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Environmental Sciences Division

**BELTED KINGFISHERS AS ECOLOGICAL MONITORS OF
CONTAMINATION: A REVIEW**

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Publication No. 4017

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Date Published: March 1993

Prepared for
Office of Environmental Restoration and Waste Management
(EX 20 10 30 1)

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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ABBREVIATIONS AND ACRONYMS

AHH	aryl hydrocarbon hydroxylase
EFPC	East Fork Poplar Creek
GIS	geographical information system
MeHg	methylmercury
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PCBs	polychlorinated biphenyls

EXECUTIVE SUMMARY

This report presents results of the data collection phase of an evaluation of the feasibility of using kingfishers as biological monitors of contamination. This phase included review of pertinent literature and a preliminary census of kingfishers and nesting sites around the Oak Ridge Reservation (ORR). The work was performed as part of the remedial investigation of Waste Area Grouping 2, White Oak Creek/White Oak Lake, at Oak Ridge National Laboratory.

Aquatic systems serve as transport pathways and reservoirs for most of the contaminants known to be present in the White Oak Creek watershed. Mercury, polychlorinated biphenyls (PCBs) and ^{137}Cs have been measured at elevated concentrations in fish from White Oak Creek and White Oak Lake. Terrestrial species that forage heavily on fish may be at risk from these contaminants. In addition, piscivorous terrestrial animals may serve as effective indicators of contaminant transfer from aquatic organisms to terrestrial biota.

The belted kingfisher is a piscivorous bird that consumes ~50% of its weight each day. Kingfishers feed regularly on several ORR streams and are likely to be exposed to contamination present in fish from those streams. A kingfisher collected on White Oak Lake in 1991 contained 568 pCi/g of ^{137}Cs in muscle tissue; this concentration exceeds levels found in any other waterfowl collected from the lake.

Organochlorine contaminants (including PCBs) have been studied extensively in piscivorous birds, though not in kingfishers. Those birds which rely most heavily on fish in their diet appear to demonstrate the most detrimental effects, including eggshell thinning, behavioral changes, deformities, physiological abnormalities, and death.

Birds may accumulate mercury in the inorganic and methyl forms. Methylmercury (MeHg) is the most readily absorbable and highly toxic form of Hg. The effects of MeHg poisoning include a variety of reproductive and somatic effects. Mercury accumulation in birds appears to vary among species with regard to age, sex, and diet. Mercury levels in feathers and eggs have been used to monitor Hg contamination in aquatic systems.

Radionuclide uptake occurs primarily through the food chain, affecting those birds which feed most heavily upon fish.

Kingfishers were observed on all streams surveyed on the ORR. Possible nesting sites were identified along the Clinch River and Poplar Creek.

Additional investigations should be conducted to determine whether kingfishers feeding in more highly contaminated areas are being adversely affected by the contaminants.

1. INTRODUCTION

Aquatic systems serve as transport pathways and reservoirs for most of the contaminants known to be present on the Oak Ridge Reservation (ORR). Organisms that live in aquatic systems accumulate some of these contaminants from their food and directly from the water or sediment. For this reason, most biological monitoring and ecological assessment activities focus on measurement of the fate and effects of contaminants within aquatic ecosystems. However, a wide array of terrestrial organisms feeds on aquatic organisms and may accumulate contaminants from aquatic prey. Clearly, those terrestrial species that forage most heavily on aquatic prey are most at risk from the contaminants that bioaccumulate through the aquatic food chain. In addition, highly piscivorous terrestrial animals may serve as effective indicators of contaminant transfer from aquatic organisms to terrestrial biota. Therefore, attention is now being focused on measuring the impact of aquatic contamination in piscivorous wildlife, and interest is increasing in identifying suitable biological monitors within the terrestrial ecosystem.

The belted kingfisher (*Ceryle alcyon*) is a piscivorous and territorial avian species that may be a suitable monitor of contaminant accumulation at specific sites on the ORR. Kingfishers have been sighted feeding regularly from ORR waterways and are likely to be exposed to contamination present in fish from those streams. A kingfisher collected on White Oak Lake in 1991 had a ^{137}Cs concentration of 568 pCi/g in muscle tissue, which exceeds levels found in any other waterfowl collected from the lake (Blaylock et al., 1992).

An investigation into the efficacy of using the kingfisher as an ecological indicator of aquatic contaminants on the ORR was initiated in late August 1992. The primary objective of this study was to acquire information concerning the ecology of the kingfisher to determine how the species could be used within the framework of the Biological Monitoring and Abatement Program at Oak Ridge National Laboratory (ORNL). A second important objective of the study was to examine the possible somatic and reproductive effects of polychlorinated biphenyls (PCBs), Hg, and various radioactive contaminants on piscivorous birds by reviewing pollution ecology studies conducted on those species. Finally, this study included collection of information on the abundance and distribution of kingfishers and their nest sites on the ORR.

