PATTERNS OF MERCURY CONTAMINATION IN A WINTERING WATERFOWL COMMUNITY

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Abstract: Mercury contamination levels were studied in several species of waterfowl wintering on a reactor cooling reservoir (Par Pond) of the U.S. Department of Energy's (U.S. D.O.E.) Savannah River Plant near Aiken, South Carolina. Samples from 177 American coots (*Fulica americana*) indicated that this species which is largely vegetarian on its wintering grounds, had lower levels of mercury accumulation than did 4 other aquatic species which were more carnivorous in their food habits. Coot feathers had the highest frequency (88.1%) of detectable levels of mercury, and gut contents had the lowest (0.2%). Mercury in coot feather samples was not affected by month of collection or location within the reservoir. The highest frequency of mercury in breast muscle occurred in the first birds to arrive in early fall. Frequencies of mercury contamination in breast muscle then tended to decline generally throughout the remainder of the fall, winter and spring. Radiocesium cycling patterns were useful in interpreting monthly changes in mercury contamination of Par Pond coots, despite differences in both temporal and spatial cycling patterns of these contaminants in the resident waterfowl community.

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Understanding the patterns of cycling and concentration of contaminants in animal populations is important, particularly with respect to free-living populations of game species which may be eaten by man. Waterfowl in particular are frequently exposed to contaminants that are introduced into aquatic ecosystems (Fimreite et al. 1971; Brisbin et al. 1973; Odom 1974). Contaminant evaluations, however, require knowledge of basic habits and ecological relationships of the species and populations under consideration and information on cycling and concentration patterns within the population.

This study involved the cycling and concentration patterns of mercury in a waterfowl community which has been extensively studied with respect to cycling and accumulation of radionuclide contaminants, particularly radiocesium (Brisbin et al. 1973). In addition, several basic ecological studies have been conducted on both the waterfowl community (Brisbin 1974) and the reservoir ecosystem in which it resides (Parker et al. 1973; Tilly 1975). This information proved useful in understanding the patterns of radionuclide cycling in this waterfowl community and should also be of value in helping to explain the cycling patterns of mercury or other heavy metals in these same birds.

Studies of contaminant cycling and accumulation in free-living game populations should, wherever possible, strive to produce results which are predictive in nature. Such studies, however, frequently require sampling programs involving large numbers of individuals so that spatial and temporal changes in cycling patterns may be determined and quantified. For this reason, the American coot was chosen for particular attention, as had been the case in the previous studies of radionuclide cycling. In the particular waterfowl community under consideration, the coot was the most abundant of all wintering species present and could be readily sampled in large numbers from particular locations and at specified time intervals with relative ease. In addition, the relatively weak flying ability of the coots made them a more likely species for indicating particular localized areas of contaminant concentration in the area under study (Brisbin et al. 1973).

This study was conducted on Par Pond, a reactor cooling reservoir located on the U.S. D.O.E. Savannah River Plant near Aiken, South Carolina. This 1130 ha reservoir was formed in 1959 by damming a natural stream watercourse resulting in 3 major arms, each of which have different histories of thermal impact and radionuclide contamination (Fig. 1). The Hot Arm of the reservoir receives heated cooling water from a nuclear production reactor. Water at ambient temperatures is pumped back through the reactor from the West Arm of the reservoir, forming a closed-loop cooling system. The North Arm of the reservoir also received heated reactor effluents until the summer of 1964 when, following a release of radiocesium, the introduction of reactor effluents into this arm of the reservoir ceased and temperatures again returned to ambient levels, resulting in the present situation as depicted in Fig. 1. The reservoir serves as the wintering refuge for between 5,000-10,000 migratory waterfowl of approximately 20 species, most of which arrive in October-November and depart during the following spring for their more northerly breeding grounds (Norris 1963, Brisbin 1974).

