

Belted Kingfishers (*Ceryle alcyon*) as indicators of methyl mercury availability in aquatic systems (1997-2003)

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Submitted to:

Surface Water Ambient Toxic Monitoring Program

Submitted by:

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Introduction

Problem Statement: Although methylmercury (the most toxic form of mercury) and other aquatic-based persistent bioaccumulative toxins are prevalent throughout Maine's freshwater (Evers et al. 1998, 2004) and marine environments, accurately assessing levels of these toxins, and thus risks posed to both wildlife and humans, is difficult. This difficulty exists because toxin availability to fish and wildlife 1) varies geographically and is strongly influenced by physiogeochemical factors, 2) varies according to age- and species-specific accumulation rates (Thompson 1996), and 3) is difficult to assess within important estuarine habitats because of the transient nature of many species using estuaries. To accurately measure and interpret exposure/risk levels to aquatic and non-aquatic vertebrates, a standardized sampling of target biosentinels is needed that will allow comparisons of exposure levels to a wide variety of species, in a wide variety of habitats, and across a wide geographic range. Without such a sampling method, one that is both practical and able to accommodate such inherent ecological variation, it is difficult to set management priorities that reflect the best interests of both humans and wildlife.

Justification and urgency of the study: In late nineties, high concentrations of methylmercury (MeHg) in fish from Maine lakes, ponds, rivers, and streams prompted the Maine Department of Environmental Protection (ME DEP) to issue a statewide "fish consumption advisory," warning Maine citizens to limit consumption of fish from all fresh waters. Children and pregnant women were warned not to eat fresh water fish except one meal per month of brook trout or landlocked salmon (Maine Bureau of Health, 2000). Other contaminants, such as PCBs, DDTs, and dioxins have been responsible for recent advisories on lobster tomalley, bluefish, striped bass and other ocean fish (Maine Bureau of Health 2001), and for additional fish consumption limits on certain waters (Maine Bureau of Health 2000). Contaminant levels, and thus impacts on noncommercial wildlife species are less well known. Concerns about these gaps in knowledge were highlighted at the 1998 "New England Governors and Eastern Canadian Premiers" conference sponsored by the U.S. EPA and ME DEP. Recommendations from the report "Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action" included additional research on the cycling and bioavailability of mercury in aquatic ecosystems and on the ecological impacts of elevated fish mercury levels, "particularly for fish-eating wildlife such as eagles, loons, osprey, otter, and mink" (NESCAUM 1998). In addition, Strategy 9 from "Mercury in Maine," a report by the Land and Water Resources Council to the Maine legislature in January 1998, recommends "focusing biological research efforts on the effects of mercury on the health of loons, fish and other wildlife with elevated mercury levels" (Maine DEP 1998).

Objectives

1. Determine mercury exposure and risk to aquatic systems using the Belted Kingfisher as a standard indicator species;
2. Compare mercury exposure between the Androscoggin and Kennebec River watersheds, and among five major habitat types (e.g., marine, estuary, rivers, lakes, and reservoirs) within Maine, and between other states;
3. Compare Hg levels of prey items collected at kingfisher nest sites and foraging areas;
4. Evaluate the potential of this sampling design for assessing statewide exposure and risk to wildlife, by using the Belted Kingfisher as a universal indicator species.

Why Belted Kingfisher

The U.S. Environmental Protection Agency (USEPA) in its report to Congress (1997), states that piscivorous birds, including the Belted Kingfisher, are at especially high risk to methylmercury contamination because of their high position in the aquatic food chain. Within aquatic systems, the USEPA identifies four trophic levels in the aquatic food web, each level having a significantly higher exposure to methyl mercury (MeHg) than the level below it because of bioaccumulation. Level 1, phytoplankton, have the lowest mercury exposure while Level 4, piscivorous fish, have the highest. Fish-eating birds that feed at level 4 ingest approximately 5 times more MeHg than birds foraging at level 3. For kingfishers that feed on 70g of level 3 prey daily, the USEPA calculated the average daily exposure to mercury to be 25 micrograms/kg/day. When fish are less available, kingfishers will consume crayfish (Davis 1980) that can also have elevated mercury concentrations (Parks et al.1991).

Besides being at high risk to Hg bioaccumulation, the Belted Kingfisher is a piscivore that breeds throughout most of continental United States and Canada and is found in both fresh and saltwater habitats. Given this wide range of geography and ecology, vulnerability to toxin accumulation, and demonstrated ability to capture and sample both kingfishers and their prey (Albano 2000, Davis 1982, Evers et al. 2003), the species could potentially serve as an excellent indicator of contaminants across most aquatic ecosystems.

Belted Kingfisher Natural History

The Belted Kingfisher (*Ceryle alcyon*) is a relatively common and widely distributed obligate piscivore. It inhabits a diversity of habitats ranging from small streams to large rivers, ponds to large lakes and reservoirs, emergent wetlands, estuaries, and marine environs (Bent 1940, Hamas 1994), and feeds on small prey items that are generally 4-14 cm long (Bent 1940, Davis 1982, Albano 2000). In Ohio, 88% of the adult diet was composed of fish ranging from 6-12 cm (Davis 1980) and young were fed fish with mean size of 8-9 cm for their first four weeks along the Connecticut River in western Massachusetts (Albano 2000).

The Belted Kingfisher is a monogamous species; males and females contribute nearly equally to parental effort during every phase of the breeding cycle (Albano 2000). Both sexes are strongly territorial and defend their nesting and feeding territories against conspecifics (Davis 1980). Adult male kingfishers may be permanent residents on territories with year-round water access (e.g., coastlines, rivers and estuaries; (Pittaway 1994, Albano 2000). Kingfishers nesting in Maine inhabit their breeding territory from mid April (when nests are excavated) into July and early August (when fledglings disperse). Territory size depends on nest and food availability and juxtaposition of feeding areas (Davis 1982). Belted Kingfishers excavate a 1-3 m burrow in the open, sandy banks of bays, rivers, and lakes. The burrow is usually located within 0.5-2m from the top of the bank and thus most nests can be accessed for repeated sampling of the young. The availability of suitable nesting sites (i.e. earthen banks) appears critical for the distribution and local abundance of this species (Hamas 1994). In Ohio and Pennsylvania, kingfishers selected the highest banks for nesting relative to the surrounding unoccupied banks and preferred agricultural areas with banks covered with herbaceous vegetation-probably to avoid root masses that interfere with tunnel excavation (Brooks and Davis 1987). Kingfishers will often nest in active or abandoned gravel pits located in close proximity to water. Both sexes share the 24-28 day incubation of 5-7 eggs, hatching typically occurs by early to mid June, and young may leave the nest burrow after four weeks. The average brood of 6-7 fledglings typically remains within 300-500 m of the nest burrow for the next 3-4 weeks, frequently being fed by their parents (Albano 2000).

Belted Kingfishers are relatively short lived compared to most piscivores (e.g., ~ 4-5 years, Albano 2000, BRI unpubl. data; USFWS unpubl. data) and often demonstrate site fidelity. Both, males and females will breed multiple years in the same territory. In 1998, for example, we recaptured a female on Flagstaff Lake,

Maine on the same territory as found in 1997. In 1999, we recaptured a male in the same bank in Casco Bay, Maine where he was trapped in 1998. Albano (2000, pers. comm) recaptured a number of his study birds in Massachusetts in different years, including a nesting female recaptured 4 times in 5 years at nest banks all within 3 km.

Kingfishers tend to eat what is locally most available (Davis 1980, Sayler and Lagler 1946), especially surface fish from 4-14 cm long, but also crayfish, insects, and small amphibians (Davis 1982). In Ohio, Davis (1982) found that following periods of heavy rain, when waters were turbid, kingfishers often switched to crayfish. Although there is limited information available on the size of kingfisher foraging territories, size may depend on prey density and/or presence of other kingfishers in the area. Belted Kingfisher's home range is relatively small and generally between 0.4 and 2.2 km (Brooks and Davis 1987). Davis (1982) determined that linear stream territories were approximately 1 km during the breeding season. Cornwell (1963) observed the kingfisher territories during breeding season were approximately 1.8 square miles. Albano (pers. comm.) estimated that kingfishers nesting along the Connecticut River typically foraged within 2 km of their nests.

