2.06, df=24) or between Piedmont and SRP gray foxes (t=2.02, t0.05=2.57, df=5).

Mercury concentrations (ppm wet weight) detected in raccoon skeletal muscle and liver were similarly compared (Table 5). Liver mercury levels were much higher than skeletal muscle mercury levels in all groups. Although sample sizes are small, since muscle and liver specimens could not be collected from all animals from which hair specimens were taken, there was a tendency for mercury levels to be lowest in Piedmont raccoons and higher in Upper Coastal Plain and Lower Coastal Plain raccoons. Raccoons from the SRP exhibited the highest mean mercury levels in both skeletal muscle and liver.

No consistent differences were detected between hair mercury concentrations of white-tailed deer from different physiographic regions in Georgia and northern Florida (Table 6). Very low levels of mercury were present in hair of deer from both Piedmont and Lower Coastal Plain habitats in Georgia and from Eglin Air Force Base, Florida. Analysis of 26 deer skeletal muscle specimens from Georgia, Flordia, South Carolina and Alabama by neutron activation revealed no mercury in any specimen (ie. concentrations were less than 0.2 ppm wet weight).

Table 4. Mercury concentrations (ppm) in hair of gray and red fox from the Piedmont, Upper Coastal Plain and Lower Coastal Plain of Georgia, and from the Savannah River Plant in South Carolina.

Species	Origin	Sample Size	Mean	Standard Deviation	Range
Gray Fox	Piedmont	28	0.50	0.29	N.D.-1.06
	Upper Coastal Plain	7	0.28	0.09	0.16-0.38
	Lower Coastal Plain	20	0.76	0.73	0.11-2.75
	Savannah River Plant	6	2.84	2.83	0.82-8.41
Red Fox	Piedmont	6	0.55	0.27	0.24-0.98
	Lower Coastal Plain	3	0.49	0.27	0.19-0.27

Table 5. Mercury concentrations (ppm, wet weight) in skeletal muscle and liver of raccoons from the Piedmont, Upper Coastal Plain and Lower Coastal Plain of Georgia, and from the Savannah River Plant in South Carolina.

Origin	Skeletal Muscle				Liver			
	Sample Size	Mean	Standard Deviation	Range	Sample Size	Mean	Standard Deviation	Range
Georgia								
Piedmont	3	0.13	0.09	0.03-0.19	-	-	-	-
Upper Coastal Plain	6	0.22	0.18	0.02-0.48	6	2.34	2.41	0.06-5.67
Lower Coastal Plain	22	0.28	0.26	0.05-1.34	4	1.43	0.88	0.84-2.72
South Carolina								
Savannah River Plant	5	0.39	0.15	0.17-0.56	4	4.53	3.13	0.81-7.88

Table 6. Mercury concentrations (ppm) in hair of white-tailed deer from the Piedmont, Upper Coastal Plain and Lower Coastal Plain of Georgia and northern Florida.

Origin	Sample Size	Number Containing Detectable Mercury	Percent	Range of Concentration
Georgia				
Piedmont	31	10	32	N.D.-0.59
Upper Coastal Plain	9	0	0	-
Lower Coastal Plain	22	4	18	N.D.-0.21
Florida				
Eglin Air Force Base	5	5	100	0.13-0.40

DISCUSSION

Accumulation of mercury in fish, waterfowl, and upland game birds has been well documented in Sweden (Berg et al. 1966, Borg et al. 1969), Canada (Fimreite et al. 1970) and the United States (Kleinert and Degurse 1972, Dustman et al. 1972, Whitehead 1972). Little information is available regarding mercury levels in mammals. Kleinert and Degurse (1972) detected only traces of mercury in white-tailed deer, cottontail rabbits *(Sylvilagus floridanus)* and gray squirrels *(Sciurus carolinensis)* in Wisconsin. Huckabee et al. (1973) compared hair trace metal concentrations of coyotes *(Canis latrans)* and rodents from mineralized and non-mineralized areas in Wyoming. It was found that animals from mineralized areas tended to have higher hair mercury levels than animals from non-mineralized areas, and that coyotes tended to have higher hair mercury levels than rodents on which they preyed. However, home ranges of coyotes overlapped both mineralized and non-mineralized areas, so that it could not be determined whether the higher mercury concentrations detected in coyote hair resulted from biomagnification or from higher ambient environmental exposure of certain individuals.