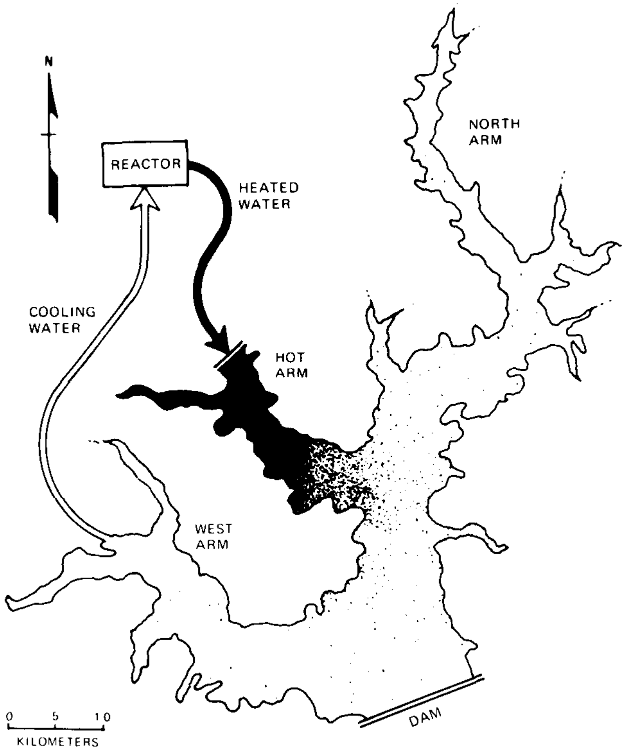

Fig. 1. Map of the Par Pond cooling reservoir on the U.S. Department of Energy's Savannah River Plant. Intensity of strippling is roughly proportional to the degree of influence of the influx of heated reactor cooling effluents which enter the reservoir in the Hot Arm. The locations of the reactor and thermal canals connecting it to the reservoir are presented diagrammatically.

Interest in mercury levels in wintering waterfowl on this reservoir was generated by reports that large-mouthed bass (*Micropterus salmoides*) from Par Pond had mercury levels as high as 3-5 ppm in their flesh (J. P. Giesy and J. H. Jenkins, pers. comm.). A likely source of mercury input has been the pumping of make-up water from the nearby Savannah River through the reactor cooling system and then into the reservoir. In 1970-71 Savannah River water was contaminated with mercury mostly from chlor-alkali plants which were discharging into the river upstream from the cooling-water intake for the SRP reactor system (Georgia Water Quality Control Board 1971). The occurrence and biological significance of mercury contamination of wildlife populations in the United States and Canada has been widely documented (Fimreite and Karstad 1971; Zeller and Finger 1971; Vermeer and Armstrong 1972; Cumbie 1974; Fimreite 1974; Odom 1974; Heinz 1976).

The objective of this study was to determine the levels of mercury contamination in organs and tissues of coots collected from Par Pond using the same sampling scheme as that used earlier to determine the temporal and spatial patterns of radiocesium cycling in coots from this same area (Brisbin et al. 1973). Mercury determinations were also made for a few other species of Par Pond waterfowl with more carnivorous habits than the largely vegetarian coot.

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MATERIALS AND METHODS

Thirty coots, 10 from each of the 3 reservoir arms, were collected each month by shooting from October 1977 through March 1978. Samples of other aquatic birds were also collected in February [7 horned grebes (*Podiceps auritus*), 3 lesser scaup (*Aythya affinis*), 6 buffleheads (*Bucephala albeola*) and 3 ruddy ducks (*Oxyura jamaicensis*)] for comparison with the coots. All birds were weighed, frozen in plastic bags and stored at -8 C until chemical analyses were initiated.

The mercury contents of the liver, kidney, fat, breast muscle, primary feathers and gut contents were determined for all coots collected during November and January. Feathers had the highest mercury content and mercury levels in the other tissues were largely nondetectable. Since breast muscle is the portion normally consumed by humans, mercury contents of this tissue and feathers were determined for coots collected in October, December, February and March. Liver, breast muscle and primary feathers of ducks and grebes were analyzed for mercury.

Samples were analyzed for mercury by the flameless atomic absorption method with a Perkin-Elmer model 272 Atomic Absorption Spectrophotometer, following procedures described by Hatch and Ott (1968), Uthe et al. (1970) and the U.S. Environmental Protection Agency (1972). Tissue samples weighing 0.20 to 0.25 g were placed in a biological oxygen demand bottle. Five ml of concentrated sulfuric acid (H_2SO_4) and 1 ml of concentrated nitric acid (HNO_3) were added and the solution placed in a water bath at 60 C for 1 hour. Samples were cooled to 4 C in an ice bath, 15 ml of potassium permanganate solution were added and the mixture allowed to stand overnight. Distilled water was added to make a total volume of 125 ml and 6 ml of hydroxylamine hydrochloride solution was added to reduce excess permanganate. Five ml of stannous chloride was added and the sample immediately attached to the aeration apparatus of the spectrophotometer.