Mercury exposure in kingfishers

The diet of fish and crayfish puts the Belted Kingfisher at-risk from persistent bioaccumulative toxins such as mercury. We collected small yellow perch (6-15 cm) from several reservoirs and natural lakes in northwestern Maine. The mean Hg levels of these perch were 0.12 parts per million (ppm) (+/- 0.07 sd) wet weight (ww) and some individuals contained over 0.30 ppm (i.e., Flagstaff Lake) (Evers et al. 2004). Blood Hg levels measured in kingfishers on Flagstaff and Chesuncook reservoirs (2.12 ppm) were 60% higher than those tested from Maine's natural lakes (1.26 ppm) (BRI unpubl. data).

The USEPA estimates that MeHg intake of kingfishers (40 ug of MeHg per kg of body weight per day) is nearly 3 times higher than that of the Osprey (*Pandion haliaetus*) and the Bald Eagle (*Haliaeetus leucocephalus*) (USEPA 1997). These estimates are based on average fish Hg levels of 0.08 ppm and a daily uptake of 75 g of fish. Mean Hg levels of Maine fish are generally well above this Hg level and daily food uptake of adult kingfishers may range between 75-150 g of fish (Albano 2000). Given this potential rate of toxin intake, their widespread distribution, and the relative ease of their capture, kingfishers are potentially excellent indicators of MeHg availability and likely other bioaccumulative contaminants.

Study Area

The study area encompasses a variety of aquatic habitats across Maine (Figure 1). The data from our additional projects in New Hampshire, Massachusetts, Vermont and Michigan were also included.

A. Merrymeeting Bay Watershed (estuary). Merrymeeting Bay is formed by the confluence of two major rivers (the Kennebec and Androscoggin) and four smaller tributaries (the Eastern, Abagadasset, Cathance, and Muddy Rivers). The Bay is an inland, freshwater river delta, but is influenced by 6-foot tidal action. The Bay is shallow, which combined with the tidal forces limits stratification of the water column that is characteristic of most bays and lakes (Hayden 1998). There is insufficient information on the contaminant levels in wildlife from the bay area. A 1991-92 study on Bald Eagles (*Haliaeetus leucocephalus*) revealed that the eggs from the Merrymeeting Bay area had the highest levels of PCB's, DDE and dioxin of all those regions sampled in Maine (Welch 1994).

B. Casco Bay (marine). The 985 square miles of land and water that drain into the Bay form its watershed. Casco Bay stretches from Cape Elizabeth east to Cape Small in Phippsburg, and northwest to Bethel. The water surface is approximately 200 square miles. Twelve lake systems and four major rivers (Presumpscot,

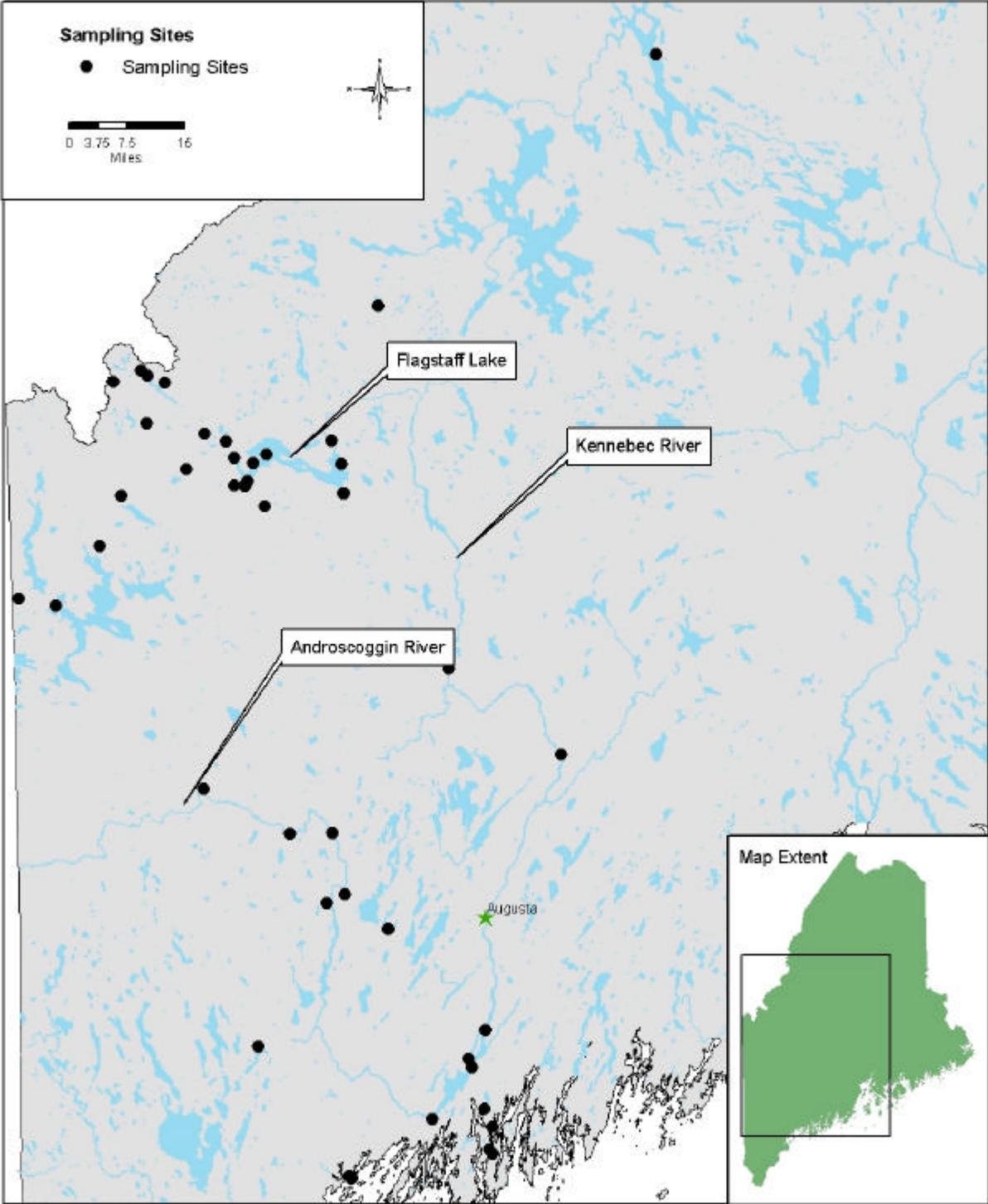
Royal, Stroudwater, and Fore) feed the bay (Casco Bay Plan 1996). Kingfisher nests sampled during this study were located in Winslow Park in Freeport.

C. *Androscoggin River*. Originates in New Hampshire and flows into Maine past Rumford. The Androscoggin River joins the Kennebec River above Bath. Historically, the Androscoggin River was polluted by discharge from several pulp and paper mills located along the river.

D. *Kennebec River*. Stretches from Moosehead Lake near Greenville Maine to Popham Beach, south of Bath. There are 9 dams on this river located between Augusta and Moosehead Lake. Kennebec also receives discharge from various industries built along the river.

E. *Flagstaff Lake/Dead River (reservoir)*. Located at the headwaters of the Dead River, Flagstaff was a river system that was flooded in 1950's to create a reservoir for hydropower operations. Its present watershed is 28 square miles. Flagstaff is a shallow lake with fluctuating water levels and high mercury levels in fish and piscivorous birds (Evers et al. 2004).

Figure 1. Belted Kingfisher sampling locations, Maine, 1997-2002.



