This is to certify that the

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Regulation of Bald Eagle (*Haliaeetus leucocephalus*) Productivity in the Great Lakes Basin: An Ecological and Toxicological Approach.

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William Wesley Bowerman IV

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John P. Giesy

Major professor

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REGULATION OF BALD EAGLE (*Haliaeetus leucocephalus*) PRODUCTIVITY IN THE GREAT LAKES BASIN: AN ECOLOGICAL AND TOXICOLOGICAL APPROACH

By

William Wesley Bowerman IV

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ABSTRACT

REGULATION OF BALD EAGLE (*Haliaeetus leucocephalus*) PRODUCTIVITY IN THE GREAT LAKES BASIN: AN ECOLOGICAL AND TOXICOLOGICAL APPROACH

By

William Wesley Bowerman IV

The bald eagle population, within and adjacent to the Great Lakes Basin, constitutes the greatest single population within the contiguous United States. Bald eagles were largely extirpated from the Great Lakes by the mid-1960s, due to the effects of DDE. Eagles began to repopulate and raise young again along the shores of the Great Lakes, with the exception of Lake Ontario, by the 1980s.

The studies reported here focused on factors limiting bald eagle populations. Ecological factors investigated included food habits, nest tree use, winter habitat use, and the identification of potential nesting habitat. Bald eagles primarily foraged on fish (suckers, bullheads, northern pike, carp, and freshwater drum). Eagle nests were built primarily in white pines, but in cottonwoods near Lake Erie. Potential nesting habitat exists along the shorelines of all Great Lakes, primarily along Lakes Huron and Superior. Habitat availability, however, may limit the Lake Erie subpopulation, which has little unoccupied habitat and great density of nesting eagles.

Toxicological aspects investigated included monitoring concentrations of PCBs and p,p'-DDE in plasma, mercury and selenium in feathers. Hematological biomarkers were used to assess health of eaglets. Bill deformities in nestlings were also investigated. Concentrations of p,p'-DDE or PCBs, but not mercury or selenium, were significantly,

and inversely correlated with regional reproductive productivity and success rates. Lesser reproductive productivity in some lesser contaminated areas are believed to be related to greater nesting density.

Reproductive productivity of bald eagles within this population is primarily regulated by concentrations of organochlorine compounds along the shorelines of the Great Lakes, and density dependant factors in the interior, relatively uncontaminated areas. The continuing recovery of this population will depend on maintaining greater productivity in interior areas to compensate for lesser fecundity and greater adult mortality along the shorelines of the Great Lakes.

To those who believed in me and made this all possible:

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Jim Sikarskie, Jim Ludwig, Bob Radtke, Gary Dawson,

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Tom Weise, and my parents, Butch and Barb.

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University Veterinary Clinic.

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GENERAL INTRODUCTION

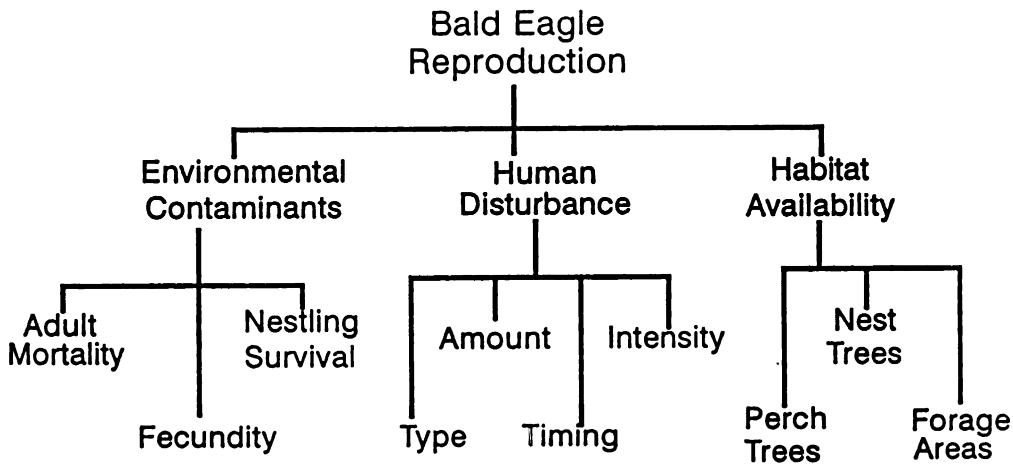
The bald eagle (*Haliaeetus leucocephalus*) is a species that has, within the past 30 years, gone from localized extirpation from large geographical areas throughout North America, to a rapidly expanding population. Within the Great Lakes Basin, the bald eagle was largely extirpated along the entire shoreline and islands of the Great Lakes by the mid-1960s. The major reason for this large-scale decline in population was the use of the pesticide 1,1,1-trichloro-2,2-bis (4-chlorophenyl)-ethane (DDT) through the action of its metabolite 1,1-dichloro-2,2-bis (p-chlorophenyl)-ethane (DDE) which caused eggshell thinning. After the U.S. Environmental Protection Agency banned the use of DDT within the United States in 1972, bald eagle populations began to recover and expand (Grier 1982). By the early 1980s, the number of breeding eagles within the basin began to increase and young were seen again along the shores of most of the Great Lakes.