Mercury levels were determined by plotting sample absorbance readings from the spectrophotometer on a curve established by absorbance readings obtained from standard solutions containing 0-1.5 μg of mercury. This method gives total mercury levels, (ppm), per g wet weight, with a detectability limit of 0.10 ppm.

Results were analyzed by comparing frequency of detectable vs. non-detectable mercury levels in feathers and muscle tissue from all coots collected. Whenever appropriate, analyses of variance were used to evaluate the effects of collection date and reservoir locations upon mercury levels found in coot tissues.

RESULTS AND DISCUSSION

Various coot tissues and body components differed with respect to the frequency of detectable levels of mercury contamination (Table 1). Feather samples had the highest frequency while only a few of the gut content samples showed detectable mercury levels. Other tissues had intermediate frequencies of contamination ranging from 22.4 to 45% detectable. Previous studies of avian species have indicated higher levels of mercury contamination in liver and kidney than in breast muscle (Tejning 1967; Vermeer and Armstrong 1972; Odom 1974; Hesse et al. 1975), and this same tendency is reflected in the present study. Direct comparisons of average levels of mercury content with other studies are not practical, however, because of the relatively high number of samples showing undetectable levels of mercury in the present study.

Table 1. Frequency of occurrence of detectable levels of mercury in various tissues of coots collected from the Par Pond reservoir of the U.S. D.O.E. Savannah River Plant during November 1977 and January 1978.

Tissue	*Percentage Showing Detectable Levels*[a]	*Number Examined*
Feathers	88.1	59
Fat[b]	44.0	23
Kidney	45.0	59
Liver	35.6	58
Muscle	22.4	60
Gut Contents	0.2	59

[a]The detection level was 0.10 ppm wet weight.

[b]Fat was analyzed for the month of January only.

The low number of samples showing detectable mercury levels in certain tissues prevented the use of a standard chi-square analysis to determine differences between months with respect to the frequency of detectable vs. non-detectable levels in coot feathers and muscle. Therefore, a G-test for independence (Sokal and Rohlf 1969) was used to test for such differences. This test indicated that the frequency of detectable levels in feathers did not change between months ($G = 6.62$; $df = 5$; $p > 0.05$). However, the frequency of detectable mercury in muscle did change between months ($G = 26.77$; $df = 5$; $p < 0.01$) (Fig. 2). Since a relatively high proportion of feather samples had detectable mercury, a two-way analysis of variance was conducted to determine the effects of month and location upon actual levels in the feathers. Samples showing less than the minimum detectable level (0.10 ppm) were assigned values of 0.05 ppm. This analysis of variance showed that neither month, location, nor month x location significantly affected feather mercury level ($F = 2.17$, $df = 5$, $p = 0.06$; $F = 1.39$, $df = 2$, $p = 0.25$; and $F = 1.73$, $df = 10$, $p = 0.08$, respectively). It is possible, however, that with larger sample sizes a significant effect of month upon feather mercury levels might be revealed. This is particularly suggested by the fact that the interaction term for month x location was also close to being significant.

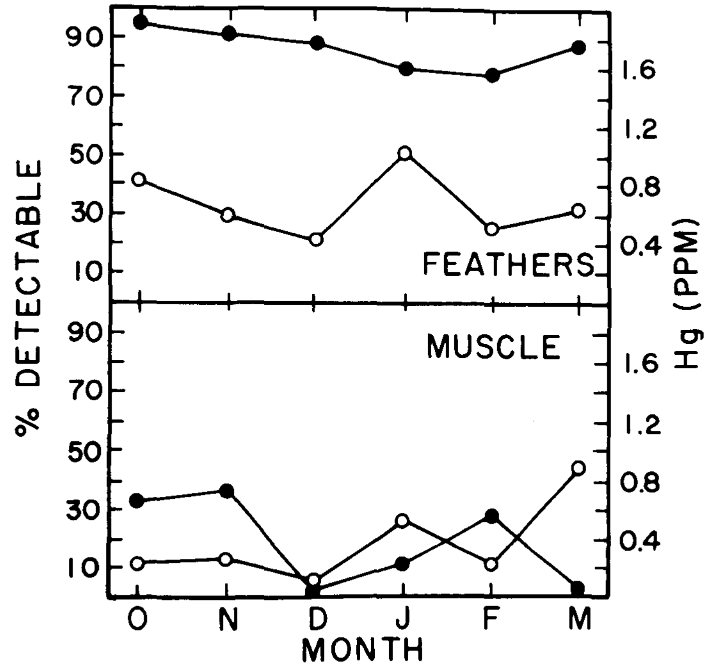

Fig. 2. Frequency and levels of mercury contamination in primary feathers and breast samples from coots collected on the Par Pond reservoir of the u.S. D.O.E. Savannah River Plant during the period from October 1977-March 1978. A total of 30 birds were sampled from the reservoir each month. Open figures represent average levels of mercury for samples containing detectable levels (greater than 0.1 ppm wet weight). Solid figures represent frequency of occurrence of detectable levels.

