MERCURY CONCENTRATIONS IN TISSUES OF FLORIDA BALD EAGLES

FINAL PROJECT REPORT

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Submitted by:

Petra Bohall Wood
West Virginia Coop. Fish and Wildlife Research Unit
West Virginia University
P.O. Box 6125
Morgantown WV 26506-6125

John White
Florida Game and Fresh Water Fish Commission
P.O. Box 1903
Eustis FL 32727

Anthony Steffer
Biological Research Associates
3910 US Highway 301 North
Suite 180
Tampa FL 33619

John M. Wood
Division of Forestry
West Virginia University
P.O. Box 6125
Morgantown WV 26506-6125

H. Franklin Percival
Florida Coop. Fish and Wildlife Reseach Unit
University of Florida
117 Newins-Ziegler Hall
Gainesville FL 32611

Submitted to:

Charles Facemire
U. S. Fish and Wildlife Service
1875 Century Blvd
Atlanta GA 30345

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INTRODUCTION

High mercury (Hg) concentrations have been documented in several aquatic systems throughout Florida (Hord et al. 1990, Royals and Lange 1990, Ware et al. 1990). As a top predator of aquatic systems, bald eagles (Haliaeetus leucocephalus) can bio-accumulate mercury resulting in elevated concentrations in tissues (Wiemeyer et al. 1984, 1989). The efficiency of mercury transfer between trophic levels is amplified at high trophic levels (Eisler 1987). Elevated mercury concentrations in adult eagles can have negative effects on productivity (Wiemeyer et al. 1984).

Mercury concentrations in species that are often found as eagle prey in Florida highlight the potential problem of bio-accumulation. Although various species of fish, including many high-level predators such as catfish (Ictalurus spp.), gar (Lepisosteus spp.), pickerel (Esox spp.), and bowfin (Amia calva) are a large part of the diet of bald eagles in Florida, they also feed extensively on all species of wading birds, coots (Fulica americana), other waterfowl, and a variety of mammals, herptiles, and other birds (P.B. Wood and A. Steffer, unpubl. data).

High concentrations of mercury have been found in liver tissue of wading birds, particularly those that feed on large fish (Table 1) (M. Spalding, pers. commun.). Mottled duck (Anas fulvigula) mercury concentrations are relatively low. This species is representative of coots, common moorhens (Gallinula chloropus) and purple gallinules (Porphyrula martinica) which also are herbivorous. Largemouth bass (Micropterus salmoides) have fairly high concentrations. Ware et al. (1990) found that 51 of 80 lakes and rivers sampled had mean mercury concentrations in bass greater than 0.5 mg/kg, a level the U.S. Food and Drug Administration (FDA) considers dangerous for human consumption. Mercury in gar and bowfin also was high, up to 7 ppm.

Prior to this study, little information was available on mercury concentrations in bald eagles in Florida. Wiemeyer et al. (1984) published data on mercury concentrations in 5 bald eagle eggs collected in Florida. With the increase of waste incinerators throughout the state and increasing mercury concentrations in many aquatic systems, it was important to obtain baseline information on bio-accumulation of mercury. Because eagles are widespread throughout the state and are a top-level predator of aquatic systems, they should be a good indicator species.

OBJECTIVES

We designed this study to determine mercury concentrations in eagles using two sources of data. First, we collected blood and feather samples from nestling bald eagles and feathers of adult eagles at specific nest sites to examine mercury concentrations in relation to characteristics of nearby lakes and to assess current concentrations of mercury in Florida eagles. Second, we obtained tissues (primarily liver) from eagle carcasses collected throughout the state of Florida as another source of data to document current concentrations.

STUDY AREA AND METHODS

We obtained samples from eagles at nests associated with 20 water bodies (18 natural lakes, 1 phosphate pond, and the Gulf of Mexico) throughout north and central Florida (Figure 1) during this study. The original plan was to collect samples during March and April from 15 nests in 4 areas (n=60) from several different river and wetland systems, with at least 4 nests located on the same lake or river system. In mid March 1993, however, a severe winter storm interrupted nesting (nestlings were blown out of nests and some nests were destroyed) at several bald eagle nests that we had planned to sample. In addition, early nesting by many pairs of eagles resulted in young that were too old to safely remove from their nest in March and April. Consequently, we collected samples from every climbable, surviving nest with nestlings of the right age and where access was granted by the landowner. The March storm also resulted in injuries to several nestling eagles that were treated at the Florida Audubon Society, Birds of Prey Center, in Maitland. We obtained samples from these birds also. We contacted the National Wildlife Health Research Center, the Florida Audubon Society Birds of Prey Center, and the Southeastern Raptor Rehabilitation Center to obtain liver, feather, and/or blood samples from eagle carcasses recovered throughout Florida.

Nestlings were the original focus of the study for several reasons. First, it is easier to collect samples from large numbers of nestlings and to tie specific nests to the nearby foraging areas of the adults. Any mercury found in nestlings would have to come from prey provided by adults. Thus, the source of mercury in nestlings can be assumed to be the nearby foraging areas of the nesting adults. Conversely, adult and subadult eagles are very difficult to capture; thus sample size would be very small. Individual subadults frequently range over a large portion of Florida, making it difficult if not impossible to pinpoint the source of any residues detected.

Each nestling was removed from its nest by a tree climber (usually A. Steffer) experienced with handling nestling eagles and lowered to the ground in a duffel bag. All measuring, banding, and sampling was completed by personnel on the ground. Each nestling was banded with a USFWS aluminum leg band on the right leg. We measured bill depth, length of the foot pad, and length of the eighth primary. We also weighed each nestling.

We collected both blood and feather samples from each of the nestlings banded. Nestling feather samples were used as a comparison for adult feather mercury concentrations. Mercury concentrations in blood are less variable than those in feathers and represent mercury obtained from prey recently ingested (S. Wiemeyer, pers. commun.). Feather mercury concentrations of nestlings represent mercury concentrated during the life of the nestling.

We removed the outer 2/3 of 5 lower breast/upper abdominal feathers from older nestlings (7-9 weeks old). Younger or less developed nestlings have somewhat smaller breast feathers, so we increased the sample to 7 feathers to obtain approximately the same amount of feather material for each bird. Body feathers provide the most representative sample for estimating mercury concentrations and show the least variation between feathers (Furness et al. 1986). Breast and abdominal feathers emerge on nestlings at about 4-6 weeks after hatch (Bortolotti 1984).

Blood samples from nestlings were drawn from the brachial vein in the right wing with a 2-cc, sterilized syringe. We collected 1-2 cc of blood per bird. A fresh syringe and needle were used for each sample. Blood samples were transferred immediately to heperinized vacuum containers and placed in a cooler while in the field. They were stored frozen until they were shipped to the analytical laboratory.

Because we could not obtain blood samples from nesting adults, we used feathers to compare mercury concentrations in adults and nestlings. We collected all adult feathers that we found on the ground in the immediate vicinity of each nest. Each feather type (primary, secondary, tertiary, and contour) was chemically analyzed as a separate sample. Eagles are territorial at their nest sites, therefore, we assummed the feathers were from the breeding pair at a given nest. Breeding adults appear to be non-migratory, thus much of the mercury present in adult feathers likely was accumulated in Florida near the breeding territory. Mercury concentrations in adult eagle feathers should be only slightly less than when the feather was molted since Appelquist et al. (1984) found a less than

10% change in mercury concentration in guillemot (Uria aalge) and black guillemot (Cepphus grylle) feathers exposed to various environmental factors for 8 months.

One objective of this study was not only to determine baseline mercury concentrations in nestling and adult eagles, but also to try to identify the lakes from which birds were obtaining mercury. We mapped the distribution of mercury concentrations in feathers of adults and nestlings by lakes. To map the distribution of feather mercury concentrations in eagles, we grouped the data into three categories: <5 ppm, 5-11 ppm, >11 ppm. We selected these cutoffs because Eisler (1987) reported that 5-11 ppm of mercury in feathers for various bird species was associated with reduced hatch and sterility. In addition, Heinz (1979) reported that 9-11 ppm mercury in mallard feathers was associated with behavioral changes and reduced reproduction. However, it is not known if mercury in feathers at these concentrations will affect eagles in the same way. We examined pH (Canfield 1981) and trophic state index (Brezonik et al. 1982) of each lake to determine whether there was any correlation between these measures and mercury bio-accumulation in bald eagles.

We recorded all prey remains found at each nest site. We also searched for fresh prey in and under each eagle nest visited. We found fresh fish at 3 nests and collected a small portion of muscle tissue for analysis of mercury contamination. The remainder of the fish was replaced in the nest. Each prey item found was ranked according to its position in the food chain based on diet information provided by F. Margraf (pers. commun.), Martin et al. (1951), and Collins (1981); 1.0 for herbivores, 2.0 for first-level carnivores, and 3.0 for higher-level carnivores. We gave carnivores a higher index to reflect the bio-accumulation of mercury in higher levels of the food chain. We assumed that aquatic prey species would bio-accumulate more than terrestrial prey species. Therefore, ranks given to terrestrial prey were adjusted by multiplying by 0.5, while aquatic prey species' ranks were not adjusted. A food-chain index was calculated for each nest that contained prey remains by averaging the ranks of all the prey species found in each nest. A nested analysis of variance (ANOVA), which adjusted for differences among lakes, was used to test the hypothesis that the concentration of mercury in the blood and feathers of nestlings is positively correlated with the trophic position of the prey found at each nest. The ANOVA included lake and food-chain index nested within lake as dependent variables. Data were log-transformed prior to analyses. Although we realize that prey remains collected at nests are not a complete picture of the diet of each pair of eagles, these food-chain indices are at least a rough approximation of the trophic level at which individual eagles are feeding.

All blood, feather, and liver samples obtained in 1993 were analyzed for mercury concentrations at Hazleton Environmental Laboratory, Inc., a laboratory approved by Patuxent Analytical Control Facility. Blood and liver samples were shipped to the analytical laboratory frozen on dry ice. The 1992 samples were analyzed by a laboratory at the School of Veterinary Medicine, University of Florida. All mercury concentrations are presented in mg/kg (ppm) wet weight. Data were analysed with PC version 6.3 of the Statistical Analysis System (SAS) on a micro-computer. Specific statistical tests used are presented in the results.

RESULTS AND DISCUSSION

We obtained blood and feather samples from nestling eagles at 33 nests on 18 lakes and adult feather samples from 20 nests on 10 lakes in 1993 (Table 2). The 1993 data included samples from 11 nestlings from 7 nests that were treated at the Florida Audubon Society, Birds of Prey Center. P. Wood and A. Steffer collected 9 samples from 5 nests on 3 lakes in 1992.