Methods

Capturing Birds

The study was conducted in the Merrymeeting Bay Region, Casco Bay, Androscoggin and Kennebec Rivers, natural lakes in the watersheds, and Flagstaff Lake in Maine (Figure 1) during May-July 1997-2000. We used a motorboat, canoe, and/or kayaks to survey lakes and rivers for kingfisher burrows. Active and old gravel pits in the study area were surveyed by car and foot. Burrows that had fresh kingfisher “tracks” (Bent 1940, Hamas 1994, Albano 2000) were concluded to be active and carefully excavated from the rear to determine the status of the nest. While the nest was excavated, a mist net loop trap (Figure 2) was placed in front of the burrow to catch the adult if flushed from the nest. If the nest was in the egg laying or incubation stage, the eggs were examined for the stage of development. Transparent eggs indicate early stage of embryo development, and dark mass inside the egg suggests the embryo is further along (Lokemoen and Koford 1996). A precut plywood “door” was placed to reseal the excavated entrance at the rear of the nest chamber between visits. This rear door was covered with soil and a heavy rock or a dead tree placed over the covered area to prevent predators from digging out and disturbing the burrow (Davis 1980, Albano 2000). None of the nests accessed in this manner were subsequently depredated.

At those nests discovered during the nestling period, nestling age was determined by weight and stage of feather development (Hamas 1975, 1994, Albano 2000), and blood samples were collected from the birds that were at least two weeks old. If the chicks were younger than two weeks, we returned at a later date to band them and collect blood samples for Hg analysis.

When the nest location made accessing the burrow prohibitive (e.g., when the nest was located under a tree or too far down on the bank), we captured the adults by placing a mist-net in front of the burrow. Birds were caught in the net when trying to enter the burrow.

Occasionally we found a kingfisher foraging but did not know where it nested. In such cases, we used a playback recording of a kingfisher call with a belted kingfisher model placed by a mist-net on the shore. This capture method takes advantage of belted kingfisher’s highly territorial nature. When a bird on its feeding territory encounters an “intruder,” it attacks the model and gets trapped in the net (Davis 1982, Albano 2000). We banded all birds with USFWS bands.

Blood and feather collection

For both adults and young, we used 25 gauge disposable needles to puncture a cutaneous ulnar vein in the wing and 1 cc syringes or green top microtainers with a blood flow adaptor to collect 0.1 to 0.6 cc (cubic centimeters) of blood (Figure 3). Blood samples were stored in 0.6 cc green top microtainers, placed on ice, and frozen within 2-4 hours of collection. The second secondary feather (from adults) was clipped at calamus (below the base of the vein), placed in clean, labeled plastic bags, and refrigerated until analysis.

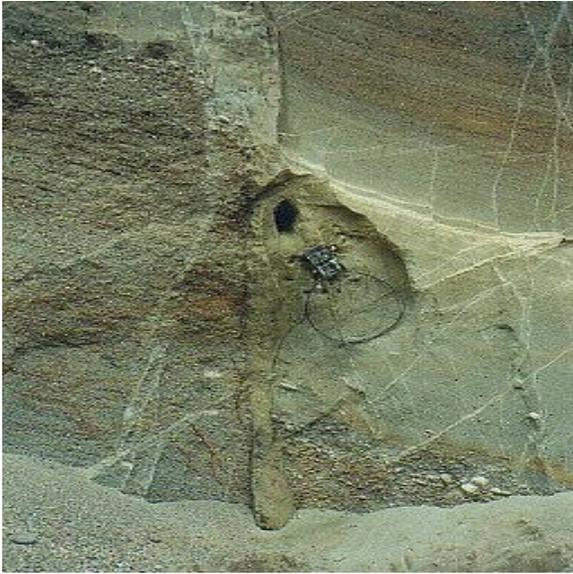


Figure 2. Trap used to capture adult belted kingfishers.



Figure 3. Blood collection from a kingfisher nestling.

Sampling of Nestling Food Items

We opportunistically collected fish delivered to the nest while catching the adults at the entrance to the nest burrow. As a kingfisher flew into the mist net, it dropped the fish it was carrying in its bill. We placed the fish in clean, labeled, plastic bags and froze them within 2-4 hours. Prior to freezing, the fish were identified to species, and length and weight were recorded.

Fish Sampling

In July and August 1998-99 we sampled fish that we determined to be potential kingfisher prey. We placed two minnow traps baited with white bread at or near each nest site. Where feasible, we used a hand-held 6-foot high, 50-foot long seine with 1/8-inch mesh to catch minnow-size fish. Fish were handled as described above.

Results and Discussion

Field Surveys and Blood/Feather Analysis

- 1997. Field surveys for nesting kingfishers focused on REMAP (Regional Environmental Monitoring and Assessment Program) lakes and nearby gravel pits (in Maine, New Hampshire, Vermont (1999) and Michigan (2000).
- 1998. Surveys focused along each river flowing into the Merrymeeting Bay, including Androscoggin River from Lisbon Falls and the Kennebec River from Richmond down to the Bay. We also surveyed all of Abagadasset, Cathance, and Muddy Rivers, and 3 km of the Eastern River. Volunteer field assistants

also surveyed most of the water bodies between the Bay and the coast. In addition to contacting local birders and naturalists about known kingfisher nesting sites, all identified active and abandoned gravel pits in the Bay's watershed were visited and searched for kingfisher burrows. Because the focus of the 1998 study was the Merrymeeting Bay watershed, less search effort was put into locating nests in Casco Bay. Two active burrows were found by searching sand banks in the vicinity of Winslow Park, in Freeport.

1999. Surveys focused on the Androscoggin River from Azischohos Lake down to Merrymeeting Bay, and the Kennebec River from North Anson to Merrymeeting Bay and captured kingfishers nesting in the banks of the rivers or in the gravel pits in close proximity to the rivers. We also captured and sampled kingfishers from Flagstaff Lake and its watershed.
2000. Sampling efforts were centered in and about Flagstaff Lake in Somerset Co. This work was funded by Florida Power and Light Inc. (FPL), yet we include these results here because the information is relevant to our earlier study funded by ME DEP (Figure 1).

Kingfisher matrices were analyzed with Cold Vapor Atomic Fluorescence at the University of Maine at Orono by Dr. Terry Haines and at the Trace Element Research Lab at the Texas A & M University in College Station, Texas by Dr. Bob Taylor. Detection limits of 25 ppb were used for all samples. Analysis of standard reference materials (TORT-2 lobster hepatopancreas), blanks, and spike recoveries were all within acceptable specifications. Blood and feather samples were homogenized and prepared using standard protocols (see Evers et al. 1998). Adult blood and feather samples were analyzed individually while blood samples from juveniles of the same brood were usually pooled.

As part of a study funded by the Surface Water Ambient Toxic Monitoring Program (SWAT), we captured Belted Kingfishers and their prey from four major habitat types: marine, estuary, riverine, and upper watershed lakes (separated into natural and impoundments). From May to July, 1997-2000 we sampled 68 nests and captured and collected blood samples from 58 adult and 198 juvenile kingfishers (Table 1). Samples collected after 2000 were funded by a different source and are excluded from the summary table but are included in selected statistical analyses. A total of 45 prey fish were collected at the burrows during capture of a parent. These prey items provided insight into species and size of kingfisher food items.

Table 1. Summary of sampling efforts in Maine, 1997-2000.

<i>Habitat Type</i>	<i>No. nests Sampled</i>	<i>No. Belted Kingfisher³</i>		<i>No. Prey Items from mistnet</i>
		<i>Adult¹</i>	<i>Juvenile²</i>	
Marine (Casco Bay)	4	4	12	2
Estuary (Merrymeeting Bay)	7	11	27	13
Riverine	18	14	49	12
Natural Lakes	15	9	13	8
Reservoirs (Flagstaff/Azis.)	24	20	97	10
Total	68	58	198	45

¹Represents the number of adults for which blood and feather samples were collected.