Actual mercury levels in coot muscle were not analyzed statistically because most of the samples were below limits of detectability. However, detectable mercury levels in coot muscle tended to increase noticeably during the wintering period while frequencies of muscle contamination tended to decline during the same period (Fig. 2).

Levels of mercury in the largely vegetarian coots were considerably lower than levels in other (more carnivorous) waterfowl species from the reservoir. Increased levels of mercury in species occupying higher trophic levels were also reported by Vermeer and Armstrong (1972) who found that common mergansers (*Mergus merganser*) had the highest levels of mercury in breast muscle of several species of Canadian prairie ducks examined. Fimreite et al. (1971) also showed that mean mercury levels in livers of birds collected near sites of industrial contamination in Canada were positively correlated with the percentage of animal matter in the birds' diets. The species in the latter study whose diet most closely resembled that of Par Pond coots was the wood duck (*Aix sponsa*) whose diet contained 10% animal matter according to the above authors. Mercury levels in wood duck livers averaged 0.16 ppm which compares closely to an average value of 0.13 ppm for 60 coot livers collected from Par Pond in November 1977 and January 1978, calculating the latter average by assigning values of 0.05 to all samples showing less than the detection limit. More carnivorous Par Pond species (Table 2) had mercury levels similar to species consuming higher proportions of animal matter in Canada (Fimreite et

Table 2. Mercury levels in liver, muscle and feathers from waterfowl collected from the Par Pond reservoir of the U.S. D.O.E. Savannah River Plant in February 1978.

Species	Number Examined	Percentage Animal Matter in Diet	Mercury levels (ppm wet weight)		
			Liver	Muscle	Feathers
Horned Grebe	7	97[a]	6.11 (0.33)[d]	2.38 (0.08)	6.85 (1.17)
Bufflehead	6	67-84[b]	1.23 (0.16)	1.17 (0.31)	1.75 (0.53)
Lesser Scaup	3	50[b]	0.77 (0.19)	0.46 (0.07)	1.55 (0.11)
Ruddy Duck	3	19[b]	0.74 (0.01)	0.33 (0.09)	0.80 (0.08)
Coot	30	3[c]	(not determined)	0.09 (0.02)	0.44 (0.07)

[a]Bent (1963)

[b]Bellrose (1976) – average of all values referenced for wintering populations.

[c]Jones (1940) – average of all values given for months of October through March.

[d]Figures represent average values with standard errors being given in parentheses. In calculating averages, values falling below the minimum detection limit (0.10 ppm wet weight) were assigned a value of half the detection limit.

al., 1971). Thus, aquatic birds in Par Pond had levels of mercury similar to birds collected from regions of known industrial contamination (Fimreite et al. 1971; Hesse et al. 1975). As mentioned earlier, make-up water for reactor cooling from the Savannah River is undoubtedly 1 factor responsible for this phenomenon. Environmental impact assessments of closed-loop reactor or power plant cooling systems should consider the possible concentration from evaporative cooling of contaminants found in projected sources of the make-up water.

The Food and Drug Administration action level for mercury is 0.50 ppm for fish and shellfish for human consumption. These guidelines which were set in 1974 will be revised to 1.0 ppm during the Fall of 1978. Total maximum human exposure to mercury, however, is still 210 μg per week. Coots are hunted both in this country and abroad for both sport and occasionally as a widely exploited food resource (Ripley 1976). It is thus important to note that 4 out of the 177, or 2.3% of the coots examined in this study had mercury levels greater than 0.50 ppm. Two of these birds were collected in January and 1 each in February and March, when the average level of contamination in the population was increasing (Fig. 2). Maximum levels of mercury in coot breast muscle during these 3 months were 0.72, 0.50 and 0.88 ppm, respectively. Moreover, 14 of the 19 other waterfowl examined (Table 2) exceeded 0.50 ppm in muscle. All of the grebes but 1 had greater than 1.00 ppm mercury in muscle. By comparison, Baskett (1975) found that 7.6% of the breast muscle samples from 176 dabbling ducks and 151 diving ducks from throughout the United States exceeded 0.50 ppm. Species differences and seasonal differences in diet within species, however, must be considered. Moreover, frequencies of occurrence of more toxic forms of methyl- and ethyl- mercury need to be determined in addition to total mercury in order to assess health risks from human consumption of waterfowl (Basket 1975).