2. REVIEW OF THE LITERATURE

This section presents information derived from more than 40 published studies of kingfishers and other piscivorous birds. Three major areas are addressed: kingfisher ecology, techniques for field study of kingfishers, and pollution ecology of piscivorous birds. Because no pollution studies of kingfishers have been published, this section concludes with a discussion of how findings from studies on other piscivorous birds might apply to kingfishers.

2.1 KINGFISHER ECOLOGY

2.1.1 Food

Kingfishers primarily feed on surface swimming and shallow water fish species (Bent 1940; Eipper 1956; Davis 1980). Fishing success is greatest in water ≤ 60 cm deep (Prose 1985; Brooks and Davis 1987). Several studies pertaining to the feeding ecology of

kingfishers have found that the birds feed on those fishes that are most available within its feeding range (White 1938, 1953; Salyer and Lagler 1949; Davis 1982). Alternate foods such as crayfish, lizards, frogs, small snakes, salamanders, and insects may be utilized when fish are not abundant or when water turbidity reduces fishing success. Kingfishers prefer to forage along sheltered areas of rivers or lake shores and avoid turbid and rough water surfaces (Salyer and Lagler 1949). More than 75% of the kingfisher's diet is comprised of cyprinid species, with crayfish comprising another ~13% of the diet (Salyer and Lagler 1949, Davis 1980).

An adult kingfisher consumes an average of ten, ~10-cm-long fish per day (Davis 1988a). In ORR streams, a minnow of this size would typically weigh 6–8 g (M. G. Ryon, ORNL, personal communication to T. L. Ashwood, ORNL, December 11, 1992). Adult kingfishers weigh from 130 to 170 g (Davis 1980). Thus, kingfishers consume nearly 50% of their body weight each day.

Davis (1988a) estimated that a pair of kingfishers with nearly fledged young requires about 90 fish per day to feed their offspring and themselves. White (1936) estimated that the number of fish consumed daily by a nest of 7 birds would be approximately 150 fish. During inclement weather, fishing success is drastically reduced, and nestlings often starve to death (Davis 1988a).

2.1.2 Nesting

The physical characteristics of habitats are often the basis for nest site selection in avian species (Hilden 1965 and Cody 1981 in Brooks and Davis 1987). Environmental cues such as high vertical earthen banks and stream riffles may attract kingfishers to a potential nesting site. The birds also assess food availability and suitability of the soil substrate (Brooks and Davis 1987) before attempting to excavate a burrow (Fig. 1). Kingfishers commonly breed along streams and lake edges where banks are covered with herbaceous vegetation and where clear, shallow water facilitates easy fishing (Bent 1940; Davis 1980; Brooks and Davis 1987). Kingfishers are seldom seen along waterways where dense vegetation obscures vision (Bent 1940) or where tree roots and rocks would impede the excavation of a nesting burrow (Brooks and Davis 1987).

The height of the nesting burrow depends largely on the height of the bank (Bent 1940; Cornwell 1963). Flooding is a strong selection pressure in favor of birds that build high entrances and long tunnels (Davis 1980). Nesting burrows excavated at least 1 to 2 m from the water and 0.5 to 1 m from the top of the bank (Fig. 1) are the most successful in protecting the birds from rising water levels and predators such as snakes, raccoons, or skunks (Bent 1940; White 1953; Brooks and Davis 1987). Tunnels may range from 1 to 5 m long in sandy soil but may be shorter where there is a mixed substrate of sand, clay, and humus (Davis 1980). Excavation of a nest site can take as little as 3 days or as long as 2 to 3 weeks, depending on the composition of the soil (Bent 1940). When suitable nesting banks are not available, kingfishers will occasionally nest in road cuts, holes of decaying trees, or in soil caked onto the roots of a fallen tree (Bent 1940, Cornwell 1963, Prose 1985). Kingfishers may also nest away from water. Cornwell (1963) found several kingfishers nesting up to 1.6 km away from the nearest water source.

Fig. 1. Kingfisher nesting burrow.

2.1.3 Territoriality

Territory sizes vary seasonally. Kingfishers defend large breeding territories that contain nesting banks and food resources. Nonbreeding territories are smaller and encompass only feeding areas (Davis 1982). A mated pair will defend the breeding territory but will defend separate territories during the winter (Davis 1988a,b). Females are more territorial than males and defend larger winter territories (Davis 1988a).