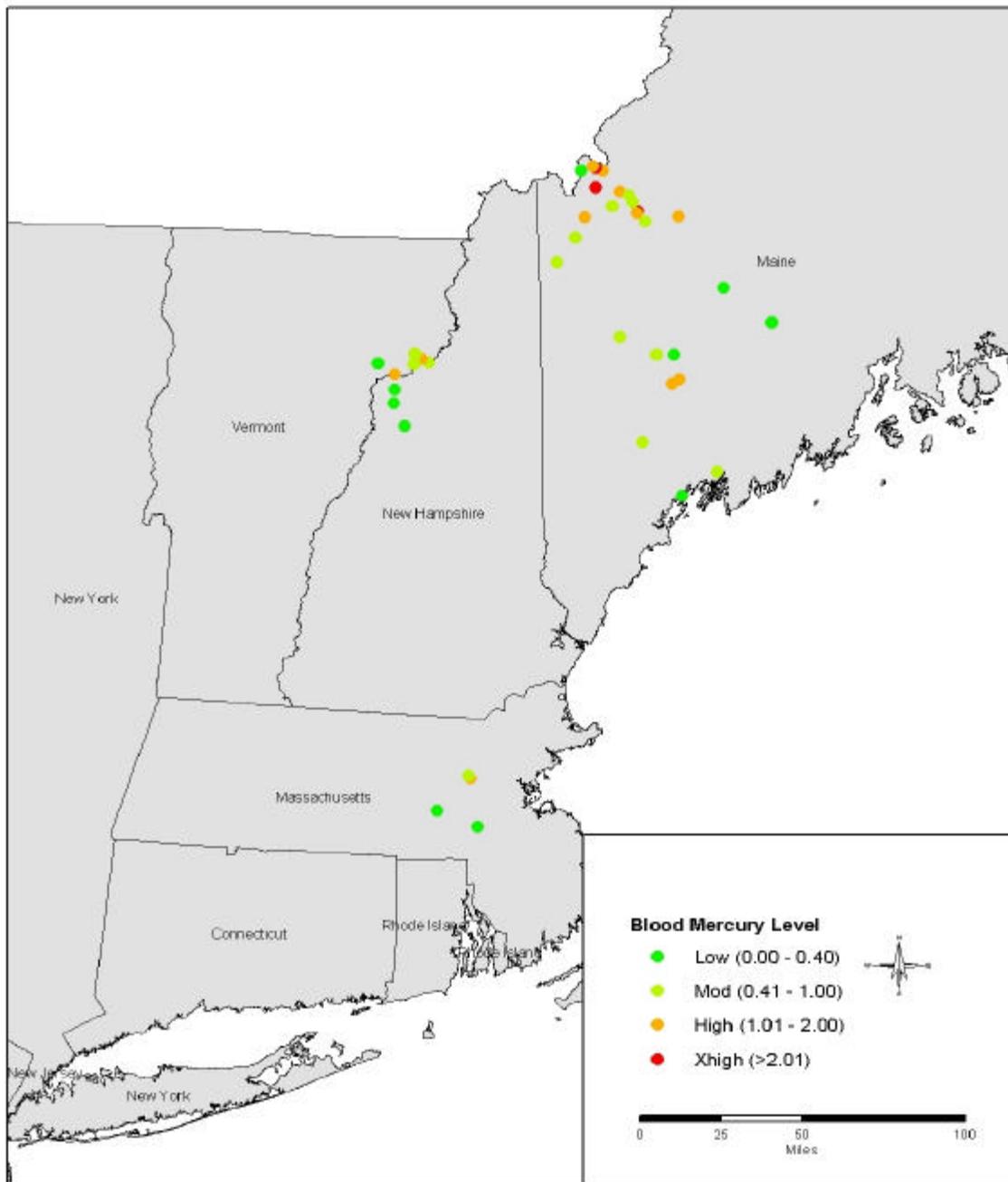
²Represents the number of blood samples collected from juveniles; several of these sampled are pooled within a brood

³A total of 9 kingfisher eggs were also collected.

Comparison of Belted Kingfisher total mercury levels among regions and habitats

Evers et al. (2004) developed four Hg risk categories (low, moderate, high and extra high) for the Common Loon. Blood Hg risk thresholds are unknown for kingfishers but, based on Hg research in the Common Loon, where Hg effects in birds are first noticeable at blood levels of 3.0 ppm (Evers et al. 2004) and comparing kingfisher Hg levels with loon levels from the same water bodies, we estimate that kingfishers with blood Hg of 1.0 ppm are at high risk from Hg exposure. Figure 3a depicts Hg risk to kingfishers from across all study areas.

Figure 3a. Sampling locations and mercury risk categories based on Belted Kingfisher blood analysis.



Considering both adult and juvenile blood mercury concentrations, levels from Maine reservoirs were higher than from river, natural lake, and the marine sites. Mean juvenile blood mercury levels in upper watershed lakes were six times higher than coastal areas (Table 2). Juvenile blood mercury levels averaged seven times lower than adults and may reflect differences in prey size. Generally, adults consume larger fish than they feed to their young nestlings (pers. obs.), and larger, therefore, older prey tend to bioconcentrate and bioaccumulate higher levels of mercury than smaller, less piscivorous prey (Evers et al. 2004).

Unlike blood samples, feather mercury levels reveal chronic body burden (Burger 1993) and may provide some insight into individual age. Mean feather mercury levels of adults sampled in Maine for this study were 8.54 +/- 9.0 ppm fresh weight (fw), with a range of 0.615-46.08 ppm (n=44) (an outlier of feather Hg=72 ppm, was removed from the analyses). Three individuals approached known thresholds of high risk (i.e., >20 ppm) (USEPA 1997). The mean feather Hg concentrations in Vermont birds were 5.75+/-4.70 (n=13), in NH 4.29+/-2.3 (n=11) and in Michigan 4.83+/-2.8 ppm (n=17).

Table 2. Mean (+/- sd) mercury levels (ppm) in kingfisher matrices, Maine 1997-2000.

Habitat Type	Adult-blood (n)	Adult-feather	Juvenile-blood
Marine	0.27 +/- 0.01 (4)	7.31 +/-4.11	0.05 +/- 0.01
Estuarine	0.73 +/- 0.39 (11)	7.42 +/-5.75	0.10 +/- 0.04
Riverine	0.80 +/- 0.43 (17) *	6.52 +/-4.57 (14)	0.17 +/- 0.06
Natural Lakes	1.04 +/-0.64 (16) *	3.98 +/-4.56 (9)	0.22 +/- 0.01
Reservoirs	1.60 +/- 1.04 (28) *	12.46 +/-12.8 (20)	0.20 +/-0.06

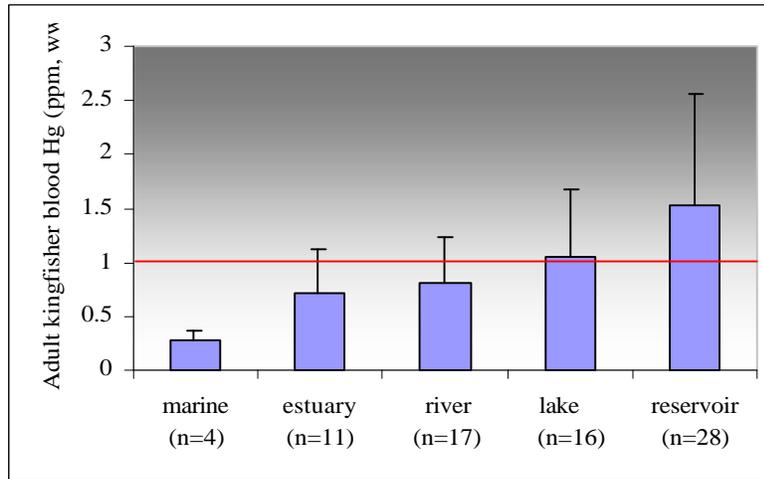
* Adult blood data were collected 1997-2003.