The cycling pattern of mercury in Par Pond waterfowl reveals striking differences from that of radiocesium in these same birds (Brisbin et al. 1973). While mercury levels in coots were lower than in the more carnivorous species, radiocesium levels of the coots averaged higher than those of any other waterfowl species studied on the reservoir (Brisbin et al., 1973). Furthermore, unlike radiocesium which was concentrated in greater amounts by coots in the North Arm of the reservoir, mercury levels in coot feather samples did not differ between locations within Par Pond. The differential concentration of radiocesium by coots in the North Arm suggests that only limited movement of these birds occurs between these three sampling areas during their winter stay. The lack of significant differences in feather mercury levels thus suggests that mercury is equally available to these birds in all parts of the reservoir or that the mercury source is external to the Par Pond system.

An understanding of the cycling patterns of radiocesium in Par Pond coots is also useful in understanding and interpreting some of the changes in frequencies of mercury contamination of the coots during their winter stay on the reservoir. The general decline in frequencies of breast muscle mercury contamination during the late fall and early winter (Fig. 2) suggests that the general availability of mercury to coots on the reservoir during this period was not as great as in those more northern areas where they had resided prior to their arrival on the reservoir in October and November. Low radiocesium levels in October and November coots indicate that birds collected in early fall are new arrivals on Par Pond. Studies by Tejning (1967) indicate that mercury accumulates in growing feathers but not in feathers already keratinized. This suggests that the coots in our study must have accumulated mercury in their feathers before they began their winter migration. Thus, further changes in contamination frequencies or levels of mercury would not be expected in coot feathers over the winter.

Previous studies of sex ratios and radiocesium levels of the Par Pond coots suggest, moreover, that the last birds to be found on the reservoir in spring are mainly northward-moving spring migrants that had wintered further to the south (Brisbin et al. 1973). The decrease in frequency of detectable mercury levels in muscle of March coots suggests further that most of these spring migrants probably spent the winter in areas uncontaminated with mercury. Those few spring migrants that do show higher mercury levels (up to 0.88 ppm) may have wintered in areas such as the lower coastal plain of southern Georgia and northern Florida (Ryder 1963). Portions of this region are known not only as localities of unusually high contaminant availability to wildlife species (Jenkins and Fendley 1968, 1971; Halbrook 1978), but also as areas containing a number of mercury contaminated watersheds (Odom 1974). The latter author reports levels of mercury in other members of the Rail family (*Rallus elegans, R. limicola, R. longirostris* and *Porzana carolina*) which were collected from areas through which some northward-moving spring migrant coots might pass prior to their arrival on Par Pond in later winter or early spring. Considering the more carnivorous diet of the above rail species, the levels of mercury reported by Odom (1974) in these birds are similar to those of some of the more contaminated coots collected from Par Pond in January, February and March (Fig. 2). It is thus possible that significant numbers of coots found on this reservoir may have acquired their mercury body burdens elsewhere during their migration and this may also be true of some of the northward-moving spring migrants as well as of the first southward-moving migrants to arrive in the fall. The results of this study thus provide a different perspective from that shown by Baskett (1975) who suggested that mercury levels within waterfowl populations were more closely linked to localized contamination events than to factors associated with the movement of birds across and between large geographic areas. In-depth banding studies are needed and are currently being initiated in order to determine precisely the wintering areas and migratory movements of all waterfowl utilizing Par Pond.

The results of this study clearly indicate that patterns associated with the cycling and accumulation of 1 contaminant (e.g. a radionuclide) cannot necessarily be used to describe how another contaminant (e.g. mercury) is distributed across space and time, between the same individuals. Differences in cycling patterns and rates can be due to differences in contaminant releases to the environment and differences in uptake and assimilation by organisms. However, a basic understanding of the habits and ecological relationships of the species and populations in question is also essential to making meaningful interpretations of contaminant cycling patterns in the species under study. An understanding of the food habits and migratory behavior of coots and other species of Par Pond waterfowl, for example, was useful in helping to understand the movement and concentration of mercury and radiocesium by these birds, despite the differences between cycling patterns of these 2 contaminant substances in the waterfowl community.

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