Although the eagles were now reoccupying the Great Lakes shorelines and islands, a great disparity was noted between their ability to reproduce at a level associated with population recovery and nesting success of eagles in more interior areas. The causal effects of this disparity in reproductive success was the impetus behind this study. The objectives of my research were to investigate some of the factors limiting the reproductive success of bald eagles along the Great Lakes shorelines and areas accessible to Great Lakes fish.

In order to conceptualize the major factors associated with successful bald eagle reproduction, three primary parameters were evaluated: habitat availability; contaminant concentration; and degree of human disturbance (Figure 1). Habitat must be both available and suitable for nesting, roosting, and perching within the breeding area. Included within the habitat parameter is the availability of prey. Concentrations of critical contaminants within the prey taken by eagles must be below thresholds associated with reproductive effects including reproductive failure and teratogenisity. Finally, the frequency, intensity, and timing of human disturbance must be below thresholds of tolerance for individual pairs of eagles. Any one of these three parameters, if above the thresholds associated with nesting success, can lead to reproductive failure. Maintenance of successfully breeding bald eagles requires that a balance of all three parameters, suitable habitat, low contaminants in prey, and low human disturbance (Figure 1) be within the range associated with nesting success for each parameter. In nature, this balance is rarely achieved, so deficiencies in one or more of the parameters drive the actual balance toward the baselines of zero reproduction. The identification of optimal conditions for each parameter was the focus of this research.

This dissertation is organized into three sections each of which present information on factors for two of the three primary parameters, habitat and contaminants, and finally relate these concepts to changes in bald eagle populations in the Great Lakes Basin. Human disturbance, although a part of this research, is outside of the scope of this dissertation and is addressed elsewhere (Grubb et al. 1993). The three sections of the dissertation are: Ecological Aspects; Toxicological Aspects; and Productivity.

Figure 1. A conceptual view of factors limiting bald eagle nesting success in the Great Lakes Basin.