Adult kingfisher blood Hg by habitat

Blood mercury concentrations in adult belted kingfishers were the lowest in marine environments (e.g., Casco Bay) and the highest in reservoirs, such as Flagstaff Lake (Table 2, figure 4). We conducted Oneway ANOVA on the Hg concentrations data that were log transformed to normalize unequal variances. The transformed data set met homoscedasticity requirements and was checked with Bartlett's test ($p > 0.5$), which is sensitive to the normality assumption. We used transformed data in all statistical analyses. We found that blood Hg levels were significantly different among habitats ($F=6.99$, $p < 0.05$). We then used a Tukey-Kramer HSD test to compare blood Hg in all pairs of means of all habitats. We found that kingfisher blood Hg levels from reservoirs were significantly higher than blood Hg in kingfishers sampled in riverine, estuarine and marine habitats ($q=2.80$, $p < 0.05$).

Mercury levels in kingfishers from estuaries, rivers and the ocean are below the estimated 1 ppm LOAEL critical concentration (Figure 4). Several birds from the reservoirs and lakes had Hg levels above the 1 ppm threshold concentration at which reproductive impairment can occur (Evers et al. 2004).

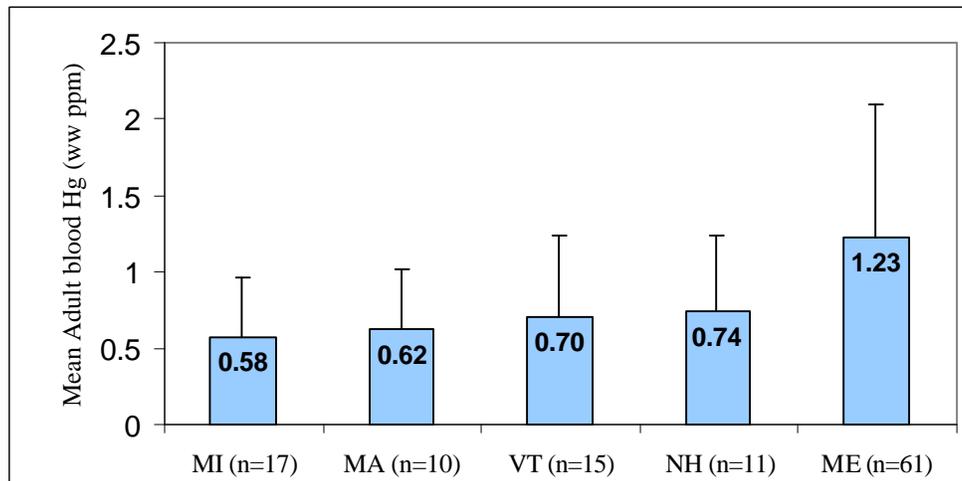
Figure 4. Mean adult kingfisher blood Hg levels (ppm, wet wt., across five habitat types (error bars represent standard deviation)), 1997-2003.



Adult kingfisher blood Hg by state

Again, all statistical analyses were performed on log-transformed data. Adult kingfisher blood Hg levels were significantly higher in Maine freshwater habitats than in Michigan, Vermont and Massachusetts (Tukey-Kramer HSD test, $q=2.77$, $p<0.05$) (Figure 5). We observed a similar trend (elevated blood Hg from west to east sites) in Common Loon blood Hg levels measured across its breeding range in North America (Evers et al. 1998). This gradual increase in Hg from west to east in North America is likely caused by distribution patterns of atmospheric pollution as it is transported by the prevailing west and southwest winds.

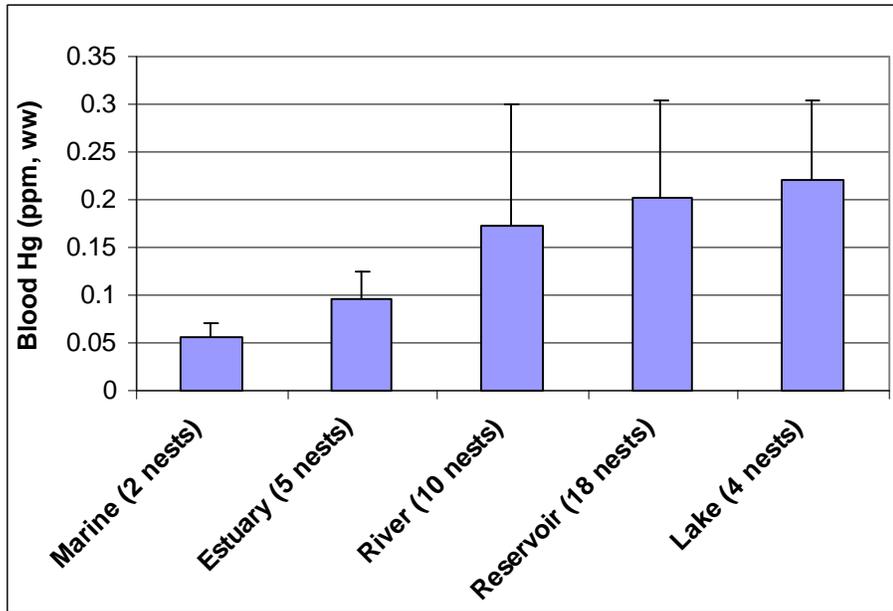
Figure 5. Adult Belted Kingfisher mean total mercury concentrations measured in blood in fresh water systems in five states, 1997-2003 (n=number of adult bird blood samples).



Nestlings

Juvenile Belted Kingfisher blood Hg levels tended to be higher in reservoirs than in marine habitats ($p>0.05$) (Figure 6). Because of the small sample sizes of juveniles sampled in the other states, statistical analyses did not reveal significant differences in Hg levels, however Maine birds had higher blood Hg levels than kingfishers tested from other states.

Figure 6. Juvenile Belted Kingfishers mean blood mercury levels measured in different habitats in Maine, 1998-2000.



Kingfisher nest prey composition

A total of 18 species of fish and crayfish were collected from adults bringing prey to their young (Table 3). The average fish length was 10.3 +/- 2.8 cm (range 6.1 to 17.1 cm) and the average weight was 15.8 g (range 2.7 to 27.1 g). The size of fish fed to nestlings typically increases with nestling age (Albano 2000). The mercury levels in fish ranged from 0.028 to over an order of magnitude higher in the upper Androscoggin River region near Mexico, ME (0.38 ppm ww in a 9.7 cm brook trout).

Clearly, kingfishers feed an assortment of prey species to their young. During our study mummichogs, brook trout and yellow perch were fed to the chicks more frequently than other species (Table 3).

Table 3. Prey items collected from mist-nets at kingfisher nests and fish mean Hg levels, 1997-2000.