We have found that mean hair mercury levels of bobcats, raccoons, opossum and gray fox increased consistently from Piedmont through Upper Coastal Plain (except for gray fox), Lower Coastal Plain and SRP animals, and that in each species the SRP specimens had the highest mean mercury levels. In each region, raccoons and bobcats tended to be highest in mercury content, followed by opossum and gray fox in that order. The highest mercury concentration detected in raccoon hair was 51 ppm, while the highest concentration in bobcat hair was 32 ppm. Both of these specimens were from the Georgia Lower Coastal Plain flatwoods west of Okefenokee Swamp. Huckabee et al. (1973) considered that hair mercury concentrations greater than 0.6 ppm indicated the presence of mercury contamination in the environment. The mercury levels reported here are much higher than those observed by Huckabee et al. and are suggestive of a trophic level relationship with carnivores having the highest mean mercury levels. Either skeletal muscle or liver of individual raccoons or bobcats from Upper Coastal Plain or Lower Coastal Plain habitats may approach or exceed the 0.5 ppm mercury concentration limit for human foodstuffs. The highest bobcat muscle mercury level was 1.93 ppm in an animal with a hair mercury level of 24 ppm, while the highest raccoon muscle mercury level was 1.34 ppm in an animal with a hair mercury level of 25.5 ppm.

Mammals collected on the SRP exhibited higher mean mercury levels than those collected from the other regions. The SRP is bordered on the west by the Savannah River, which is heavily contaminated by mercury from industrial releases (Georgia Water Quality Control Board 1971). Water from the Savannah below the principal sources of mercury at Augusta, Georgia, is used for atomic reactor cooling at the SRP. Before returning to the river, the heated water flows through a series of canals, streams and cooling ponds which are widely distributed over the reservation. It is thought that

mercury in the cooling water is concentrated by evaporation and that this results in elevated levels of mercury in the fauna of the area. Our analyses of mercury in hair of mammals from the SRP served to identify them as specimens which came from a mercury-contaminated habitat. The absence of known sources of mercury in the other regions surveyed suggests that movement of mercury in food chains may result from the operation of other environmental factors.

Mercury levels detected in wildlife in our study exhibit a geographical pattern similar to that of radioisotope accumulation. White-tailed deer, raccoons, bobcats, opossum and cottontail rabbits from Lower Coastal Plain habitats of the Southeast accummulate much higher ^{137}Cs body burdens than mammals from other physiographic regions (Jenkins and Fendley 1968). These differences in accumulation of radioisotopes in wildlife are thought to be associated with soil and water table conditions in different physiographic regions.

The mobility of mercury in ecosystems is probably also related to the chemical properties of soil and water, including acidity, nutrient pool sizes, humus content and clay content. Warren et al. (1966) reported that clay soil horizons had higher mercury contents than soil horizons in the same areas which did not contain clay. Soils high in organic matter also contained more mercury than soils low in organic matter. Trost and Bisque (1972) found that mercury levels in soils were more strongly correlated with humic acid content than with clay content, although clay adsorbed more mercury than other inorganic components tested. Lambou (1972) stated that unpolluted soils must be high in humus for mercury concentrations to exceed 150 ppb.

In alkaline soils, mercury tends to be bound to soil minerals, while in acid soils mercury becomes bound to humic acids (Harriss 1971). The sandy soils of Coastal Plain habitats are often poorly drained, acid soils with small pools of available nutrients and low ion exchange capacity, whereas Piedmont soils have a high clay content and high exchange capacity for nutrients due to the chemical properties of clay minerals. Radioisotopes and other nutrients therefore enter nutrient cycles more readily in Coastal Plain soils than in Piedmont soils. In acid soils, localization of mercury in humus rather than adsorption to clay minerals would tent to retain mercury in the zone of active metabolism of soil organisms increasing the mobility of mercury in food webs.