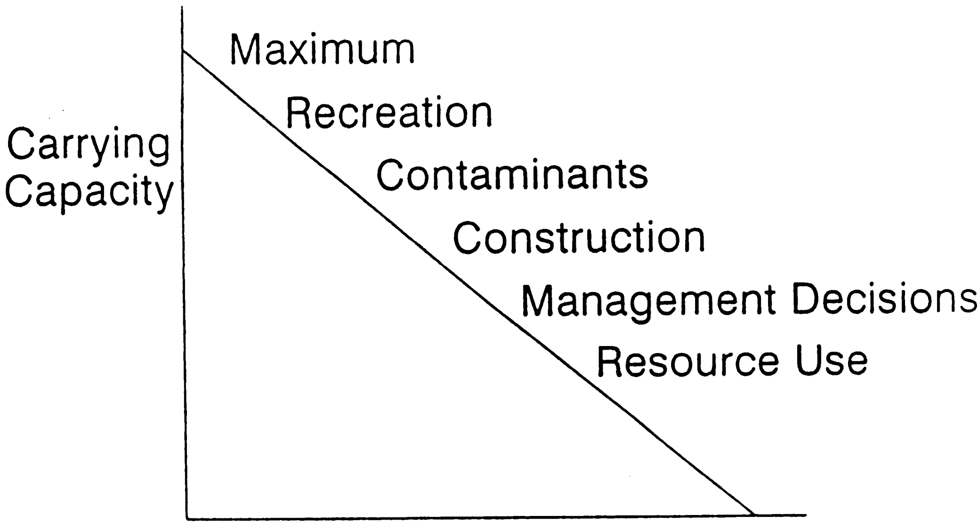


Bald Eagle Reproduction
Environmental Contaminants
Human Disturbance
Habitat Availability
Adult Mortality
Nestling Survival
Fecundity
Amount
Intensity
Type
Timing
Nest Trees
Perch Trees
Forage Areas

Within the Ecological Aspects Section, the topics of prey use, breeding and winter habitat use, and identification of potential breeding habitat along the shorelines of the Great Lakes are addressed. Within the Toxicological Aspects Section, the topics of DDE and PCB concentrations in the blood of nestling bald eagles, the effects of mercury and chlorinated hydrocarbons, developmental deformities, and biochemical indicators of chemical exposure (biomarkers) are discussed. Within the Productivity Section, the topics of differential productivity across the basin and the effects of DDE and PCB concentrations on productivity are covered.

More detailed information on the factors limiting reproductive success will allow calculation of a more accurate estimate of the carrying capacity of the ecosystem of interest. This is a complex problem and managing for the maximum population includes not only the biological aspects of species of interest, but also ecological, economic, and social considerations. The optimal carrying capacity is one that resource management agencies can actually manage for based on their evaluation of these complex factors. For the bald eagle, several factors influence these decisions (Figure 2). The historical number of bald eagle breeding areas in Michigan has been estimated to be more than 400. However, this estimate, which was made at a time when killing eagles was still legal, was based on recollection of individuals and not on a scientific survey. This estimate was also made before the advent of the use of the pesticide DDT. Based solely on physical habitat availability, the number of potential breeding areas that could be occupied currently could be even greater than the number of historical breeding areas. However, a number of factors can limit the occupancy of bald eagle breeding areas.

Figure 2. Cumulative factors influencing optimal carrying capacity for bald eagles in Michigan.


Carrying
Capacity
Maximum
Recreation
Contaminants
Construction
Management Decisions
Resource Use

These include the cumulative effects of human recreation, environmental contaminants, housing and construction, resource agency managment decisions, and natural resource utilization by humans. All of these factors fall within one or more of the three general parameters that were earlier identified. The carrying capacity for eagles in the Great Lakes Basin therefore is not known.

The research presented here determines the potential habitat available to bald eagles and is a starting point for management agencies to develop appropriate management plans. Ultimately, the final two categories, resource agency management decisions and natural resource utilization will be the major factors affecting eagle populations. Natural resource agencies will regulate timber production and forest type; fish species within lakes, rivers, and reservoirs; recreation sites and access; and population composition and numbers of fish and wildlife species used as prey by bald eagles. Natural resource utilization will determine the quality and quantity of habitat (nest, perch, and roost trees, and uncontaminated fishing grounds) and where it is located in the Great Lakes ecosystem including what pollutants occur in the environment. The purpose of this research is not to tell the resource agencies how these decisions should be made, but rather, to assist them in weighing factors for several land management decisions they will face now and in the near future.

LITERATURE CITED

Grier, J.W. 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Science 212:1232-1235.

Grubb, T.G., W.W. Bowerman, J.P. Giesy, and G.A. Dawson. 1993. Responses of breeding bald eagles to human activity in northcentral Michigan. Canadian Field Naturalist. In Press.