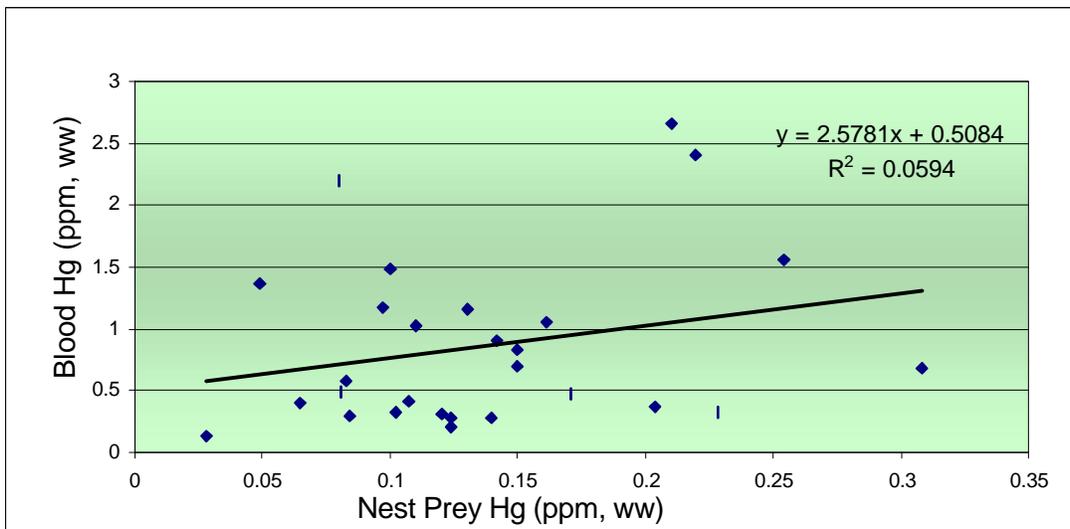
Nesting Habitat		Species	N=# of fish	Mean Hg (ww, ppm)
Marine	Atlantic silverside	<i>Menidia menidia</i>	1	0.120
	Mummichug	<i>Fundulus heteroclitus</i>	1	0.028
Estuary	Alewife	<i>Alosa pseudoharengus</i>	2	0.090
	Golden shiner	<i>Notemigonus crysoleucas</i>	2	0.116
	Bluegill sunfish	<i>Lepomis macrochirus</i>	1	0.061
	Mummichug	<i>Fundulus heteroclitus</i>	4	0.112
	Spottail shiner	<i>Notropis hudsonius</i>	3	0.122
	White sucker	<i>Catostomus commersoni</i>	1	0.124
Rivers	Banded killifish	<i>Fundulus diaphanus</i>	1	--
	Black nose dace	<i>Rhinichthys atratulus</i>	2	0.254
	Bluegill sunfish	<i>Lepomis macrochirus</i>	2	0.172
	Brook trout	<i>Salvelinus fontinalis</i>	3	0.256
	Chain pickerel	<i>Esox niger</i>	1	0.126
	Crayfish	<i>Orchonectis</i> spp.	1	0.361
	Largemouth bass	<i>Micropterus salmoides</i>	1	0.137
	Rainbow smelt	<i>Osmerus mordax</i>	1	0.084
Natural Lakes	Brook trout	<i>Salvelinus fontinalis</i>	1	0.070
	Brown bullhead	<i>Ameiurus nebulosus</i>	1	0.080
	Golden shiner	<i>Notemigonus crysoleucas</i>	2	0.077
	Largemouth bass	<i>Micropterus salmoides</i>	1	0.171
	Pumpkinseed	<i>Lepomis gibbosus</i>	1	0.062
Reservoirs	Brook trout	<i>Salvelinus fontinalis</i>	4	0.075
	Creek chub	<i>Semotilus atromaculatus</i>	1	0.23
	Long-nose sucker	<i>Catostomus catostomus</i>	1	0.150
	White sucker	<i>Catostomus commersoni</i>	1	0.049
	Yellow perch	<i>Perca flavescens</i>	4	0.210

Relationship between kingfisher blood and nest prey mercury levels

Kingfishers are opportunistic predators and consume a variety of prey (Bent 1940, Davis 1980, Hamas 1994) (Table 3). We found a weak positive correlation ($p>0.1$) between nest prey and adult blood Hg levels (Figure 7). This lack of a strong correlation could be explained by the fact that kingfishers consume a variety of species that are found in more than one water body and contain different Hg levels. The correlation between juvenile kingfisher blood and prey Hg was also weak. Our prey Hg levels represent a single food

item and kingfisher blood Hg concentration reflects multiple prey items of different sizes and species in one day.

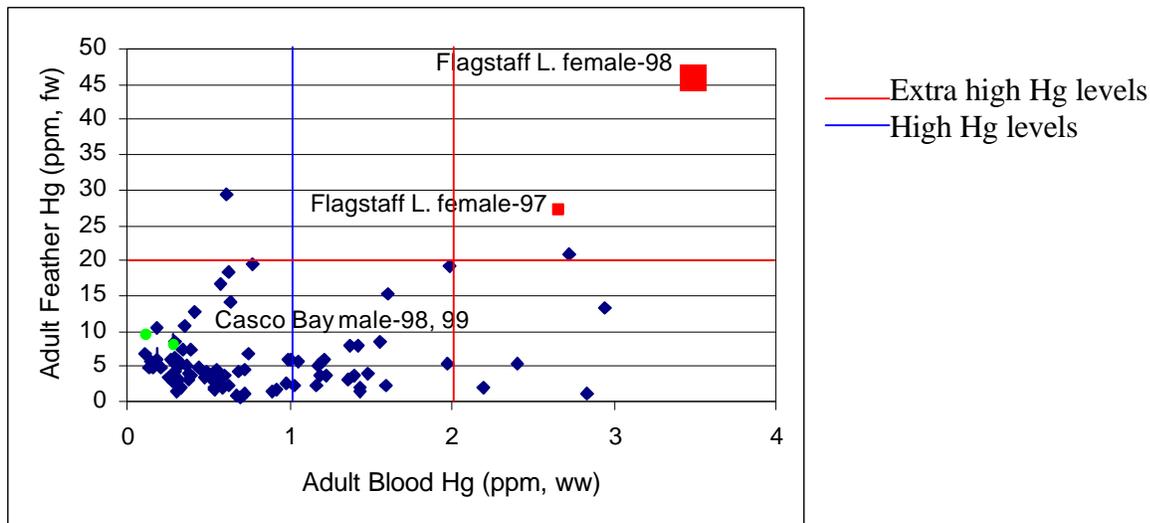
Figure 7. Relationship between adult kingfisher blood and nest prey mercury levels



Feather mercury

A relatively weak correlation was also found between blood and feather Hg levels ($R^2=0.17$). Blood Hg concentrations indicate recent exposure to contaminants (Evers 2001), whereas feather mercury concentrations of adult birds reflect chronic Hg exposure (Burger 1993) (i.e., life long body burdens of the contaminant). From previous studies (Evers et al. 1998) we found that loons from high Hg lakes bioaccumulate Hg in feathers at a rate of 8-9% a year. Compared to many piscivores (e.g., Common Loon), kingfishers are relatively short-lived species, which limits the opportunities for recapture. We observed a more dramatic increase in feather Hg concentration in one adult female kingfisher that was recaptured from a “high” Hg site. The feather Hg almost doubled in one year (Figure 8). The one recaptured adult male from a low Hg site in Casco Bay did not bioaccumulate Hg in the feathers (Figure 8, Table 4).

Figure 8. The relationship between adult kingfisher blood (wet wt.) and feather (fw= fresh weight).