Mean mercury concentrations for nestlings were lowest in blood and highest in feathers (Table 3). Nestlings had lower mercury concentrations in feathers than adults, a result of bio-accumulation in adults over time. Adult contour feathers had a slightly higher mean level of mercury than all adult feathers combined (Table 3). However, the distribution of mercury concentrations in adult feathers was similar for contours and all feathers combined (Figure 2) (Fischer's exact test: $\chi^2 = 2.69$, $\underline{P} = 0.74$). For all further analyses, we used the concentrations in all feathers for adults because sample size was larger.

We obtained liver, feather, and/or blood samples from 33 eagle carcasses recovered throughout Florida (Table 4). Feather mercury concentrations from carcasses (Table 5) were within the range of concentrations found in adult feathers collected at nests (Table 3). Blood mercury concentrations from carcasses (Table 5) were slightly higher than that of nestlings at nests (Table 3) because carcasses were primarily adult and subadult birds. Mercury concentrations in 32 liver samples were different by age ($F = 7.17$, $\underline{P} = 0.001$), with nestlings having lowest levels (Table 5). The overall mean mercury concentration in liver was 2.56 mg/kg. The concentrations found in adult and nestling livers in Florida are well below concentrations (>20 ppm) of mercury residues found in tissues of other birds that died of mercury poisoning (Finley et al. 1979). In a review of mercury studies on birds, Ohlendorf (1993) found that <1-10 ppm of mercury in liver was considered a normal background level for birds in general by some authors, while >6 ppm was considered toxic by others. Red-tailed hawks (Buteo jamaicensis) that died of mercury poisoning had 16.7-20.0 ppm of mercury in the liver (E. Evans, pers. commun.).

To determine if mercury concentrations in Florida eagles might be cause for concern, we compared data from our study with mercury concentrations in captive eagles (Table 6). The latter can be considered representative of background levels (Ohlendorf

1993). Mean mercury concentrations in blood of captive adult eagles (0.23 ppm) was similar to that of Florida nestlings (0.20 ppm). However, some Florida nestlings had blood mercury concentrations over twice as high as captive adults, up to 0.73 ppm. Feather mercury concentrations in both nestlings and adults were considerably higher than in captive eagles (Table 6). Apparently some Florida eagles are bio-accumulating mercury to concentrations higher than background levels.

Nestling bald eagles in Florida had mean blood mercury concentrations similar to nestlings from Maine and Washington (Table 6). Nestlings from Oregon had the highest blood mercury concentrations. Feather mercury concentrations were only half that found in Maine and Great Lakes nestlings. Adult feather mercury concentrations were similar to those found in Alaska, but much lower than adults sampled on the Great Lakes. Eisler (1987) reported that 5-11 ppm of mercury in feathers for various bird species was associated with reduced hatch and sterility. Heinz (1979) reported that 9-11 ppm mercury in mallard feathers was associated with behavioral changes and reduced reproduction. Sterility was observed in sparrowhawks Accipiter nisus at 40 mg/kg of mercury in feathers (Solonen and Lodenius 1984). Liver concentrations in adult and subadult Florida eagles were higher than found in liver in Oregon eagles. Thus, Florida eagles are bio-accumulating mercury but not to the extent of Great Lakes eagle populations. It is not known, however, what effects low levels of mercury have on eagles and at what concentration eagles might become impaired resulting in death from other sources of mortality.

We obtained nestling blood and feather samples from 22 nests with 2 or 3 young (Table 2). There was no significant difference ($\overline{x}$ difference = -0.02, SE=0.02, t=0.23, P=0.82) between blood mercury concentrations in siblings using a paired-difference t-test. We also compared feather mercury concentrations in siblings and again found no significant difference ($\overline{x}$ difference = -0.11, SE=0.39, t=0.21, $P=0.83$). We then calculated mean nestling and adult feather mercury concentrations for 15 nests and compared the non-transformed data using Pearson product-moment correlation. When we excluded 1 outlier, we found a positive correlation (r=0.63, $P<0.02$) between adult and nestling feather mercury concentrations (Figure 3). Nests with high adult feather mercury concentrations had high nestling feather concentrations.

We also examined the relationship between mercury concentrations in nestling feathers and blood. A Pearson product-moment correlation on non-transformed data from both years combined was not significant (n=57, r=0.23, $P=0.08$) (Figure 4). However, the plotted data showed a pattern of 2 diverging lines. When we examined only the 1993 data and omitted 2 outliers, we found a positive correlation (n=46, r=0.81, $P=0.0001$) between nestling blood and feather mercury concentrations (Figure 5). In 1992, there was no relationship between blood and feather mercury concentrations, possibly because the 1992 samples were analyzed by a different laboratory with less sensitive equipment; the lowest concentration of mercury in nestling blood in 1992 was greater than the mean in 1993 (Table 3).

We sampled nestlings at 3 nests in both 1992 and 1993 (Figure 6) and obtained data from adult feathers at one nest (PO40) in 2 years. Statistical analyses were not performed because of small sample size. In all nestling samples, 1992 blood mercury concentrations were slightly higher; again likely the result of having 2 different labs do the chemical analyses resulting in higher detection levels for 1992 samples. At 2 nests, nestling feather mercury concentrations were somewhat higher in 1993. At one nest, AL17, the 1993 nestling feather mercury level was considerably higher than in 1992. The mercury concentration in adult feathers from nest PO40 was 5.87 mg/kg in 1991 compared to 8.84 mg/kg in 1993.

We obtained blood, feather, and liver samples from 4 eagles: 2 nestlings, a 2-year-old bird, and an adult (Figure 7). Sample size was insufficient to statistically examine relationships between mercury concentrations in these 3 tissues. In all cases, mercury concentrations were lowest in blood and highest in feathers. We obtained liver and feather samples from 9 eagles (Table 4). A Pearson product-moment correlation on non-transformed data was not significant ($r=0.13$, $\underline{P}=0.79$).

We mapped the distribution of mercury concentrations in feathers of adults (Figure 8) and nestlings (Figure 9) by lakes to identify the source of mercury. Four water bodies (Gulf, Kissimmee, Lochloosa, and Russell) had mean adult feather mercury concentrations greater than 11 ppm (Figure 8, Table 7), although some individual nests at other lakes also had adult feather mercury concentrations >11 ppm (Table 8). High adult feather mercury concentrations were not consistently associated with any one lake or region, although the Gulf ($n=1$) sample was the highest overall.

Data on mercury concentrations in fish on the lakes we sampled was limited primarily to bass. Although eagles rarely feed on bass, we assumed that mean bass mercury concentrations at lakes sampled by Ware et al. (1990) were an indicator of mercury concentrated within other fish species in these lakes. For example, if bass mercury concentrations were low on a given lake, we expected other fish species to have relatively low mercury levels. However, bass mercury concentrations did not correlate well with adult feather mercury concentrations (Figure 8). For example, lakes associated with the Kissimmee River system had moderate levels of mercury in bass (0.5-1.5 ppm) while feather mercury concentrations for adult eagles fell into all 3 categories. We found a similar pattern with nestling feather mercury concentrations (Figure 9). The fish data may not be directly comparable with our eagle data because samples were not collected at the same time and they were not analyzed at the same laboratory; however, the basic trends should have remained the same. Consequently, sampling only fish populations did not provide an accurate estimate of the trends in mercury concentrations in eagles in this study. Futhermore, as mentioned earlier, Florida eagles have an extremely varied diet that includes much non-fish prey, particularly wading birds. Consequently, we were not suprised to find no relationship between eagle and bass mercury concentrations.

We further examined mercury concentrations in relation to the food-chain index developed from prey remains found at nests. We found prey remains in 22 of the 33 nests visited in 1993 (Tables 8 and 9), representing 10 lakes. A nested ANOVA of mercury concentrations in blood and contour feathers of nestlings at the 22 nests with prey remains indicated a significant overall relationship with food-chain index within a lake (blood: $F=3.35$, $\underline{P}=0.02$; feather: $F=3.84$, $\underline{P}=0.01$). The trend at 4 lakes, those with greater than 2 nests per lake, is shown in Figures 10 and 11. Nestling blood mercury concentrations (Figure 10) at Lake Jackson and Orange Lake were significantly different at some of the nests with varying food-chain indices, but concentrations were not positively correlated with food-chain index. The correlation with nestling blood at Lake Jackson was negative, the opposite of expected. Nestling feather mercury concentrations at Orange Lake (Figure 11) were higher ($\underline{P} < 0.05$) at the nest with the highest food-chain index; this was the only positive correlation we observed. A nested ANOVA on mercury concentrations in adult feathers collected at 10 nests did not show a significant relationship with food-chain index within a lake ($F=2.14$, $\underline{P}=0.18$). We might see a more consistent relationship between mercury concentrations and food-chain index if data collected on prey remains at each nest were more complete.

Two other factors that can affect mercury concentrations are pH and trophic state. In high pH, eutrophic systems, mercury is less available for uptake by living organisms (Eisler 1987). Mercury concentrations in adult and nestling feathers were not correlated with pH or trophic state index (TSI) using Pearson product-moment correlations on non-transformed data (Table 10). Mercury concentrations in nestling blood were correlated significantly with pH and TSI. However, the correlations were weak as indicated by low r values. Low blood mercury concentrations were associated with higher pH, eutrophic systems. In general, mercury concentrations in all samples were higher in mesotrophic systems than in eutrophic systems (Table 11), although only nestling blood samples were significantly different (Student's t-test: $t=-2.61$, $P=0.01$). Similarly, Ware et al. (1990) and Lange et al. (1993) found lower mercury concentrations in bass in high pH, eutrophic systems. It is possible that feather mercury concentrations did not show a significant correlation because of a much greater variation in feather than in blood mercury concentrations.

To obtain information on historic concentrations of mercury in Florida bald eagles, we contacted 13 museums throughout the United States for feather samples from Florida eagle specimens. Six museums provided feathers from the lower breast/upper abdomen of 20 specimens collected in Florida between 1885 and 1977 (Table 12). We thought that mercury concentrations in these feather samples would provide a historical perspective on changes in environmental levels over time when compared to the mercury concentrations of feathers collected from adults at nest sites during this study. However, information provided by R. Payne, University of Michigan Museum of Zoology suggests that inorganic mercury salts may have been used in the preparation of older specimens. Newer specimens stored with older specimens also may have become contaminated. Hawks and Williams (1986) provide extensive documentation of the use of mercury on natural history specimens, including bird skins, in the 1800's. Although it is likely that few of the specimens we obtained were treated with mercury, we cannot be sure and cannot use these data.