SECTION I:

ECOLOGICAL ASPECTS

CHAPTER 1

FOOD HABITS OF NESTING BALD EAGLES IN THE UPPER MIDWEST

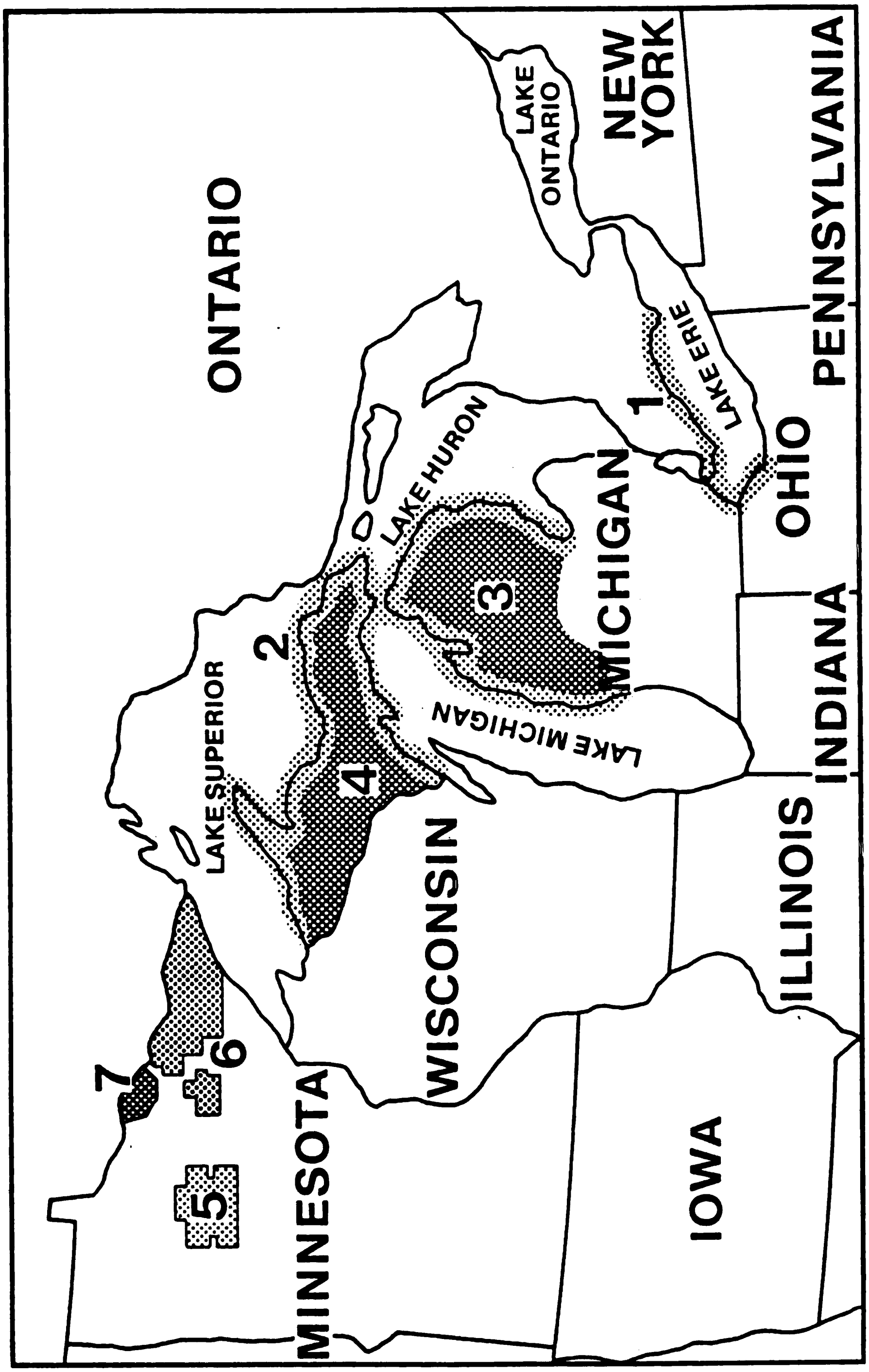
Bald eagles (*Haliaeetus leucocephalus*) nesting in areas away from ocean coasts typically depend on shallow feeding fish as the major part of their diet, but they are also known to be quite opportunistic (Brown and Amadon 1968; Dunstan and Harper 1975; McEwan and Hirth 1979; Todd et al. 1982; Haywood and Ohmart 1986). Productivity of raptors is primarily regulated by food availability, nesting habitat availability, and low human disturbance (Newton 1976). Eagle population growth is based on survival, especially of immature individuals, with food being the ultimate limiting factor (Grier 1980). Loss of an adequate prey base for as little as one to two weeks during the breeding season can cause nest abandonment by bald eagles (Hansen 1987).