Territory size is related to habitat type. River territories range from 2.4 to 4.8 km or more, whereas lakeside territories tend to be smaller, ranging from 0.8 to 2.4 km of shoreline (Salyer and Lagler 1949). Cornwell (1963) found that individual kingfishers in Itasca Park, Minnesota, had a daily range of 0.8 to 8 km from the nest site, although fishing locations were most often within 1.6 km of the nest. The minimum habitat area required for belted kingfishers is estimated to be 1.0 km of lakeshore or stream (Prose 1985). Territory size is also correlated to food abundance. Some territories may be exceptionally large because of dense vegetative cover, fast currents which reduce visibility, or unfishable pools (Davis 1982; Prose 1985). Kingfishers may temporarily abandon their territories during times of heavy rain or strong winds to search for food (Davis 1988a,b).

2.1.4 Breeding

Breeding times vary by locality. Davis (1980, 1988a) found that kingfishers in Ohio breed between March and May, whereas in Texas, unseasonably mild weather often initiates early nesting, and breeding may occur as early as January. In general, female kingfishers lay a clutch of 6 to 7 eggs between early April and mid-June, with peak activity occurring between late April and mid-May (Bent 1940). Kingfishers will only fledge one brood per year; however, if flooding destroys their nest early in the nesting season, a pair birds may lay a replacement clutch.

Brooks and Davis (1987) found nestling survival to be 80% in their study of kingfishers in Pennsylvania and Ohio. Davis (1980) found that the average weight of fledglings is 167 g, whereas the average weight of adults is 160 grams. Davis also determined that fledgling weight is a function of territory size. Those pairs that defend larger territories may benefit by producing larger young. The incubation period lasts 23 days, and there is an additional nestling occupation of 23 days (Davis 1980).

Fledglings remain near the nest for several days while they learn to fish (Bent 1940). Juveniles disperse in midsummer (White 1953).

The plumage of juvenile kingfishers looks similar to that of the adult female—having a rust-colored pectoral band (Bent 1940; Davis 1980). The juvenile retains this plumage throughout the first winter. The young birds have a first prenuptial molt between February and April, which involves most of the body feathers. Adults have an annual, postnuptial molt, usually in August, September, or October (Bent 1940).

2.1.5 Migration

Migration patterns of the belted kingfisher are not well understood; however, winter migration appears to be dependent on the severity of the weather. Males are reluctant to leave their territories and will stay as long as water remains ice-free and fish are available (Davis 1988a). Females are more likely to migrate south and return for the breeding season (Davis 1988a). Females often return to the same mate and nesting site every year (Bent

1940; Davis 1988a).

2.2 FIELD STUDY TECHNIQUES

Kingfishers are difficult to capture by conventional methods, and they respond unfavorably to any disturbance around the nest site. Adults are suspicious of mist nets or other obstacles placed near or in front of nesting burrows (Thiel 1985). Nest desertions are fairly common; however, several authors were able to successfully conduct studies of the feeding ecology and growth and development of nestlings. Davis (1982) reported that data collection is more likely to cause nest desertion early in the nesting cycle (before incubation) than after the eggs have hatched. Davis (1980) excavated a back entrance to the nest chamber to observe hatching success and development of young kingfishers. Following each inspection, a wooden door was placed over the opening to the nest chamber. The soil was replaced, and a large stone was positioned over the back entrance to prevent predation and rain damage.

Although kingfishers quickly become wary of nets and other devices, several methods have been used to capture kingfishers for banding or color marking. Mist nets can be positioned directly in front of the nest entrance or stretched across a well-used flight path. Adults leaving the nest will be entangled in the net. A spring-loaded looped net may be attached below the entrance hole of the nest tunnel with a trip wire that releases the net over the entrance. To increase the efficiency of capture, Davis (1980) placed a stuffed kingfisher model behind the net to entice the birds into the net. A specially designed snare for kingfishers can also be placed near the nest entrance to entangle the bird by the leg (Thiel 1985).

The boundaries of a kingfisher's linear territory can be determined by walking along a river or stream and flushing the birds from their perches. By repeated flushing, the birds will be pushed to the edge of their territory and will double back and fly toward the opposite end of their territory (Davis 1988a).

Food debris in the nest may be recovered by carefully excavating the burrow from above to reveal the nesting cavity. The inner part of the cavity contains a tightly packed mixture of silt, excrement, fish scales, fish bones, and crayfish exoskeletons (Bent 1940; Eipper 1956; Cornwell 1963). Debris may be removed from the burrow and gently washed in a wire mesh receptacle. This process effectively removes all soil and excrement without loss of fish and crayfish structures (Eipper 1956). Disgorged pellets may be recovered from the nest or under perches near feeding sites (White 1936, 1937).