SUMMARY AND RECOMMENDATIONS

Mercury concentrations in Florida eagles are above background levels, but lower than those found in other populations. Studies on other bird species suggest that concentrations in Florida eagles are below those that cause outright mortality but are within the range of concentrations that can cause behavioral changes or reduce reproduction. However, it has not been determined what effects these concentrations of mercury actually have on behavior, reproduction or survival in eagles. Sublethal effects of mercury on birds can include adverse effects on growth, development, reproduction, blood and tissue chemistry, metabolism, and behavior (Eisler 1987). All of these sublethal effects can make eagles more prone to other sources of mortality. Retarded growth or development of nestlings, for example, might affect their survival. Wood (1992) found that the older sibling in 2-chick nests had significantly higher survival, probably because it monopolized food resources and became energetically fit more quickly. Thus, rapid development appears to enhance survival.

Because mercury concentrations are increasing in the environment, we recommend initiation of a monitoring program at specific nest sites to track changes in feather mercury in eagles. Although feather mercury concentrations are more variable than those in blood, feather and blood levels were significantly correlated. Mercury concentrations in feathers of nestlings and adults are highly correlated, thus collecting adult feathers at nest sites will be representative for adults and nestlings.

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Table 1. Mercury (Hg) concentrations (mg/kg) in potential prey of bald eagles in Florida.

Prey type	Tissue	Hg (mg/kg) $\bar{x}$	Hg (mg/kg) Range
Wading birds[a]			
large-fish eaters	liver	1.39	0.18 - 74.5
small-fish eaters	liver	0.73	0.12 - 5.38
small-fish/invertebrate eaters	liver	0.64	0.05 - 5.38
Mottled duck[b]	muscle	0.02	
Largemouth bass[b]	muscle		0.08 - 4.4
Bowfin, gar[b]	muscle		0.50 - 7.0

[a] Source: M.G. Spalding, University of Florida (unpublished data).
[b] Source: Ware et al. (1990).

Table 2. Sample size of tissues collected from adult and nestling bald eagles and their prey at nests in Florida, 1991-1993.

Water Body [a]	Nest	Nestling Feather	Nestling Blood	Nestling Liver	Adult Feather	Prey
1991 [b]						
Phosphate [c]	PO40				3	
1992						
George	PU18	1	1		1	
Orange	AL17	3	3		1	
	AL24A	2	2			
Tohopekaliga	OS54	2	2		3	
	OS83	1	1			
Subtotal (1992)		9	9	0	5	0
1993						
Cypress	OS65	2	2		3	
	OS68	1	1		2	
George	VO29A	2	2			
Gulf [d]	PI17				1	
Harney	SE20 [e]	1				
Jackson	OS100	1	1		1	
	OS35	1	1			
	OS41	1	1		1	
Jessup	SE02 [e]	2	2			
Kissimmee	OS20	2	2			
	OS90	1	1			
	PO78	2	2			
	PO84	1	1		2	
	PO87	2	2		1	
Lochloosa	ALLE				1	

Table 2. Continued.

Water Body [a]	Nest	Nestling Feather	Nestling Blood	Nestling Liver	Adult Feather	Prey
Marion	OS14				1	
	OS33	1	1		1	1
	OS45A	1	1		1	
	OS51	1	1		2	
Myakka	SA17 [e]	1				
Orange	AL17	2	2			
	AL24A	1	1			
	MR111	2	2		3	
	MRP	2	2			
Parker	PO49 [e]	2	2	1		
Phosphate [c]	PO40				2	
	PO115 [e]	1	1			
Pierce	PO82	2	2		2	
Russell	OS85	2	2		1	1
Tohopekaliga	OS31	1	1			
	OS36	2	2			
	OS54	2	2			
	OS72	2	2			
Washington	BE37 [e]	2	2	1		
Wauberg	AL40	2	2			
Weohyakapka	PO98	2	2			1
Woodruff	VO1 [e]	2				
Subtotal (1993)		52	48	2	25	3
Total		61	57	2	33	3

[a] The water body is a natural lake, unless indicated otherwise.
[b] C. Facemire, USFWS, unpublished data.
[c] Pond in a reclaimed surface-mine.
[d] Gulf of Mexico, Tampa Bay Area.
[e] Samples from nestlings treated at Florida Audubon Society, Birds of Prey Center.

Table 3. Mean mercury (Hg) concentrations (mg/kg) in tissues collected from nestling and adult bald eagles at nests in Florida, 1991-1993.

	Tissue	Hg (mg/kg)			
		n	$\overline{x}$	GM[a]	range
1991[b]					
Adult	all feathers	3	5.87	4.93	2.12 - 9.60
1992					
Nestling	blood	9	0.41	0.38	0.23 - 0.73
	contour feathers	9	1.65	1.51	0.76 - 3.13
Adult	contour feathers	1	2.01		
	all feathers	5	1.70	0.73	0.10 - 5.03
1993					
Nestling	blood	48	0.17	0.13	0.02 - 0.61
	contour feathers	52	4.46	3.68	0.87 - 14.30
Adult	contour feathers	12	12.30	10.13	4.70 - 34.70
	all feathers	25	10.95	9.43	4.00 - 34.70
1991-1993					
Nestling	blood	57	0.20	0.16	0.02 - 0.73
	contour feathers	61	4.05	3.23	0.76 - 14.30
Adult	contour feathers	13	11.51	8.95	2.01 - 34.70
	all feathers	33	9.09	6.03	0.10 - 34.70

[a] GM=geometric mean.
[b] C. Facemire, USFWS, unpublished data.

Table 4. Mercury (Hg) concentrations (mg/kg) from liver, feather, and blood samples of recovered dead bald eagles in Florida and Georgia. Samples were supplied by the National Wildlife Health Research Center, unless indicated otherwise.

Year	County	City or Place	Sex	Age[a]	Hg (mg/kg) Liver	Feather	Blood
91	Alachua		M	N	1.01	.	.
92	Alachua		F	A	2.38	.	.
93	Alachua		F	A	5.43	.	.
93	Alachua		M	I	0.35	.	.
93	Brevard	Lake Washington [b]	U	N	0.45	5.90	0.14
93	Hernando	Weeki Wachee Spring	F	N	0.21	.	.
93	Highlands		M	A	5.10	.	.
91	Hillsborough	Tampa	M	A	0.63	.	.
93	Lake		F	A	0.64	5.50	.
92	Manatee	Parrish	M	S	1.51	.	.
93	Manatee	near landfill	F	I	4.82	.	.
93	Marion	Belleville	M	A	4.46	9.37	.
88	Monroe	Gulf of Mexico	F	I	3.15	.	.
90	Orange		F	S	0.86	.	.
92	Orange		M	A	2.32	.	.
87	Osceola	Kissimmee	F	S	2.15	7.16	.
91	Osceola	Nittaw	F	A	1.71	6.30	.
92	Osceola	Interstate 75	M	A	1.24	12.20	0.74
93	Osceola	Three Lakes WMA [b]	F	I	1.77	7.26	1.35
93	Osceola		F	A	12.20	.	.
93	Osceola	Kenansville	M	A	7.00	.	.
93	Pasco		M	N	0.30	.	.
91	Pinellas		M	A	1.04	.	.
91	Polk		M	A	1.40	.	.
92	Polk	Lake Wales	F	I	4.44	.	.
92	Polk	Lake Wales	M	A	1.97	.	.
92	Polk	Frostproof	F	A	1.07	.	.
92	Polk		M	S	3.11	.	.
92	Polk	Lake Wales	M	S	0.95	.	.
93	Polk	Lake Parker [b]	U	N	0.14	2.38	0.06
90	Sarasota		F	A	2.84	.	.
93	Volusia	in county landfill	U	I	5.24	4.21	.
93	Warren	Georgia [c]	M	A	.	13.70	0.85

[a] Age catagories: adult (A); subadult (S); immature (I); nestling (N).
[b] Sample obtained from Florida Audubon Society, Birds of Prey Center.
[c] Sample obtained from Southeastern Raptor Rehabilitation Center.

Table 5. Mercury (Hg) concentrations (mg/kg) in bald eagle liver from carcasses collected in Florida, 1987-1993.

Tissue	Hg (mg/kg)			
	n	$\bar{x}$	GM [a]	range
Feather	10	7.40	6.64	2.38 - 13.70
Blood	5	0.63	0.38	0.07 - 1.35
Liver	32	2.56	1.60	0.14 - 12.20
Adult	16	3.21	2.25 A [b]	0.63 - 12.20
Subadult	5	1.72	1.53 A	0.86 - 3.11
Immature	6	3.29	2.45 A	0.35 - 5.42
Nestling	5	0.42	0.33 B	0.14 - 1.01

[a] GM = geometric mean.
[b] Within a column, geometric means with the same letter are not significantly different ($\underline{P}>0.05$, Waller-Duncan K-ratio t-test).

Table 6. Mercury (Hg) concentrations (mg/kg) in tissues of bald eagles in Florida and from other populations.

Age[a]	Tissue	Hg (mg/kg) $\bar{x}$	Hg (mg/kg) Range	Location	Source
CAPTIVE BIRDS					
A	Feathers				
	-artificial diet	<0.1		Mich. Zoos	E. Evans (pers. comm.)
	-semi-natural diet		0.80-3.80	Mich. Zoos	E. Evans (pers. comm.)
	Blood	0.23	0.17-0.31	Patuxent	Wiemeyer et al. (1989)
WILD BIRDS					
A	Feathers	8.10		Alaska	E. Evans (pers. comm.)
		9.09	0.10-34.70	Florida	Wood et al. (this study)
		21.90		Great Lakes	E. Evans (pers. comm.)
	Blood	2.28	1.76-2.96	Oregon	Frenzel & Anthony (1989)
AS	Liver	1.89	0.92-3.90	Oregon	Frenzel & Anthony (1989)
		2.56	0.14-12.20	Florida	Wood et al. (this study)
N	Feathers	4.05	0.76-14.30	Florida	Wood et al. (this study)
		9.30		Great Lakes	E. Evans (pers. comm.)
		9.47	1.13-33.29	Maine	USFWS (1992)
	Blood	0.20	0.02-0.73	Florida	Wood et al. (this study)
		0.23	0.01-1.10	Maine	USFWS (1992)
		0.23	0.07-0.65	Washington	Wiemeyer et al. (1989)
		1.20	nd[b] - 4.20	Oregon	Wiemeyer et al. (1989)
	Liver	0.42	0.14-1.01	Florida	Wood et al. (this study)

[a] Age catagories: adult (A); adult and subadult (AS); nestling (N).
[b] Below detection limit of equipment (i.e., not detected).

Table 7. Mean mercury (Hg) concentrations (mg/kg) from bald eagles and their prey in Florida, and chemical characteristics of the associated water bodies.