The bald eagle population within the upper midwest, including our study area, constitutes the largest single population within the contiguous United States (USFWS 1991). To understand the foraging ecology of nesting bald eagles in the upper midwest, we collected prey remains from nests within seven continuously monitored subpopulations within and adjacent to the Great Lakes Basin from 1989 to 1993. We also determined the feeding habits, prey species and size, and foraging habitat used by six pairs of bald eagles nesting along the Au Sable and Manistee rivers in northern Michigan.

STUDY AREA

Our study area consisted of seven areas (Figure 3). These were defined as: 1) the area within 8.0 km of the United States' (U.S.) and Canadian shorelines of the Great Lakes along Lake Erie (LE) and 2) within the state of Michigan along Lakes Superior, Michigan, and Huron (GLM); 3) the northern lower peninsula (LP), and 4) the upper

Figure 3. Seven study areas for comparison of bald eagle food habits in the upper midwest, 1989-1993. Study areas were: within 8.0 km of the Great Lakes along 1) Lake Erie, or 2) Lakes Superior, Michigan and Huron in Michigan; and interior areas of 3) the northern lower and 4) upper peninsulas of Michigan; and 5) the Chippewa and 6) Superior National Forests, and 7) Voyageurs National Park, Minnesota.

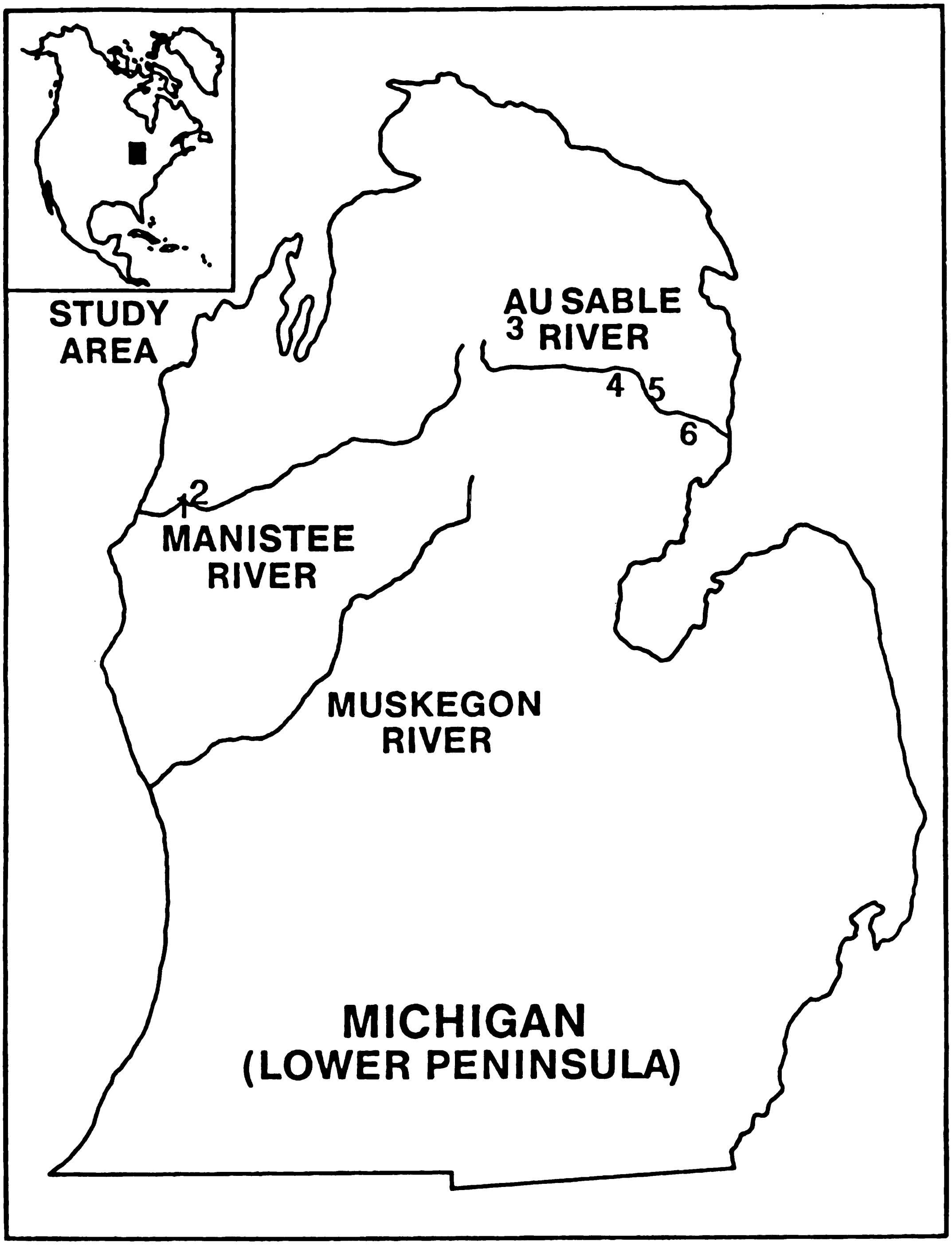

ONTARIO
LAKE ONTARIO
NEW YORK
PENNSYLVANIA
LAKE ERIE
1
LAKE HURON
OHIO
MICHIGAN
3
INDIANA
2
LAKE MICHIGAN
LAKE SUPERIOR
4
WISCONSIN
ILLINOIS
6
7
5
MINNESOTA
IOWA

peninsula of Michigan (UP); and 5) the Chippewa National Forest (CNF), 6) the Superior National Forest (SNF), and 7) Voyageurs National Park (VNP) in Minnesota (Figure 3).