2.3 POLLUTION ECOLOGY STUDIES OF PISCIVOROUS BIRDS

Many biomonitoring studies have been conducted on fish-eating birds, but no studies of kingfishers were found in the literature. Herons, osprey, mergansers, and a variety of sea birds have been used to monitor PCBs, Hg, and radionuclide contamination. Various reproductive and somatic effects of contaminants on fish-eating birds have also been documented for several species.

2.3.1 Polychlorinated Biphenyls

Laboratory and field studies suggest that PCBs may cause a variety of effects in several avian species.

Black-crowned night herons (*Nycticorax nycticorax*) on Lake Ontario experienced low nesting success (< 1 young fledged per nest); in this study, PCBs ranged from 9.8 to 63 ppm in eggs and DDE ranged from 4.5 to 12.4 ppm (Price 1977 in Fleming et al. 1984). In black-crowned night herons living in San Francisco Bay, a significant negative correlation ($p < 0.05$) between embryonic weight and mean PCB residues over a range of 0.8 to 52.0 mg/kg in eggs was found (Hoffman et al. 1986). Whether or not the effects were persistent through hatching could not be determined. Steidl et al. (1991) found that elevated levels of PCBs were at least partly responsible for reduced hatching success in ospreys (*Pandion haliaetus*) at Delaware Bay. Similarly, Wiemeyer et al. (1975) found evidence that PCBs may have been an important factor in the reduced reproductive success and population decline of ospreys in Connecticut.

Significant eggshell thinning in piscivorous species exposed to organochlorines has been documented by several authors. Birds may excrete up to 50% of organochlorine residues in their bodies into a clutch of eggs, and residues in second clutches may be lower than residues in first clutches (Custer et al. 1983). Anderson et al. (1969) found measurable declines in shell weight and thickness in white pelicans (*Pelecanus erythrorhynchos*) and double-crested cormorants (*Phalacrocorax auritus*) associated with DDE and PCB. Blus et al. (1980) found a negative relationship between maximum PCB (Aroclor 1260) levels (9 µg/g in eggs) and eggshell thickness in great blue herons (*Ardea herodias*) of the Columbia Basin, Oregon and Washington. Despite the eggshell thinning the birds seemed to be reproducing normally.

In a study of great blue herons, green-backed herons (*Butorides striatus*), and black-crowned night herons in the Tennessee Valley, Fleming et al. (1984) found no significant correlation between PCB residues and eggshell thinning in great blue heron eggs. The effects of PCBs and organochlorine pesticides on the reproductive success of great blue herons is uncertain; however, great blue herons are less sensitive to DDE than are black-crowned night herons (Fleming et al. 1984). Blus (1980) found no evidence to relate organochlorine residues to reduced reproductive success of great blue herons in the Columbia River Basin. Information is inconclusive concerning the sensitivity of green-backed herons to PCB residues.

Elliot et al. (1989) found no significant relationship between the number of great blue heron hatchlings fledged and PCB levels ranging from 0.418 to 1.22 mg/kg wet weight in eggs. However, reproductive problems in great blue herons with PCB levels of 15 mg/kg in eggs have been reported (Laporte 1982 in Elliot et al. 1989).

In a study conducted by Faber et al. (1972) of common egrets (*Casmerodius albus*) and great blue herons, the egrets contained PCB residues ranging from 15 ppm in brain tissue to 93 ppm in liver tissue. These levels are suspected of being a major factor in eggshell thinning and subsequent reproductive failure of egrets. The average decrease in thickness of the egret eggshells (15.2%) was greater than the average decrease (10.4%) in the great blue heron eggshells. This indicates that, like black-crowned night herons, egrets may also be more susceptible to the eggshell thinning effects of PCBs than are great blue herons. Egrets feed primarily on aquatic organisms, mostly fish (Palmer 1962 in Faber et al. 1972). The diet of great blue herons is more variable and includes insects, crustaceans, mice, shrews, reptiles and amphibians (Blus et al. 1980).

In another study of green-backed herons, little blue herons (*Egretta caerulea*), and yellow-crowned night herons (*Nycticorax violaceus*), Niethammer et al. (1984) found that PCB residues in body tissues among these species seemed to be related to food habits. Levels were highest in green-backed herons, followed by little blue herons, and yellow-crowned night herons had the lowest levels. Green-backed herons consume small fishes; little blue herons feed on fish, crustaceans, insects, and spiders; yellow-crowned night herons feed primarily on crayfish. PCB levels in heron food items were highest in bluegill (*Lepomis macrochirus*) and were not detectable in crayfish. Contamination levels were higher in adults compared with immature herons. However, immature herons can accumulate contaminant levels comparable to adults within the first few months of their lives as a result of being fed local food items from a contaminated area. In general, the PCB levels in herons reflected the amount of fish consumed. Heron species exhibiting the most eggshell thinning were ones with the greatest percentage of fish in their diet (Niethammer et al. 1984).