		Adult Feather Hg			Nestling Feather Hg			Nestling Blood Hg			Prey			
Water Body [a]	Year	n [b]	$\bar{x}$	Range	n [c]	$\bar{x}$	Range	n [c]	$\bar{x}$	Range	Hg[d]	pH	TS[e]	TSI[f]
Cypress	93	5	9.87	4.00-19.30	3	6.64	5.27-7.68	3	0.18	0.16-0.20	.	7.81	E	76.1
George	92	1	1.20		1	0.85		1	0.23		.	8.43	E	67.6
	93	0	.		2	1.72	1.56-1.87	2	0.06	0.06-0.07	.	8.43	E	67.6
Gulf [g]	93	1	34.70		0	.		0	.		.	.		.
Harney	93	0	.		1	3.45		0	.		0.74	.	M	45.8
Jackson	93	2	10.11	8.81-11.40	3	3.43	2.96-4.35	3	0.14	0.06-0.24	.	.	E	67.4
Jessup	93	0	.		2	1.26	0.86-1.66	2	0.04	0.03-0.05	.	8.37	E	83.5
Kissimmee	93	3	12.16	7.29-16.10	9	5.98	1.24-8.85	8	0.18	0.10-0.26	0.63	7.92	M	58.9
Lochloosa	93	1	19.80		0	.		0	.		.	7.37	E	66.5
Marion	93	5	8.04	4.70-17.60	3	2.77	1.97-4.35	3	0.07	0.06-0.08	0.05[h]	7.83	E	70.4
Myakka	93	0	.		1	2.80		0	.		0.60	7.55	M	50.2
Orange	92	1	5.03		5	1.36	0.76-1.70	5	0.50	0.27-0.73	0.25	7.20	M	58.8
	93	3	9.08	5.07-13.90	7	3.86	2.09-8.78	7	0.16	0.02-0.25	0.25	7.20	M	58.8
Parker	93	0	.		2	2.27	2.15-2.38	2	0.08	0.07-0.10	0.10	8.93	E	79.1
Phosphate [i]	93	2	8.84	7.09-10.60	1	3.93		1	0.23		0.41[j]	.		.
Pierce	93	2	7.07	5.59-8.55	2	5.86	5.85-5.86	2	0.16	0.13-0.18	.	7.79	M	59.0
Russell	93	1	13.9		2	12.55	10.80-14.30	2	0.43	0.38-0.49	0.08[k]	.	E	64.2

Table 7. Continued.

Water Body [a]	Year	Adult Feather Hg n [b]	Adult Feather Hg x̄	Adult Feather Hg Range	Nestling Feather Hg n [c]	Nestling Feather Hg x̄	Nestling Feather Hg Range	Nestling Blood Hg n [c]	Nestling Blood Hg x̄	Nestling Blood Hg Range	Prey Hg [d]	pH	TS [e]	TSI [f]
Tohopekaliga	92	3	0.76	0.10-2.01	3	2.41	1.82-3.13	3	0.32	0.27-0.36	0.67	8.07	E	68.9
	93	0	.		7	3.39	2.63-4.32	7	0.13	0.07-0.21	0.67	8.07	E	68.9
Washington	93	0	.		2	5.85	5.79-5.90	2	0.17	0.14-0.20	.	7.84	M	59.3
Wauberg	93	0	.		2	0.97	0.96-0.99	2	0.07	0.06-0.07	.	7.77	E	71.2
Weohyakapka	93	0	.		2	7.09	3.48-10.70	2	0.56	0.52-0.61	0.01 [l]	7.03	M	51.9
Woodruff	93	0	.		2	2.52	2.48-2.55	0	.		.	7.20	E	.

[a] Water body is a natural lake, unless indicated otherwise.
[b] Number of feather samples.
[c] Number of individual nestlings.
[d] Concentrations in largemouth bass (Micropterus salmoides) reported by Ware et al. (1990), unless otherwise indicated.
[e] Trophic State (TS) of the lake; Mesotrophic (M) or Eutrophic (E). Source: Brezonik et al. (1982).
[f] Trophic State Index (TSI) of the Lake; TSI > 60 = Eutrophic. Source: Brezonik et al. (1982).
[g] Gulf of Mexico, Tampa Bay Area.
[h] Fresh redear sunfish (Lepomis microlophus) that we collected at nest OS33.
[i] Pond in a reclaimed surface-mine.
[j] USFWS unpublished data for largemouth bass.
[k] Fresh black crappie (Pomoxis nigromaculatus) that we collected at nest OS85.
[l] Fresh bluegill (Lepomis macrochirus) that we collected at nest PO98.

Table 8. Mercury (Hg) concentrations (mg/kg) in adult bald eagle feathers collected in or on the ground adjacent to nests in Florida, March and April 1993.

Water Body [a]	Year	Nest	Foodchain Index [b]	Feather Type [c]	Hg (mg/kg) Feather	Hg (mg/kg) $\bar{x}$ of Nest
Cypress	93	OS65	1.33	C	19.30	13.27
				S	8.41	
				T	12.10	
		OS68	1.40	C	5.57	4.79
				T	4.00	
George	92	PU18	.	U	1.20	1.20
Gulf [d]	93	PI17	2.67	C	34.70	34.70
Jackson	93	OS100	3.00	T	11.40	11.40
		OS41	1.66	P	8.81	8.81
Kissimmee	93	PO84	1.25	C	7.29	11.70
				S	16.10	
		PO87	1.75	C	13.10	13.10
Lochloosa	93	ALLE	0.75	C	19.80	19.80
Marion	93	OS14	.	C	6.30	6.30
		OS33	.	C	4.70	4.70
		OS45A	2.00	S	17.60	17.60
		OS51	.	C	6.80	5.79
				P	4.79	
Orange	92	AL17	.	U	5.03	5.03
	93	MR111	1.66	C	13.90	9.08
				S	5.07	
				T	8.27	
Phosphate [e]	91	PO40	.	U [f]	5.90	5.87
				U [f]	9.60	
				U [f]	2.11	

Table 8. Continued.

Water Body [a]	Year	Nest	Foodchain Index [b]	Feather Type [c]	Hg (mg/kg) Feather	$\bar{x}$ of Nest
Phosphate [e]	93	PO40	2.00	C	10.60	8.84
				T	7.09	
Pierce	93	PO82	2.00	C	5.59	7.07
				S	8.55	
Russell	93	OS85	1.63	T	13.90	13.90
Tohopekaliga	92	OS54	.	C	2.01	0.76
				P	0.10	
				S	0.17	

[a] Water body is a natural lake, unless indicated otherwise.
[b] Average of all prey remains ranked by their position in the food chain (herbivore, first-level carnivore, or higher-level carnivore) and weighted by habitat (terrestrial or aquatic). A period indicates that prey remains were not found at that nest.
[c] Feather types collected: contour (C), primary (P), secondary (S), tertiary (T), and unidentified (U).
[d] Gulf of Mexico, Tampa Bay Area.
[e] Pond in a reclaimed surface-mine.
[f] U. S. Fish & Wildlife Service (unpublished data).

Table 9. Continued.

Water Body[a]	Year	Nest	Foodchain Index[sup]b	ID Number[sup]c	Ha (ma/kg Feather	Blood	Liver
Myakka	93	SA17	.	208	2.80	.	.
Orange	92	AL17	.	16982	1.70	0.50	.
				16983	1.62	0.73	.
				16984	0.76	0.64	.
		AL24A	.	16985	1.28	0.36	.
				16986	1.42	0.27	.
	93	AL17	2.07	16812	8.78	0.25	.
				16813	6.99	0.21	.
		AL24A	1.30	16831	2.31	0.25	.
		MR111	1.66	16829	2.09	0.09	.
				16830	2.45	0.02	.
		MRP	1.50	16810	2.10	0.17	.
				16811	2.29	0.11	.
Parker	93	PO49		115	2.38	0.07	0.14
				116	2.15	0.10	.
Phosphate[sup]d	93	PO11S		133	3.93	0.23	.
Pierce	93	PO82	2.00	16820	5.85	0.13	.
				16821	5.86	0.18	.
Russell	93	OS85	1.63	16816	10.80	0.38	.
				16817	14.30	0.48	.
Tohopekaliga	92	OS54	.	16989	3.13	0.27	.
				16990	1.82	0.36	.
		OS83	.	16988	2.27	0.34	.

Table 9. Mercury (Hg) concentrations (mg/kg) from individual nestling bald eagles in Florida, March and April 1992 and 1993.

Water Body [a]	Year	Nest	Foodchain Index [b]	ID Number [c]	Hg (mg/kg) Feather	Blood	Liver
Cypress	93	OS65	1.33	16993	6.99	0.18	.
				16994	5.27	0.16	.
		OS68	1.40	16995	7.68	0.20	.
George	92	PU18	.	16987	0.85	0.23	.
	93	VO29A	.	16991	1.56	0.06	.
				16992	1.87	0.07	.
Harney	93	SE20	.	170	3.45	.	.
Jackson	93	OS100	3.00	16823	4.35	0.11	.
		OS35	1.00	16825	2.96	0.24	.
		OS41	1.66	16824	2.98	0.06	.
Jessup	93	SE02	.	101	0.86	0.05	.
				102	1.66	0.04	.
Kissimmee	93	OS20	.	16996	8.85	0.19	.
				16997	6.62	0.21	.
		OS90	1.71	16826	8.51	0.26	.
		PO78	2.00	16818	4.66	0.10	.
				16819	4.62	0.12	.
		PO84	1.25	16809	4.38	0.13	.
		PO87	1.75	16805	8.26	0.20	.
				16806	6.65	0.21	.
Marion	93	OS33	.	16802	1.97	0.07	.
		OS45A	2.00	16803	1.99	0.08	.
		OS51	.	16804	4.35	0.07	.

Table 9. Continued.

Water Body [a]	Year	Nest	Foodchain Index [b]	ID Number [c]	Hg (mg/kg) Feather	Blood	Liver
Myakka	93	SA17	.	208	2.80	.	.
Orange	92	AL17	.	16982	1.70	0.50	.
				16983	1.62	0.73	.
				16984	0.76	0.64	.
		AL24A	.	16985	1.28	0.36	.
				16986	1.42	0.27	.
	93	AL17	2.07	16812	8.78	0.25	.
				16813	6.99	0.21	.
		AL24A	1.30	16831	2.31	0.25	.
		MR111	1.66	16829	2.09	0.09	.
				16830	2.45	0.02	.
		MRP	1.50	16810	2.10	0.17	.
				16811	2.29	0.11	.
Parker	93	PO49	.	115	2.38	0.07	0.14
				116	2.15	0.10	.
Phosphate [d]	93	PO115	.	133	3.93	0.23	.
Pierce	93	PO82	2.00	16820	5.85	0.13	.
				16821	5.86	0.18	.
Russell	93	OS85	1.63	16816	10.80	0.38	.
				16817	14.30	0.48	.
Tohopekaliga	92	OS54	.	16989	3.13	0.27	.
				16990	1.82	0.36	.
		OS83	.	16988	2.27	0.34	.

Table 9. Continued.