The relative composition of the vegetative cover types varies greatly across the Great Lakes Basin. A northern spruce-fir forest occurs along the north shore of Lake Superior where dominant trees include aspen (*Populus grandidentata, P. tremuloides*), spruce (*Picea mariana, P. glauca*), and balsam fir (*Abies balsamea*). The central lakes area comprising the south shore of Lake Superior, and northern shores of Lakes Michigan and Huron consists of mixed northern hardwood-pine forest of maple (*Acer rubrum, A. saccharum*), oak (*Quercus rubra, Q. alba*), and pine (*Pinus strobus, P. banksiana, P. resinosa*), southern Lakes Michigan and Huron, and Lake Erie are primarily oak forests (Great Lakes Basin Commission 1975). Vegetative types within the Chippewa and Superior National Forests and Voyageurs National Park include boreal forests of black spruce, eastern tamarack (*Larix laricina*), and eastern arborvitae (*Thuja occidentalis*), and mixed northern hardwood-pine forests of quaking aspen, red, white, and jack pine, balsam fir, maple, and paper birch (*Betula papyrifera*)(Fraser et al. 1985).

Within the study area (Figure 4) within the lower peninsula of Michigan, terrain is flat to rolling with occasional hills and an elevational range of 200 to 400 m. Vegetation is predominantly continuous mixed-forest, consisting of white, red, and jack pine, aspens (*Populus grandidentata* and *P. tremuloides*), oaks (*Quercus rubra* and *Q. nigra*), maples (*Acer rubrum* and *A. saccharum*), and white birch. The area is

Figure 4. Six areas where bald eagle nests were observed to determine prey deliveries in 1990. The breeding areas studies were: 1) Wellston and 2) Red Bridge along the Manistee River; and 3) North Branch, 4) McKinley, 5) Alcona, and 6) Monument along the Au Sable River.