PCB poisoning has been associated with behavioral changes, death, and abnormalities in fish-eating birds. Deliberate egg stabbing was observed at grey heron colonies contaminated with high levels of PCBs (Millstein et al. 1970 and Cooke et al. 1976 in Elliott et al. 1989). PCB poisoning was strongly implicated in the deaths of many ring-billed gulls (*Larus delawarensis*), which contained brain levels ranging from 310 to 1110 ppm (Sileo et al. 1977 in Heinz et al. 1984). Heinz et al. (1984) suspected PCB poisoning in a great blue heron found dead with 220 ppm PCB in its brain, a level close to the lethal brain level in ring-necked pheasants (*Phasianus colchicus*). PCB poisoning was also suspected in several adult egrets that were found in convulsions and dying (Faber et al. 1972). Hays and Risebrough (1972) found abnormalities in young common terns (*Sterna hirundo*) and roseate terns (*Sterna dougallii*) in which PCB levels of 25 ppm wet weight were found in breast muscle. Prey fish contained PCB levels ranging from 10 to 180 ppm. The abnormalities in the young terns included juvenile feather loss and eye, bill, and foot deformities in newly hatched terns. These deformities resemble those produced in young chickens under experimental conditions (Hays and Risebrough 1972). There is also evidence that abnormalities in fish-eating birds on the Lower Great Lakes may have been caused by elevated PCB residues in eggs (Gilbertson et al. 1976).

In summary, the literature suggests that the combination of PCBs and organochlorine pesticides can cause a wide variety of effects on reproductive success of piscivorous birds. Recently, aryl hydrocarbon hydroxylase (AHH) induction has been suggested as a mechanism for these effects in Forster's terns (Kubiak et al. 1989) and in cormorants (Tillitt et al. 1992). Dioxin (2,3,7,8-TCDD) and a number of planar PCB congeners are believed to cause induction of AHH, and a technique has been developed to quantify toxicity in terms of dioxin equivalents by measuring AHH induction (Tillitt et al. 1991).

2.3.2 Mercury

High concentrations of Hg are often found in fish-eating birds. Wild bird species living in areas receiving little or no industrial Hg contamination have liver Hg concentrations ranging from 1 to 10 µg/g, the highest values occurring in scavengers and piscivores (Fimreite 1974). Fish-eating bird species living near sites of industrial contamination may contain up to 17 µg/g in their livers (Fimreite et al. 1971). Vermeer et al. (1973) studied Hg contamination among six duck species and found that the hooded merganser (*Lophodytes cucullatus*), which consumes primarily animal foods, contained the highest Hg levels in breast muscle. Of the prey items analyzed, the highest Hg levels were found in crayfish which is the primary prey of hooded mergansers.

There is evidence to suggest that the population decline of white-tailed eagles (*Haliaeetus albicilla*) in Sweden could be attributed to Hg exposure. Liver Hg concentrations ranged from 9 to 60 ppm, and liver Hg concentrations ranging from 12.2 to 27.1 ppm were lethal to white-tailed eagles in Finland (Henriksson et al. 1966 and Borg et al. 1969 in Fimreite et al. 1971).

Hoffman and Curnow (1979) studied Hg levels in great blue herons, black-crowned night herons, and great egrets living in southwestern Lake Erie. Differences in Hg levels among the three heron species could be attributed to age, sex, and percentage of fish comprising the diet. Tissues of adult birds showed higher Hg concentrations than did tissues from nestlings of the same population. Adult females generally contained higher Hg levels than did adult males. Concentrations were highest in adults collected during the posthatching period, followed by the prehatching, then fledgling periods. Activities involved with courtship, nesting, and rearing of young may increase caloric intake requirements and thereby increase the total Hg ingested.

Piscivorous species are primarily exposed to methylmercury (MeHg), which is the most readily absorbable and highly toxic organic form of Hg. Intestinal absorption of inorganic Hg is 1 to 3% of the ingested dose whereas absorption of MeHg approaches 100% of the ingested dose (Berglund and Berlin 1969 in Scheuhammer 1987). MeHg has a lower excretion rate, is more slowly metabolized than other organomercurials, and has a biological half-life of 2 to 3 months in bird species (Stickel et al. 1977 in Scheuhammer 1987). In contrast to inorganic Hg, MeHg readily penetrates the blood-brain barrier because of its chemical stability and lipophilicity (Scheuhammer 1987).