Water Body [a]	Year	Nest	Foodchain Index [b]	ID Number [c]	Hg (mg/kg) Feather	Blood	Liver
Tohopekaliga	93	OS31	1.13	16816	4.32	0.12	.
		OS36	0.75	16801	2.75	0.20	.
				17000	2.63	0.13	.
		OS54	2.00	16998	3.04	0.14	.
				16999	3.51	0.07	.
		OS72	1.33	16827	3.54	0.14	.
				16828	3.94	0.10	.
Washington	93	BE37	.	123	5.90	0.14	0.45
				124	5.79	0.20	.
Wauberg	93	AL40	1.08	16814	0.99	0.06	.
				16815	0.96	0.07	.
Weohyakapka	93	PO98	1.90	16807	3.48	0.52	.
				16808	10.70	0.61	.
Woodruff	93	VO1	.	128	2.48	.	.
				129	2.55	.	.

[a] Water body is a natural lake, unless indicated otherwise.
[b] Average of all prey remains ranked by their position in the food chain (herbivore, first-level carnivore, or higher-level carnivore) and weighted by habitat (terrestrial or aquatic). A period indicates that prey remains were not found at that nest.
[c] Five-digit numbers are U.S. Fish & Wildlife Service band numbers. Three-digit numbers are Florida Audubon Society, Birds of Prey Center, identification numbers.
[d] Pond in a reclaimed surface-mine.

Table 10. Sample size (n), Pearson product-moment correlations (r), and probability of significance (P) of lake pH and trophic state index (TSI) with mercury (Hg) concentrations (mg/kg) in bald eagle tissues collected at nests in Florida, March and April 1992 and 1993.

	pH			TSI		
Bald eagle tissue	n	r	P	n	r	P
Adult feathers	24	-0.32	0.12	27	-0.07	0.73
Nestling feathers	54	-0.10	0.48	58	-0.25	0.06
Nestling blood	51	-0.53	0.0001	56	-0.47	0.0003

Table 11. Mercury (Hg) concentrations (mg/kg) in blood and feathers of Florida bald eagles from nests on eutrophic and mesotrophic systems, 1992 and 1993.

	n	$\bar{x}$ [a]	GM [b]	range
Adult feathers				
Eutrophic	18	8.16 A	4.60 A	0.10 - 19.80
Mesotrophic	9	9.21 A	8.43 A	5.03 - 16.10
Nestling feathers				
Eutrophic	32	3.53 A	2.79 A	0.85 - 14.30
Mesotrophic	28	4.65 A	3.78 A	0.76 - 10.70
Nestling blood				
Eutrophic	30	0.16 B	0.12 B	0.04 - 0.48
Mesotrophic	26	0.26 A	0.20 A	0.02 - 0.73

[a] Means followed by the same letter within a pair are not significantly ($P < 0.05$) different, based on the Student's *t*-statistic.
[b] GM = geometric mean.

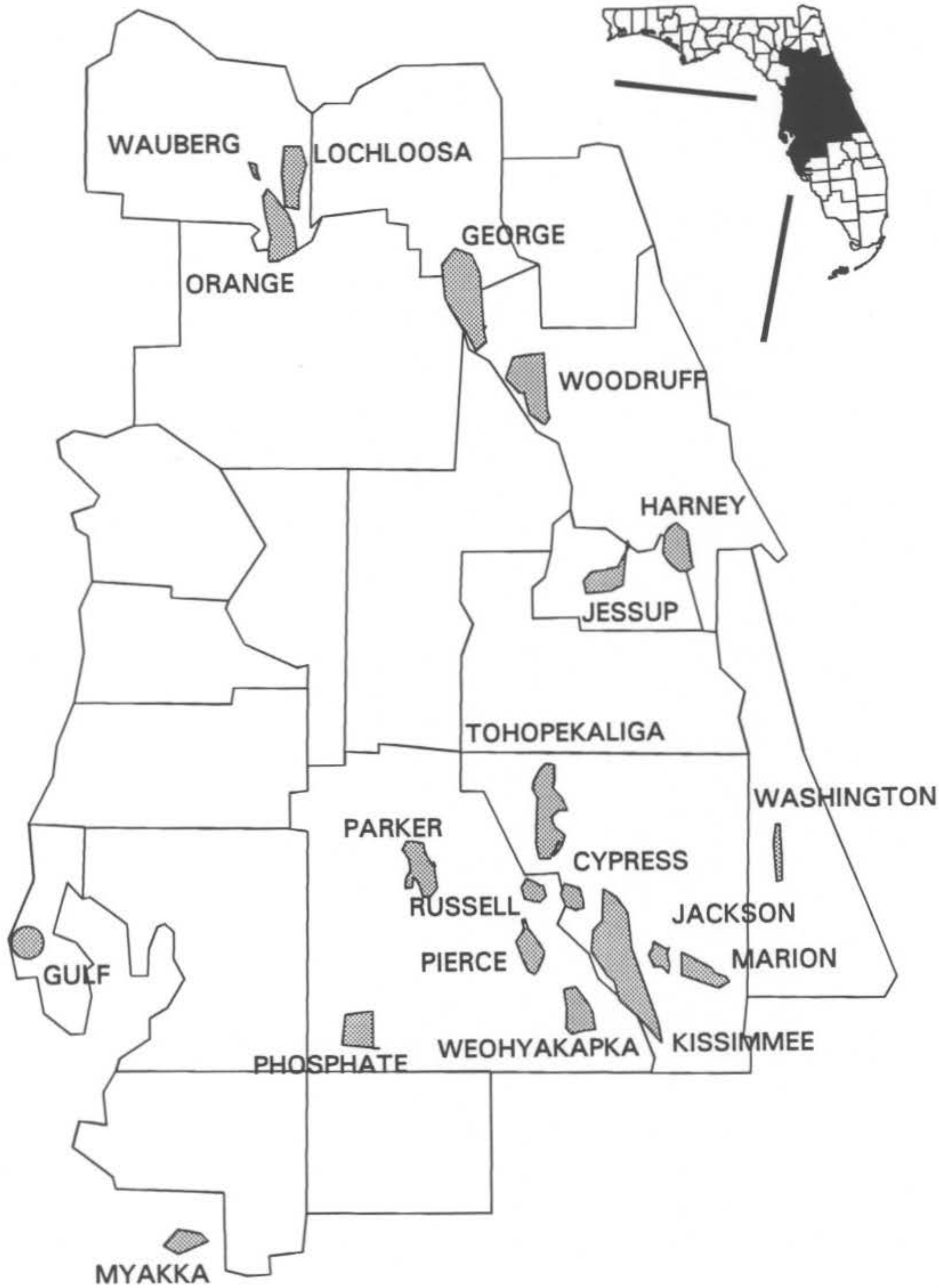

Figure 1. Florida lakes and water bodies where samples were collected at bald eagle nests, March and April, 1992 and 1993.

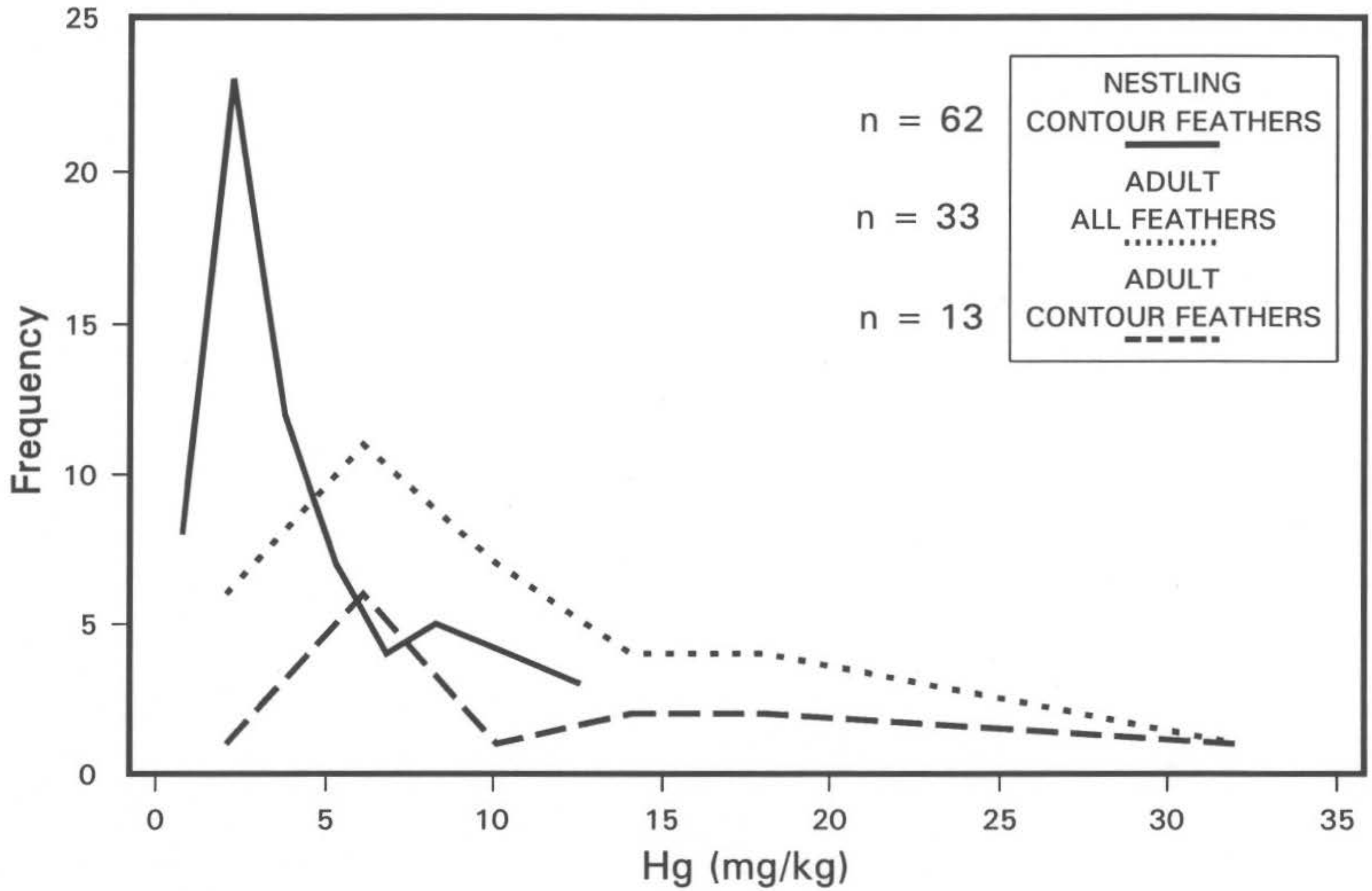

Figure 2. Distribution of mercury concentrations (mg/kg) in tissues collected from nestling and adult bald eagles at nests in Florida, March and April, 1992 and 1993.