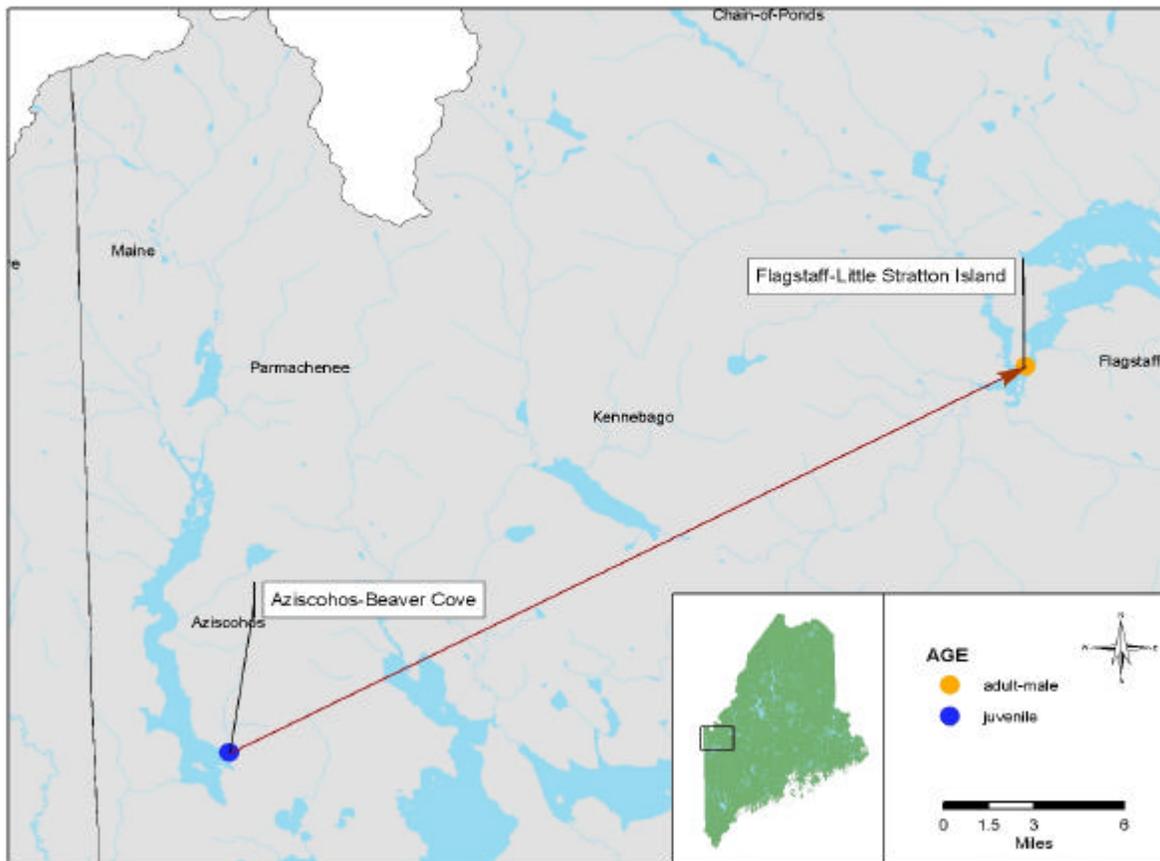


Recaptured kingfishers-between years

We recaptured four adult kingfishers over five year banding period (Table 4). In many cases, we did not attempt to recapture banded birds the following years. We visited only a handful of sites during consecutive breeding seasons. As a result, out of 29 adult birds that were banded in the “long term” study areas, we recaptured four birds, for an overall recapture rate of 14 %.

Of 198 kingfishers banded as juveniles, only one was recaptured as a breeding adult. In 1999, we banded a male nestling in one of the nests on Aziscohos Lake. This bird was recaptured as a breeding adult in 2000, 2001, and 2002 on Flagstaff Lake (approximately 28 miles NE from Aziscohos Lake) (Figure 8a). He successfully nested for 3 consecutive years in the same bank and for two of those years he nested in the same burrow. His blood and feather Hg levels were low to moderate.

Figure 8a. Locations of trapping and banding a nestling kingfisher in 1999 and subsequent recaptures of the same bird as a breeding adult in 2000-2002.



We recaptured an adult female breeding on Flagstaff Lake in 1998. She was nesting in the same bank she was in 1997. Her blood and feather mercury levels were in the “extra high” category both years and significantly increased from 1997 to 1998 (Figure 7, Table 4). We recaptured an adult male in 1999 breeding in the same bank on Lane’s Island in Casco Bay where he nested the previous year. His blood and feather mercury levels were relatively low in both years (Figure 7, Table 4).

Table 4. Blood and feather Hg levels in Belted Kingfishers recaptured during consecutive breeding seasons.

Site	Blood Hg (ppm, ww)		Feather Hg (ppm, fw)	
	Year One	Year Two	Year One	Year Two
Flagstaff-Big Is.	1997= 2.66	1998= 3.48	27.1	46.1
Flagstaff-Little Is.	2000= 1.29	2001=1.18	5.51	1.96
Casco Bay-Lane’s Is.	1998= 0.128	1999= 0.295	9.35	7.87
Natanis-Bear Brook	2001=1.44	2002=1.58	NA	

Retrapped kingfishers-within one breeding season

To determine whether Hg blood concentrations change as the summer progresses, we trapped several kingfishers twice in the same breeding season. We found a slight increase in Hg levels in as little as two-week period during the earlier phase of the nesting season, and a decline in blood Hg levels in a bird recaptured in late July in Maine (Table 5). Both kingfishers sampled in Massachusetts had lower Hg concentrations later in the season than when sampled initially. The change in Hg levels most likely reflects a change in prey selection and/or a switch to a different feeding territory. Small sample sizes and the relatively short time period separating samples make conclusions difficult to draw from these data.

Table 5. Blood Hg concentrations (ppm, wet wt.) in kingfishers recaptured within one breeding season.

Site	Date 1,	Blood Hg (ppm, ww)	Date 2,	Blood Hg (ppm, ww)
Merrymeeting Bay, ME	5/29/98	0.92	6/18/98	1.1
Turtle Rock Pit, ME	6/1/98	0.40	6/10/98	0.82
Merrymeeting Bay-Richmond, ME	6/11/98	0.29	7/01/98	0.32
North Bear Brook, ME	6/21/00	1.33	7/10/00	1.01
Sudbury River, MA	4/23/03	1.33	6/26/03	0.70
Sudbury-Rt.117 Pit, MA	5/14/03	1.01	6/10/03	0.59

Belted Kingfisher Nest Prey Mercury Results

Hg levels in the majority of prey collected from parents feeding their young were below LOAEL’s (lowest observed adverse effect level) of 0.15 ppm. Prey from Flagstaff Lake, Range Ponds, a gravel pit near Mexico, ME, and the Kennebec River by Shamut Dam, however, did exceed 0.15 ppm Hg (Figure 9). Mean Hg levels of prey from rivers were higher than those from reservoirs due to exceptionally high prey Hg concentration at the Mexico gravel pit nest near the Androscoggin River. There is likely a point source of Hg near the gravel pit (possibly a steam going through a contaminated site) that is responsible for such exceedingly high Hg levels.

Figure 9. Mean Hg levels in belted kingfisher nest prey collected from different habitats, 1997-2000 (no error bars shown because of small sample sizes).

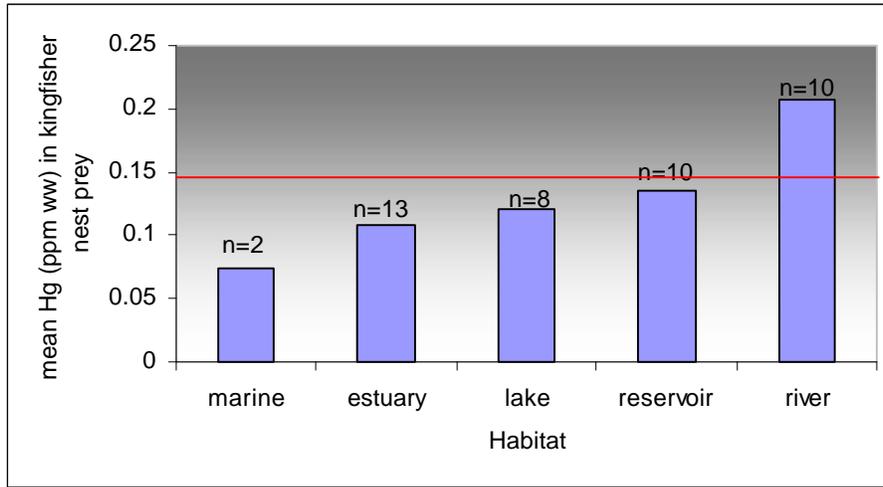
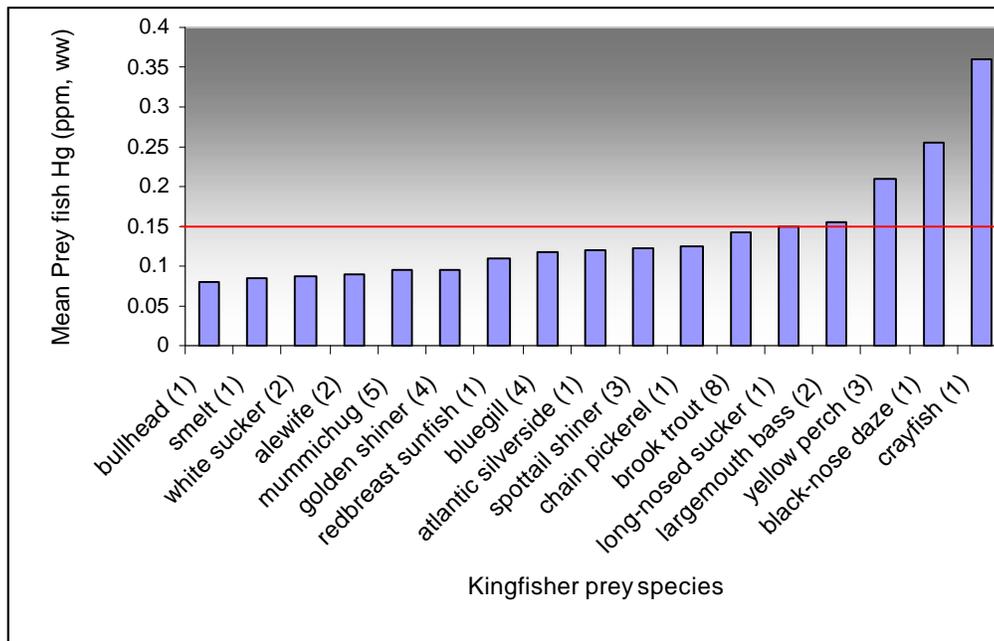


Figure 10. Mean Hg levels (ppm, ww) in prey species collected from adult kingfishers in mistnets, (number in parentheses is sample size)



Assorted fish species sharing the same water body may have different rates of contaminant uptake. This process depends on the diet and ecology of the species.