A suggested source of low-level mercury contamination over large areas is release of mercury to the atmosphere as a result of fossil fuel combustion (Joensuu 1971). Billings and Matson (1972) calculated that a 700-megawatt electric generating unit consuming 7750 metric tons of coal per day could release about 0.8 metric tons of mercury annually, and that the rate of emission of mercury due to combustion of fossil fuels in the United States would be on the order of 10^3 metric tons per year. In a large southeastern fossil fuel electric generating system, 39,000 tons of coal were consumed per day to produce 5665 megawatts of fossil fuel generating capacity during 1972 (Duke Power Company, personal communication). At an assumed coal mercury content of 0.3 ppm (Joensuu 1971), this would have released 3.87×10^6 g of mercury to the atmosphere over a 20,000 mi^2 service area. Assuming that all of this mercury was released into the atmosphere, the contribution of such releases to ambient air mercury concentrations would be on the order of 0.1 to 0.5 ng/m^3. Even assuming that mercury releases could be confined to relatively small air volumes under certain conditions, the immediate contribution of mercury from power plant stack gases would appear small compared to the 1 to 50 ng/m^3 range of air mercury concentrations reported by Williston (1968).

The fate of mercury introduced into the atmosphere from natural or industrial sources is largely unknown. Klein and Russel (1973) reported that surface deposition of trace metals released from a fossil fuel power plant was well correlated with wind direction within a range of eight to ten miles. Soil enrichment accounted well for the calculated discharges of all metals except mercury, which was apparently widely dispersed to the environment due to its volatility. Much mercury from such sources is presumably removed from the immediate area of release by winds and continental air

movements. Precipitation could remove mercury from the air over land, resulting in its introduction into nutrient cycles in terrestrial ecosystems. Local atmospheric conditions could result in a discontinuous distribution of mercury over a region, or in a tendency for mercury to become concentrated in certain areas. Low level introduction of heavy metals into ecosystems far removed from pollutant sources by precipitation washout has been reported in California (Hirao and Patterson 1974). Since the prevailing winds bring air masses over Georgia and South Carolina from the west, it is possible that atmospheric mercury from sources along the Gulf of Mexico contributes to mercury input in our region. Mobilization of mercury in food chains in southern Georgia and northern Florida may then result due to the circumstances of soil chemistry discussed above. Mercury from such sources would be of less importance in southern Florida. The somewhat lower levels of mercury we have found in raccoons from south Florida compared to those observed in northern Florida and southern Georgia are consistent with this hypothesis.

The threshold hair mercury concentration associated with neurological symptoms in humans has been reported to be about 60 ppm (Birke et al. 1972). The mercury concentrations observed in some Lower Coastal Plain mammals in our study approach this level. Subtle behavioral aberrations in animals which accumulate sublethal mercury body burdens could diminish their survival in natural ecosystems. The deleterious effects of sublethal mercurialism may be subtle and difficult to detect in native wildlife populations.

CONCLUSIONS

Our invistigations of hair mercury levels have revealed mercury accumulation in certain native mammals of the Southeast, and indicate that hair can be used for monitoring mercury concentrations in mammals. Omnivores, such as the gray fox and opossum, and an herbivore, the white-tailed deer, generally failed to have high levels of mercury in their tissues. Elevated mercury levels were presnet in individual carnivores in the southeastern Lower Coastal Plain. The raccoon has potential for use as an indicator species for mercury in the terrestrial environment. Individual raccoons or bobcats may have mercury levels in their tissues which approach or human foodstuffs. These mercury levels may have unrecognized sublethal effects in native mammals of certain habitats in the Southeast.

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