The toxic effects of MeHg poisoning include spinal cord degeneration, reduced food intake, weight loss, progressive weakness in wings and legs, inability to coordinate muscle movement, decreased hatchability of eggs, increased embryonic mortality, and increased number of unfertilized eggs (Fimreite 1971; Fimreite and Karstad 1971 in Scheuhammer 1987). The toxic effects of MeHg differ among avian species, as does the ability of various species to metabolize MeHg to the less toxic and more readily excreted inorganic form (Scheuhammer 1987). MeHg has been shown to be teratogenic in mallards, causing an increased incidence of malformations at levels of 0.5 µg/g Hg in fertile eggs and increased embryonic mortality at levels of 4 to 5 µg/g or greater (Hoffman and Moore 1979 in Scheuhammer 1987). In addition, a strong negative relationship was found between the successful use of territories by breeding loons (*Gavia immer*) and the degree of environmental Hg contamination (Barr 1986 in Scheuhammer 1987).

Differences in intestinal absorption of inorganic Hg in birds have been demonstrated (Serafin 1984 in Scheuhammer 1987). The relative order of absorptive efficiency of bird species tested for Hg absorption is kestrel (*Falco sparverius*) > screech owl (*Otus asio*) > bobwhite (*Colinus virginianus*) > quail (*Callipepla squamata*) > black-crowned night heron > mallard duck (*Anas platyrhynchos*) (Scheuhammer 1987).

Fimreite (1974) found that most of the Hg in common mergansers did not occur in the methyl form (MeHg averaged 12.3% of the total Hg content). This is in contrast to the findings for surface-feeding ducks such as mallards, common goldeneyes (*Bucephala clangula*), and pintails (*Anas acuta*), which had considerably higher MeHg fractions. Thus, Fimreite (1974) concluded that total Hg content is not a satisfactory indicator of MeHg levels in ducks because the accumulation of MeHg may be species dependent. The interspecific differences in mercurial forms among fish-eating and surface-feeding ducks may be related to differences in the secretion mechanism or in the intestinal microflora taking part in methylation of inorganic Hg (Fimreite 1974).

The kidney is the major reservoir of inorganic Hg in birds (Backstrom 1969 in Scheuhammer 1987). Kidney:liver ratios of total Hg concentrations are useful in distinguishing MeHg exposure from exposure to inorganic Hg. Only the kidney accumulates high levels of inorganic Hg; therefore, the kidney:liver ratio will be higher than unity if exposure is to inorganic Hg. Exposure to MeHg will result in a ratio much closer to unity (≈ 2) or below unity (Heinz 1976, 1980 and Finley et al. 1979 in Scheuhammer 1987). In some species of seabirds, Hg levels in internal organs can be very high, whereas the relative proportion of MeHg and inorganic Hg varies in liver tissue depending on species (Thompson and Furness 1989 in Thompson et al. 1990).

Feathers may be used to monitor Hg levels in freshwater and terrestrial ecosystems. There is a significant association between Hg concentration in muscle tissue and feathers of various avian species (Hoffman and Curnow 1979). It has been estimated that 60 to 70% of the total body burden of Hg may be present in the plumage of bird species (Honda et al. 1986 in Thompson et al. 1990). Several authors (Berg et al. 1966, Borg et al. 1970, Buhler and Norrheim 1981, Appelquist et al. 1985, and Thompson et al. 1986 in Thompson et al. 1990) have used a ratio of 7:3:1 for Hg concentrations (fresh wt) in feathers, liver tissue, and muscle tissue, respectively, to estimate internal tissue Hg concentrations on the basis of Hg concentrations in feathers. However, the time of sampling relative to molting, pattern of feather molt, type of feather analyzed, and the relative proportions of the various chemical forms of Hg in different tissues are complicating factors. The 7:3:1 ratio may be appropriate for providing broadly correct results in avian species with low MeHg burdens but is not appropriate for many seabird species (Scheuhammer 1987).

The Hg content of eggs presents another possible indirect measure of dietary Hg levels. Mercury accumulates in eggs in a dose-dependent fashion in response to increasing dietary levels of MeHg (Heinz 1976 and March et al. 1983 in Scheuhammer 1987). Because of excretion of Hg in eggs, levels of Hg in feathers may be lower in female birds than in males similarly exposed (Backstrom 1969 in Scheuhammer 1987). There is no information to show the relationship between heavy metal levels in eggs and in the feathers of birds; however, it is probable that the two media provide different data because feather Hg levels appear to relate to intake of Hg since last molt, whereas levels in eggs appear to reflect dietary Hg levels during the period of egg development (Becker et al. 1985, Furness et al. 1986, and Honda et al. 1986 in Scheuhammer 1987). More information is needed on the dose-dependent relationship between dietary MeHg levels and the Hg content of eggs and how Hg is complexed by the egg material (Scheuhammer 1987).