Prey Fish Hg concentrations

Androscoggin and Kennebec Rivers

We found that overall Hg levels in small fish (5-10 cm) sampled in the Kennebec River were higher than in the Androscoggin River. We used log-transformed fish tissue total Hg data and found that small fish from

Kennebec River had significantly higher Hg levels than small fish from Androscoggin River (Tukey-Kramer HSD test, $q=2.00$, $p<0.05$). Both rivers have various paper mills and other sources of pollution.

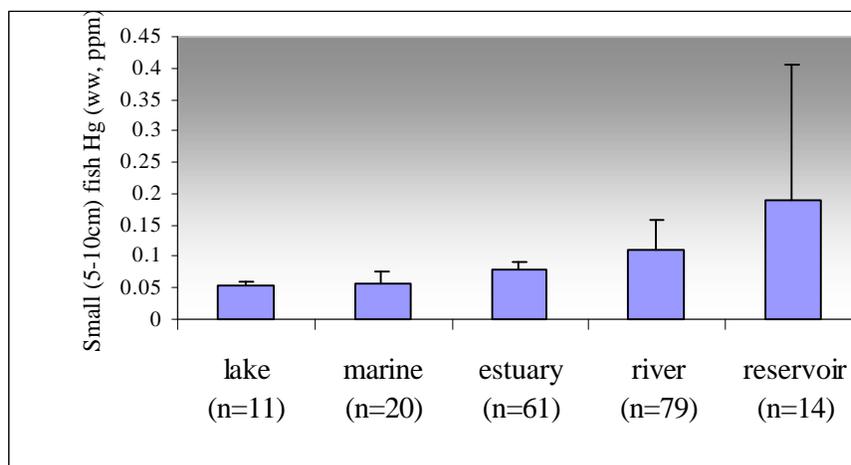
Table 6. Mean Hg concentrations (ppm, wet. wt.) in small fish from Androscoggin and Kennebec Rivers, Maine.

	N=# of fish	Mean Hg (ww, ppm)	Std Dev.	Std Error
Androscoggin River	45	0.091	0.058	0.009
Kennebec River	12	0.151	0.122	0.035

Fish collected in kingfisher territories

Patterns of Hg levels in prey fish varied according to habitat type, much like patterns of belted kingfisher blood and feather Hg levels.

Figure 11. Mean mercury concentrations (+/-sd) in small fish sampled in kingfisher territories, 1998-2000 (n=number of fish).

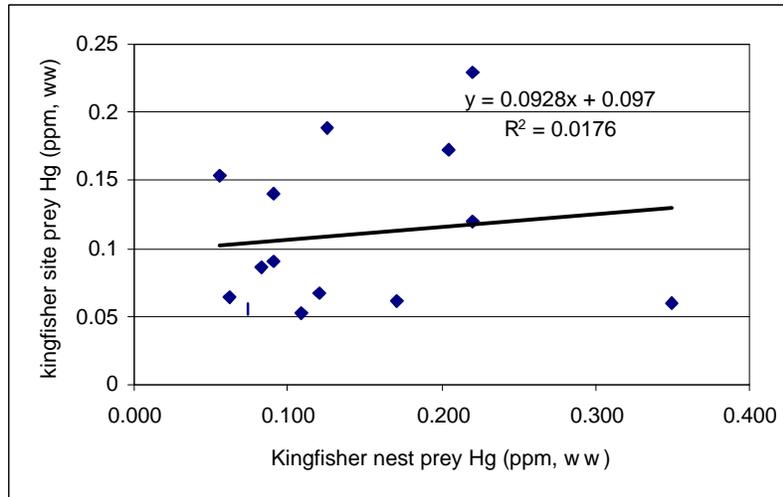


There does not appear to be a strong correlation between Hg levels in kingfisher nest prey and in fish collected in the vicinity of nest sites (Figure 12). One explanation for this lack of correlation could be the fact that kingfishers forage in a variety of habitats within their home breeding range (Hamas 1974, Albano 2000). For example, if the nest is located in a gravel pit near a lake or a major river, the adults could be foraging in a small stream that flows through or near the gravel pit and not on the expected lake or river. Supporting this idea is the fact that, occasionally, prey species collected from kingfisher nests were different than fish species collected near the nest site (Figure 10).

Based on our data, in order to accurately determine the prey composition or contaminant levels in kingfisher diet, we suggest collecting fish directly from the adult, or from the nestlings. Another way of tightening the connection between kingfisher diet and Hg blood levels would be to precisely determine foraging locations by radio-tracking (and thus sampling prey species from these locations only).

As mentioned above, three small prey items (2 brook trout and a crayfish) from a single nest located in a Mexico, ME gravel pit (near a paper mill) had exceptionally high Hg concentrations (0.31-0.38 ppm, ww). Such high Hg levels are likely attributable to a point source of Hg in the vicinity of the pit, which increases the bioavailability of Hg to aquatic organisms.

Figure 12. The relationship between nest prey Hg concentrations and fish collected near kingfisher nesting territories.



Conclusions

- Methyl mercury levels in the blood and tissue of Belted Kingfishers can vary greatly depending on the kind of aquatic habitat an individual occupies.
- Belted Kingfishers foraging on reservoirs in Maine appear to be at relatively high risk to Hg exposure: blood and feather Hg levels in breeding adult kingfishers and their nestlings at reservoir sites are significantly higher than Hg in tissues sampled from marine, estuarine, or riverine habitats
- Blood mercury levels in adult kingfishers from Maine were significantly higher than Hg levels in the blood of Michigan, Vermont and Massachusetts birds.
- Kingfishers and their prey appear to have higher Hg levels in the Kennebec River than the Androscoggin River in Maine.
- Despite great variability in blood Hg levels, perhaps related to a similar variability in foraging sites, Belted Kingfishers appear to be a useful indicator of contaminants in a given geographic area. Closer monitoring and observation of the birds would aid in the interpretation of the results.
- One reason for not detecting strong correlations between Hg in bird tissues and fish Hg might be the “opportunistic” approach to sampling. Instead of focusing in one relatively small geographic area, we sampled a few nests in a broad geographic region, which increases variability in fish species composition and contributes to greater variation among values. It would be helpful to increase the sample size of nest prey for better understanding Hg concentrations in kingfisher diet. By increasing the sample size a better correlation between blood and nest prey Hg might emerge.

Recommendations and suggestions for future work

Belted Kingfisher is a ubiquitous obligate piscivore and therefore is a useful indicator of aquatic pollution. Belted Kingfisher can be used to measure, understand and diagnose ecosystem exposure, effects and recovery from contaminants.

We found one limitation during our work with the species, which is identifying the exact location of their feeding territories. To solve this problem, we can attach radio transmitters to the adults and track the birds from their known nesting sites to the foraging territories. This technology would assist in further understanding the ecology of the species and will allow a more meaningful interpretation of the laboratory results. Such work will be more labor and cost intensive, but potential identification of point sources of toxic chemicals would justify the costs.

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