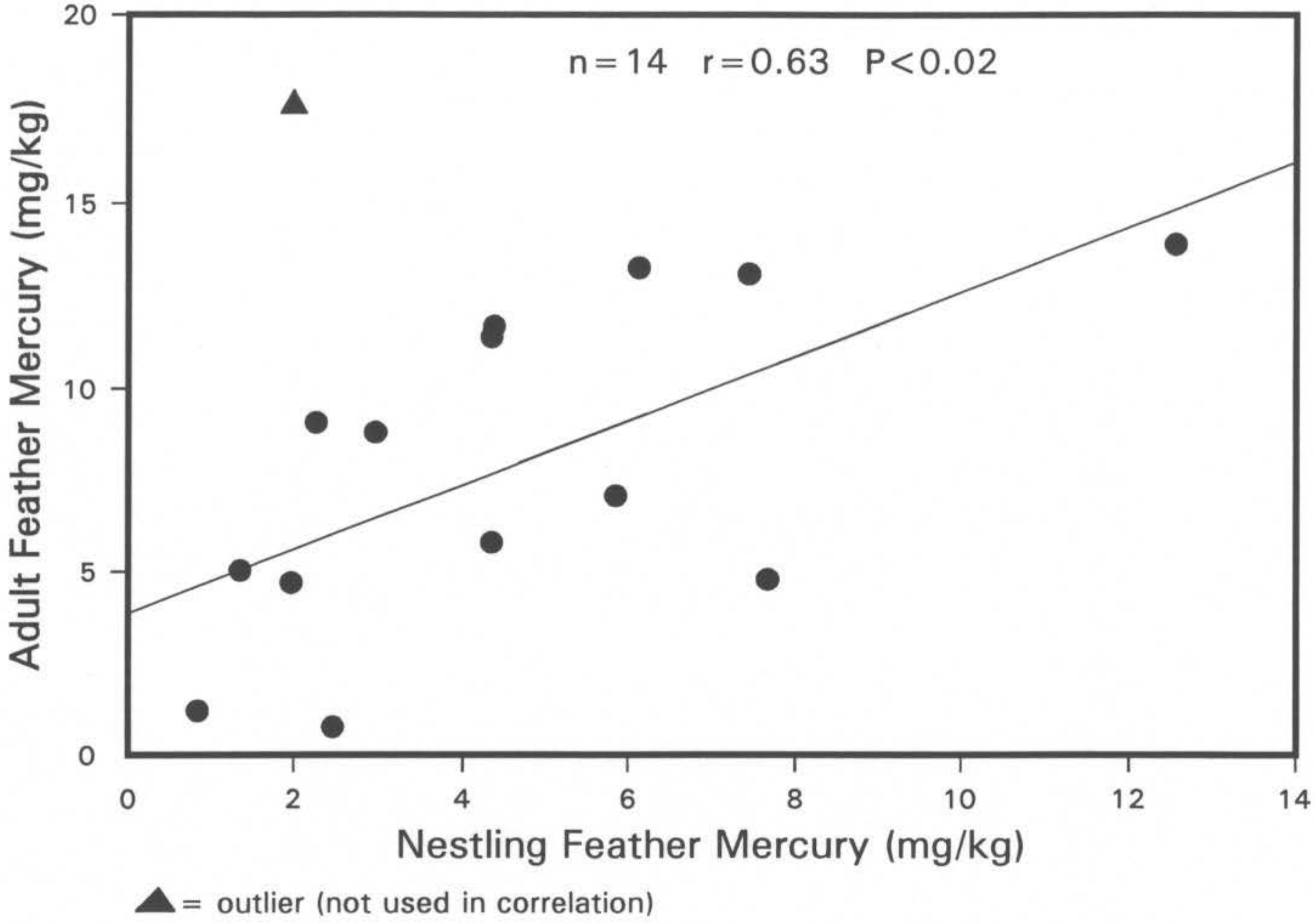

Figure 3. Pearson product-moment correlation between nestling and adult bald eagle feather mercury concentrations (mg/kg). Feathers collected at Florida nests, March and April, 1992 and 1993.

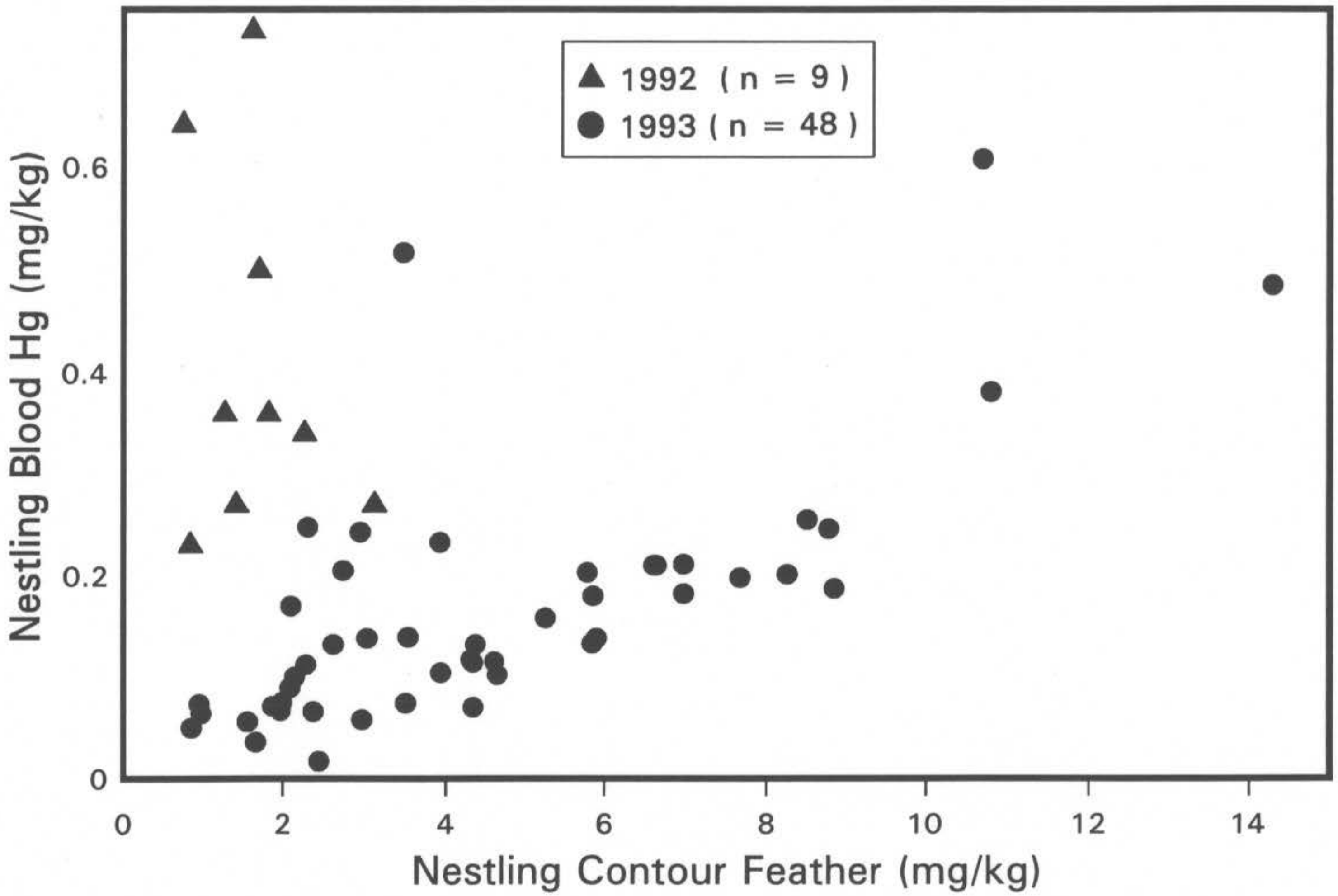

Figure 4. Relationship between nestling bald eagle contour feather and blood mercury concentrations (mg/kg). Samples collected at Florida nests, March and April, 1992 and 1993.

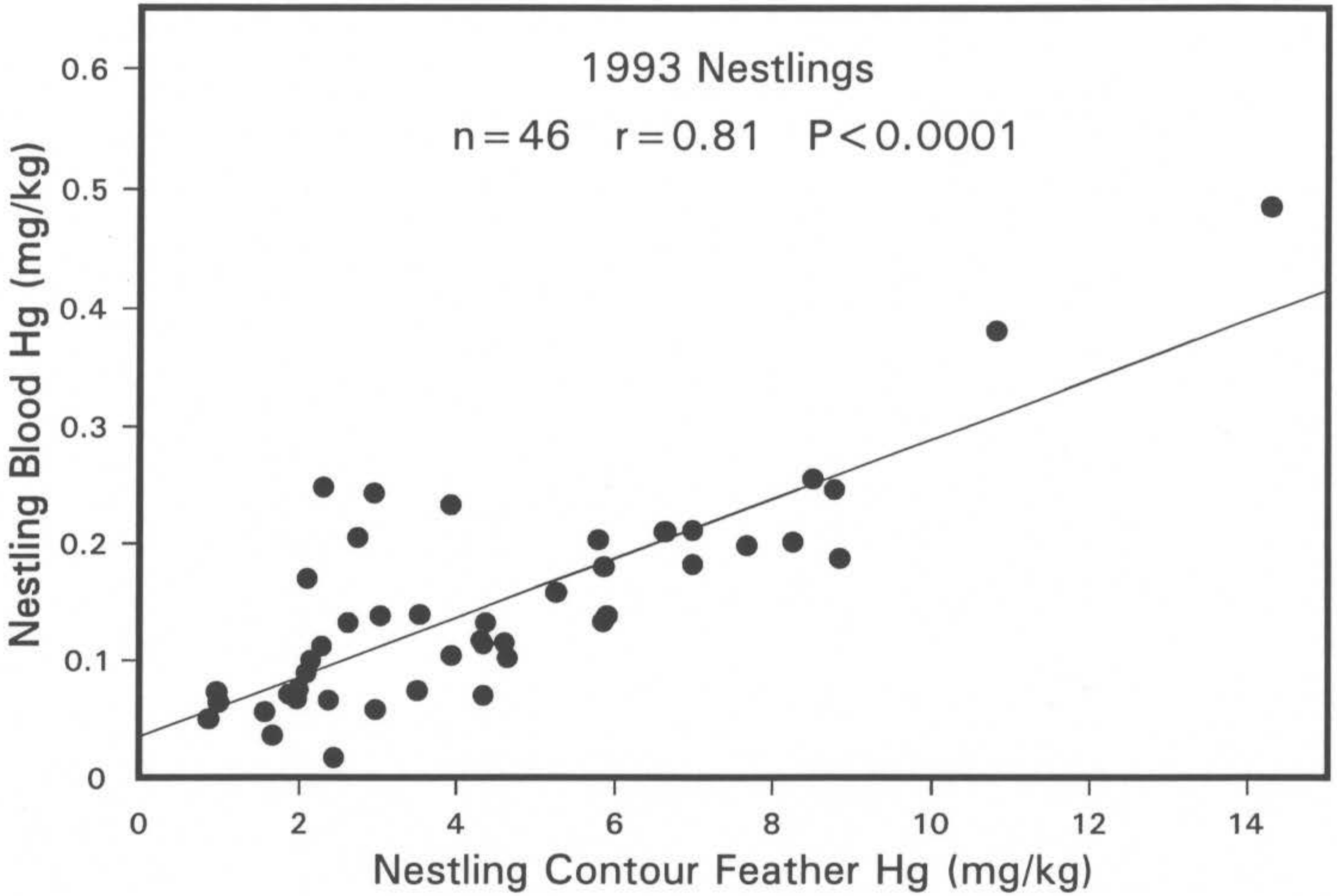

Figure 5. Linear regression of mercury concentrations (mg/kg) in nestling bald eagle contour feather and blood samples collected at Florida eagle nests, March and April 1993.