Little or no eggshell thinning has been reported in response to organic Hg exposure in a variety of avian species (Peakall and Lincer 1973 and Heinz 1974 in Scheuhammer 1987, Elliot et al. 1989). Vermeer et al. (1973) found that the threshold levels of Hg residues at which bird eggs fail to hatch vary between species. Hatching success of herring gull eggs did not seem to be negatively affected by Hg levels ranging from 2 to 16 ppm (Vermeer et al. 1973).

2.3.3 Radionuclides

The internal doses of radionuclides in birds vary and are related to differences in food habits and metabolism between avian species. In a study of radiocesium contamination in herons, Domby et al. (1977) found that in little blue herons, nestlings with higher radiocesium burdens consumed a greater percentage of fish vs amphibians. It was estimated that the biological half-life of radiocesium in a 7-day-old nestling was 6.7 days, which is similar to what has been found for other birds such as wood ducks (*Aix sponsa*)

(5.6 days) and blue jays (*Cyanocitta cristata*) (6.1 days). Straney et al. (1975) found that the ^{137}Cs uptake rates of adult and juvenile birds differed. The uptake rate in juveniles is proportional to weight and age, whereas in adults it is relatively constant. External doses of radionuclides are less variable because factors such as metabolism, body size, food consumed, and activity patterns have little effect on the external doses to waterfowl (Willard 1960, Halford et al. 1982).

Willard (1960) studied ^{137}Cs and ^{90}Sr in passerine birds living on the White Oak Lake bed at ORNL. Gross beta radioactivity assimilated by bird species living in three different habitats around the lake were measured. Bird species that feed close to the ground, such as field sparrow (*Spizella pusilla*), song sparrow (*Melospiza melodia*), chat (*Icteria virens*), and water thrush (*Seiurus motacilla*), exhibited the highest tissue levels of gross beta radioactivity. Birds species, such as goldfinch (*Spinus tristis*) and indigo bunting (*Passerina cyanea*), that occupy tall and low vegetation had levels one-tenth as high. Bird species classified as thicket birds, such as catbird (*Dumatella carolinensis*) and cardinal (*Richmondia cardinalis*), had levels one-twentieth as high. The concentrations of ^{90}Sr in bone was about six times greater than that of ^{137}Cs in muscle (Willard 1960). Seasonal changes were found in the ^{90}Sr and ^{137}Cs ratios in tissue. This indicates that radionuclide uptake by birds is primarily through the food chain (Willard 1960).

2.4 IMPLICATIONS FOR KINGFISHERS

Accumulation of contaminants in birds appears to be correlated with the proportion of fish in the bird's diet. Kingfishers consume fish for $\geq 75\%$ of their diet, and another 13% of their diet comes from crayfish. Thus, kingfishers would be expected to ingest substantial amounts of contaminants when feeding in contaminated areas. If kingfishers are sensitive to PCBs and Hg, it is possible that they may exhibit adverse effects such as eggshell thinning or reproductive impairment.

3. KINGFISHER CENSUS

This section of the paper describes the approach and results of the field component of the investigation. The purpose of this field work was to determine where kingfishers were feeding on the ORR and where they might be nesting.

3.1 STUDY AREA AND METHODS

The water bodies included in this study are the Clinch River, White Oak Lake, White Oak Creek, Bear Creek, Poplar Creek, and East Fork Poplar Creek (EFPC). Each of these streams are known to contain PCBs, Hg, or radionuclides.

PCB concentrations in Bear Creek sediments average 1.7 ppm, range from 0.39 to 4.2 ppm, and are comparable to levels found in systems where concentrations in fish exceed 1 ppm (Peterson et al. 1992). PCB levels in Poplar Creek and EFPC sediments are normally less than 1 $\mu\text{g/g}$ (Ashwood et al. 1986). In White Oak Creek and White Oak Lake, PCB concentrations in sunfish (*Lepomis spp.*) have ranged from 0.06 to 1.17 $\mu\text{g/g}$ since late 1987 (Southworth et al. 1992).

Mercury in surface sediments of EFPC ranged from 20 to 150 $\mu\text{g/g}$, and in periphyton [the food source for stonerollers (*Camptostoma anomolum*), a primary prey of kingfishers]

Hg levels were 159 ± 44 $\mu\text{g/g}$ (Ryon et al. 1990). Mercury levels in stonerollers on upper EFPC were between 1.2 and 80 $\mu\text{g/g}$ in intestine, muscle, and whole body (Ryon et al. 1990); highest levels were found in intestines—probably because of mercury-contaminated sediments in the intestines. White Oak Creek sunfish contained Hg concentrations ranging from 0.06 to 0.64 $\mu\text{g/g}$. Mercury concentrations in Clinch River sediments range from 0.7 to 5.3 $\mu\text{g/g}$ (Ashwood et al. 1986).

Sediments of White Oak Lake contain an average ^{137}Cs concentration of 3568 pCi/g. The highest ^{137}Cs level in Clinch River sediments was 14.9 pCi/g (Ashwood et al. 1986).

Prey items available to kingfishers in the vicinity of the ORR include stoneroller, blacknose dace (*Rhinichthys atratulus*), creek chub (*Semotilus atromaculatus*), Tennessee dace (*Phoxinus tennesseensis*), striped shiner (*Notropis chrysocephalus*), young shad (*Dorosoma cepedianum*), mosquito fish (*Gambusia affinis*), small sunfish (*Lepomis spp.*), and largemouth bass (*Micropterus salmoides*) fry. Stonerollers and striped shiners are abundant in EFPC, whereas young shad, mosquito fish, sunfish, and largemouth bass fry are available in White Oak Lake. In Bear Creek, blacknose dace, creek chub, stoneroller, Tennessee dace, and striped shiner are potential food items for kingfishers.

During the study, locations on the ORR that may provide suitable habitat for kingfishers were identified. Visual surveys for kingfishers on the Clinch River and Poplar Creek were made by motorboat during September 8–9, 1992. A survey of upper Bear Creek was conducted on October 26, 1992, by walking along the bank. These surveys estimated the abundance of kingfishers, located probable nesting sites along those waterways, and determined the proximity of contaminated waterways to areas where kingfishers are frequently seen. Additional locations of kingfisher activity were identified from the records of a weekly Oak Ridge area waterfowl survey conducted from May 1990 to November 1992. Kingfishers have been seen regularly at several of the survey observation sites.

3.2 RESULTS

Numerous kingfishers, suspected nesting burrows, and potential nesting banks were sighted along the Clinch River and Poplar Creek (Fig. 2). No kingfishers or nesting burrows were sighted on Bear Creek. Although the density of stonerollers in Bear Creek is believed to be large enough to support a kingfisher population (M. J. Ryon, ORNL, personal communication to C. L. Landrum, October 28, 1992), dense vegetation and lack of suitable perching sites are possible reasons for the absence of kingfishers at this location.

The waterfowl census data show a definite trend in the frequency of kingfisher sightings (Fig. 3). Breeding time is reportedly March–June as documented by several authors (Bent 1940; White 1953; Davis 1980, 1988a). April and May are months in which the least number of kingfishers are seen at their regular feeding sites. This could indicate that the birds are spending an increased amount of time at the nest site incubating the eggs. Birds may also be restricted to feeding locations that are close to nest sites during these months, thereby reducing the number of sites at which birds are seen. The consistent number of kingfisher sightings during the months of January and February indicates that the weather is sufficiently mild that many birds do not migrate from the area.

Fig. 2. Locations of kingfisher sightings and nesting areas observed during the autumn of 1992.

Fig. 3. Kingfisher sightings during weekly waterfowl surveys.

4. FUTURE WORK

Data obtained from this investigation will be used to evaluate the efficacy of using kingfishers to monitor the transfer of contaminants from aquatic prey to terrestrial biota.

Additional surveys of White Oak Lake, White Oak Creek, East Fork Poplar Creek, and lower Bear Creek are needed to estimate the abundance and distribution of kingfishers on the ORR. Delineation of the home ranges of resident kingfishers on the ORR would be helpful in determining which contaminated water sources the birds may be feeding from and to what specific contaminants they might be exposed. Information concerning kingfisher sightings, potential nesting banks, home ranges, vegetation types, and water quality could be used in conjunction with geographical information systems (GIS) technology to identify areas where kingfishers may be affected by contaminants.

Nesting burrows in the vicinity of these waterways should be located and sampled for pellets and feathers. Analyses of feathers would provide an estimate of Hg and ¹³⁷Cs levels in the birds, whereas analyses of pellets may indicate which fish species the birds feed on and the concentrations of contaminants in the prey.

5. ACKNOWLEDGMENTS

R. Winterfield constructed the GIS map. Mike Ryon, Dick Halbrook, and George Southworth provided valuable input during the study, and Dick Halbrook and George Southworth reviewed a draft of this report.

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