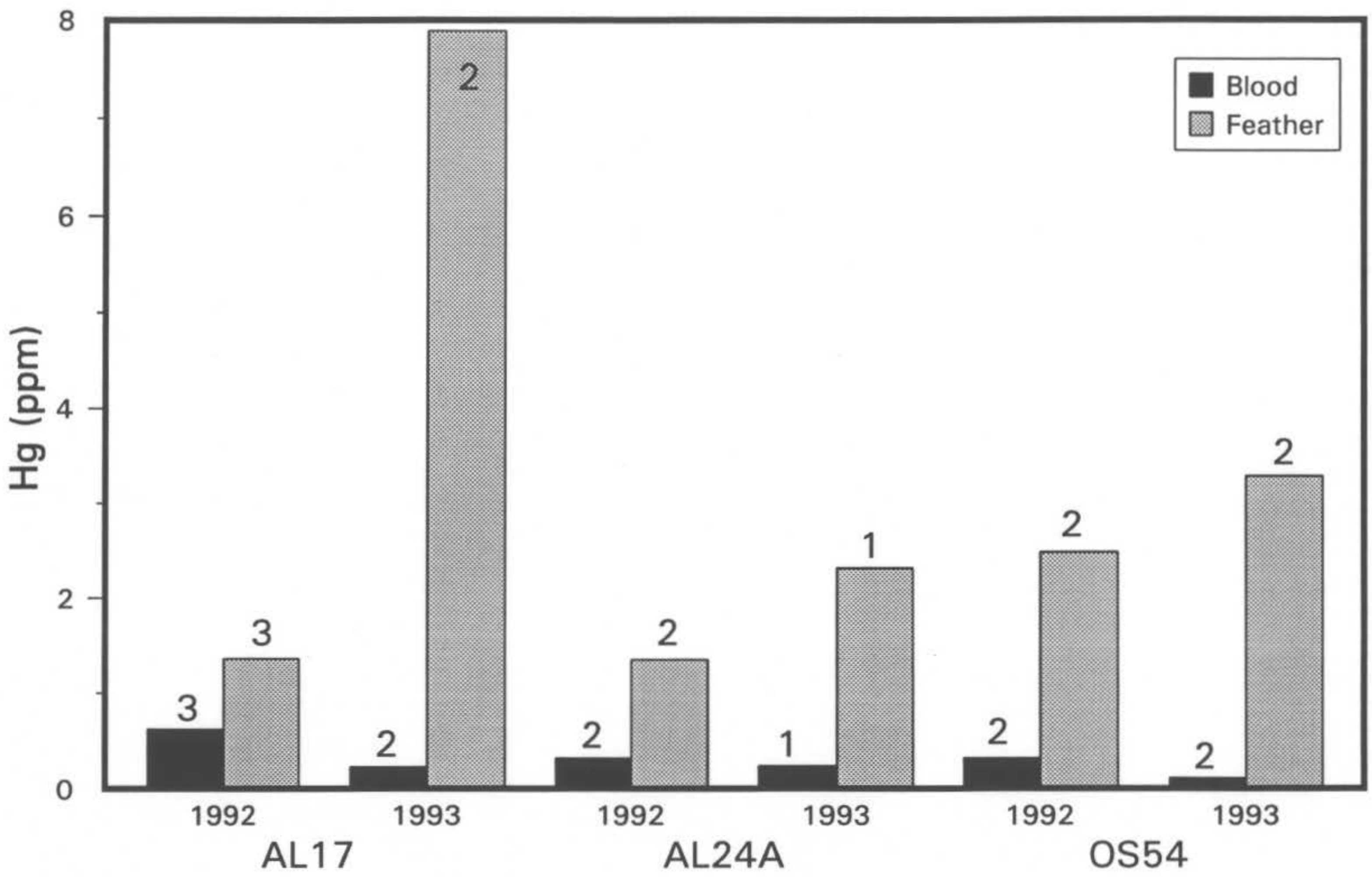

Figure 6. Mercury concentrations (mg/kg) in blood and feathers of nestling Florida bald eagles collected at the same nests in 1992 and 1993. Number above each bar indicates number of nestlings.

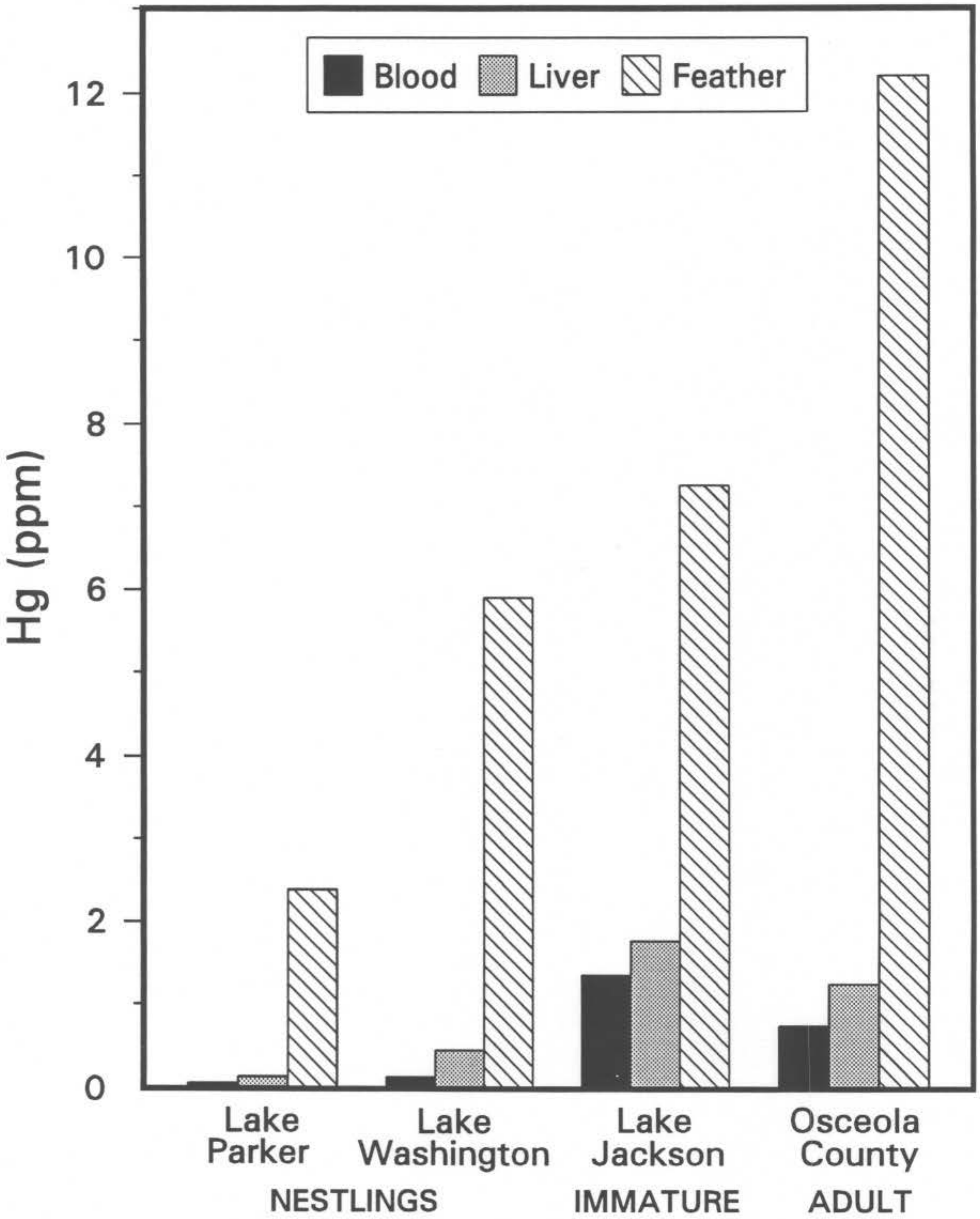

Figure 7. Mercury concentrations (mg/kg) in blood, liver, and feather tissues of 2 nestling, a 2-year-old, and an adult bald eagle in Florida.

ADULT FEATHER HG

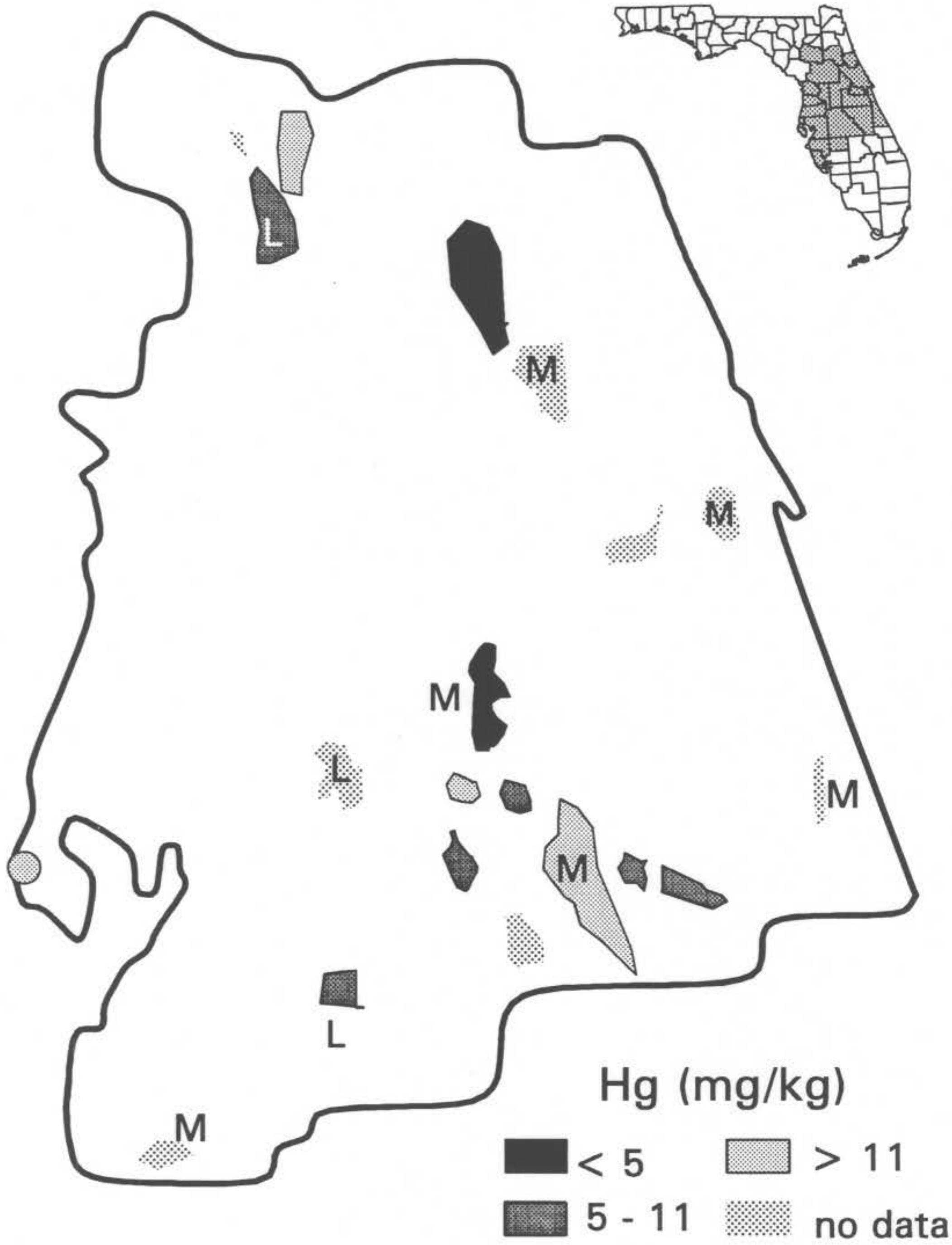

Figure 8. Mean mercury concentrations (mg/kg) by lake for adult bald eagle feathers collected at nests in Florida. Letters represent mean bass mercury concentrations (mg/kg): L=<0.5; M=0.5-1.5.

Figure 9. Mean mercury concentrations (mg/kg) by lake for nestling bald eagle contour feathers collected at nests in Florida. Letters represent mean bass mercury concentrations (mg/kg): L = <0.5; M = 0.5-1.5.

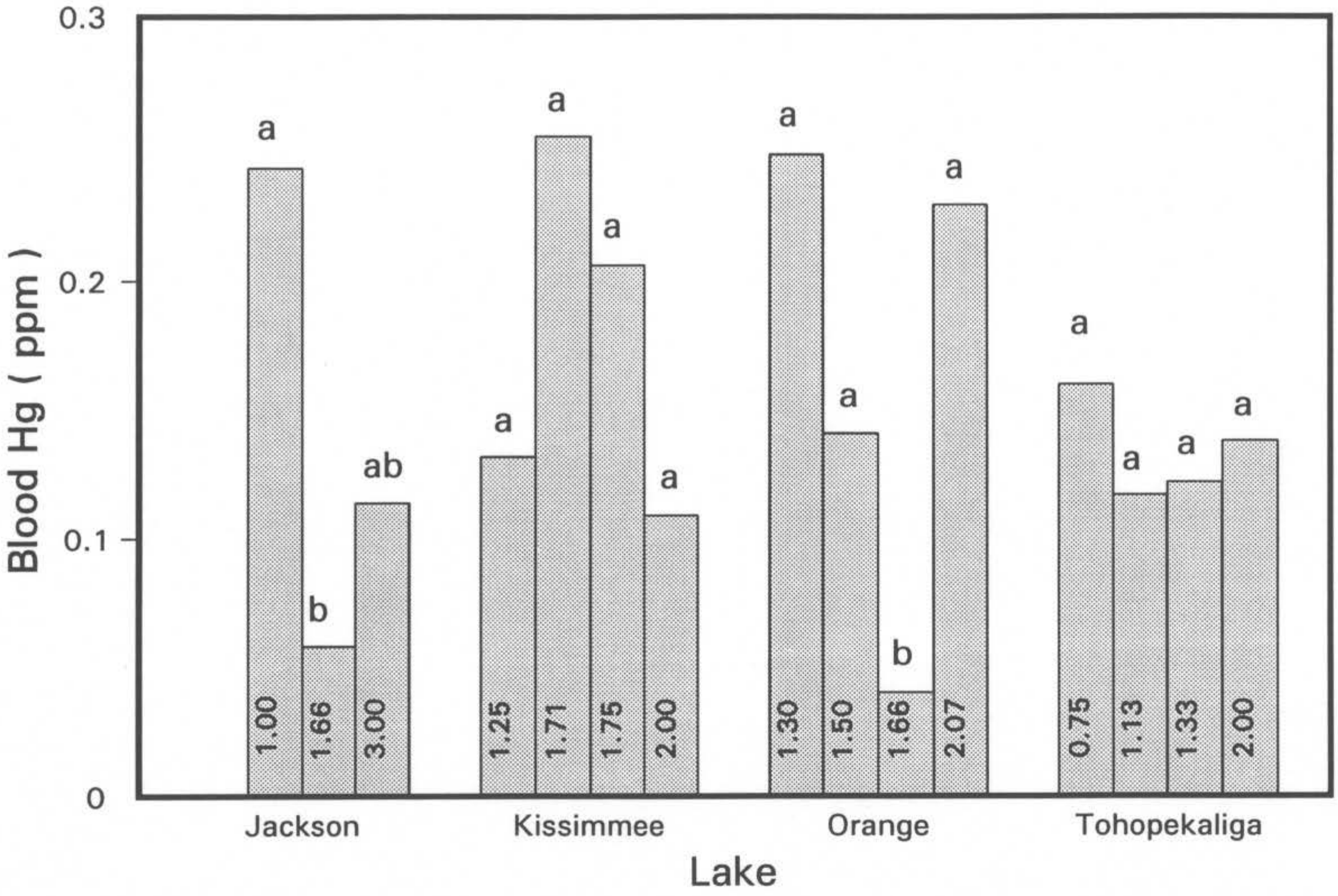

Figure 10. Nestling bald eagle blood mercury concentrations (mg/kg) on 4 lakes in central Florida in relation to food-chain index in 1993. Numbers on bars are the food-chain index. Within a lake, bars with the same letter are not significantly different ($\underline{P}<0.05$).

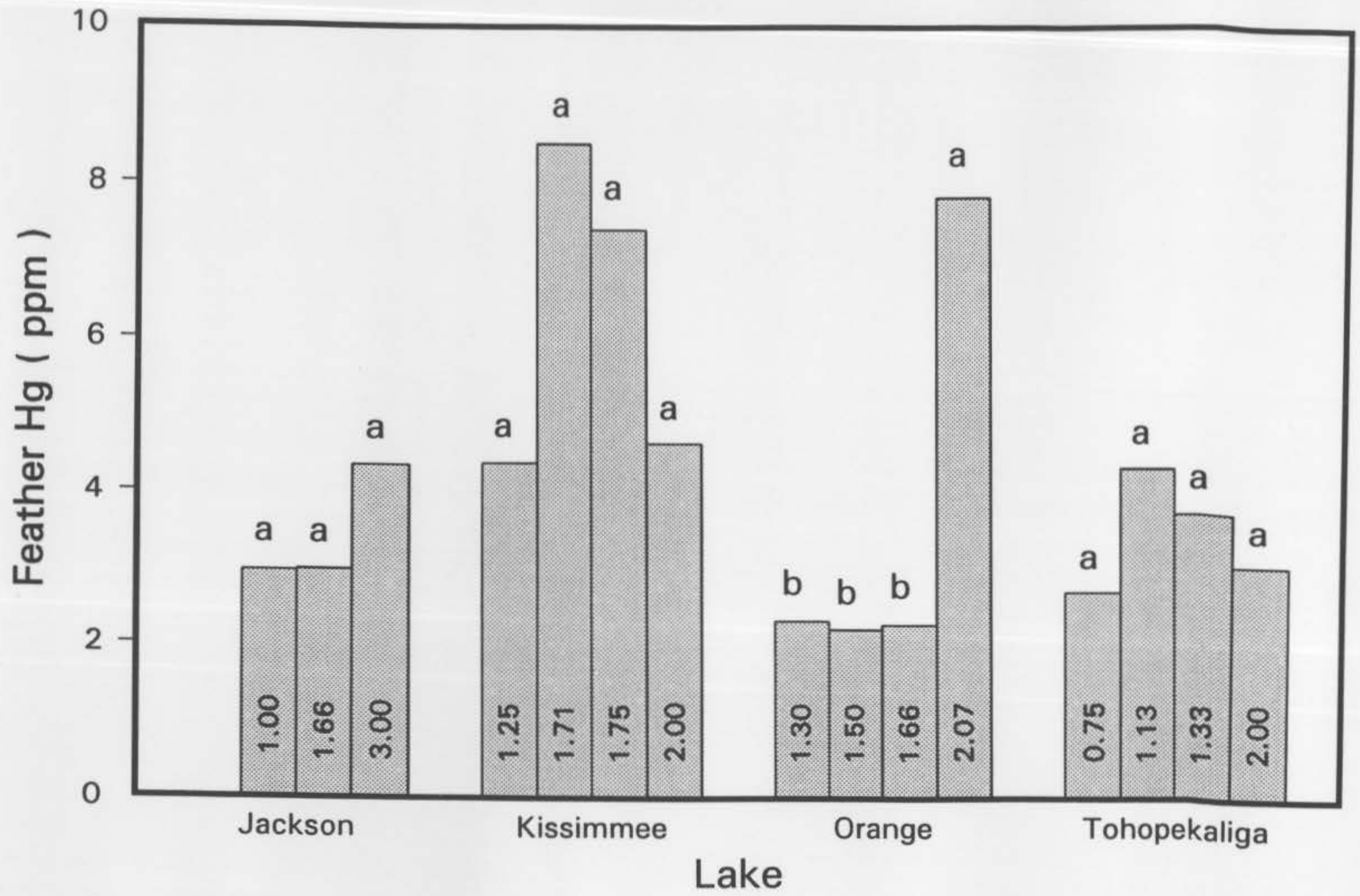

Figure 11. Nestling bald eagle feather mercury concentrations (mg/kg) on 4 lakes in central Florida in relation to food-chain index in 1993. Numbers on bars are the food-chain index. Within a lake, bars with the same letter are not significantly different ($\underline{P}<0.05$).

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