STUDY
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AU SABLE
RIVER
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5
6
1
2
MANISTEE
RIVER
MUSKEGON
RIVER
MICHIGAN
(LOWER PENINSULA)

rural and sparsely populated but supports year-round recreational activity.

METHODS

Observations of Prey Deliveries to Nests

Prey was estimated by observations of prey deliveries to nests and by analysis of prey remains. The methods for the nest watch were developed and evaluated in both Arizona and Michigan (Forbis et al. 1983; Bowerman 1991). We observed prey deliveries at six bald eagle nests (Monument, Alcona, McKinley, and North Branch on the Au Sable River, and Red Bridge and Wellston on the Manistee River; Figure 2) by use of a nest watch program, for 2100 hours in 1990. Observations were made from blinds located 300-400 m from nests. Prey items were identified to class and when possible, to genus and species. We recorded time of prey delivery and size of prey item to nearest cm. The size of each prey delivered was estimated by comparison to adult bald eagle size. We assigned prey to one of four size classes, < 15 cm, 15-30 cm, 30-45 cm, and > 45 cm. We estimated biomass using representative weights of birds, mammals, and reptiles (Steenhof 1983) and fish (Carlander 1969a 1969b).

Analysis of Prey Remains

For comparative purposes, we identified prey remains collected from within and under 285 bald eagle nests in Michigan, Minnesota, Ohio, and Ontario. Prey items were collected while banding nestling bald eagles from 1989 to 1993. We identified prey items to genus and, when possible, to species by comparison to taxonomic texts and to museum or field collected specimens. A minimum number of each prey species was determined by identifying the most abundant bone group for each species at each nest site, matching mirror image bones if present, and then totaling the number of individuals represented at that nest site by identification of the fewest number of individuals the most abundant bone group represented (Dunstan and Harper 1975). This method is conservative since mirror image bone fragments may not be from the same individual.

Species were combined for analysis based on percent composition and trophic level within fish and avian classes. Primary fish species used for comparision were suckers (*Catostomus* spp.; *Moxostoma* spp.), bullheads and catfish (*Ictalurus* spp.), northern pike (*Esox lucius*), game fish (walleye, *Stizostedion vitreum*; bass, *Micropterus dolomieu, M. salmoides*; yellow perch, *Perca flavescens*; trout, *Salvelinus fontinalis*), rough fish (bowfin, *Amia calva*; carp, *Cyprinus carpio*; freshwater drum, *Aplodinotus grunniens*; gizzard shad, *Dorosoma cepedianum*), and other centrachids (bluegill, *Lepomis macrochirus*; pumpkinseeds, *L. gibbosus*; black crappie, *Pomoxis nigromaculatus*; rock bass, *Ambloplites rupestris*). Primary bird species used for comparison were ducks (mallard, *Anas platyrhnchos*; American black duck, *A. rubripes*; blue-winged teal, *A. discors*; gadwall, *A. strepera*; American widgeon, *A. americana*; northern pintail, *A. acuta*; hooded, *Lophodytes cucullatus*, common, *Mergus merganser*, and red-breasted merganser, *M. serrator*; wood duck, *Aix sponsa*; redhead, *Aythya americana*; ring-necked duck, *A. collaris*; canvasback, *A. valisineria;* oldsquaw, *Clangula hyemalis*), Canada geese (*Branta canadensis*), herons (great blue heron, *Ardea herodias*; black-crowned night-heron, *Nycticorax nycticorax*; American bittern, *Botaurus* *lentiginosus*), gulls (herring, *Larus argentatus;* ring-billed, *L. delawarensis*; little, *L. minutus*), and other birds (red-tailed hawk, *Buteo jamaicensis*; American coot, *Fulica americana*; sora, *Porzana carolina*; European starling, *Sturnis vulgaris*; white-throated sparrow, *Zonotrichia albicollis*; bobolink, *Dolichoryx oryzivorus*; double-crested cormorant, *Phalacrocorax auritus*).

Foraging Habitat

Foraging areas were identified by observing eagles within their home ranges. Telemetry was used to locate six adult eagles at the Alcona, McKinley, Red Bridge, and Wellston nests (Figure 4) when visual tracking was not possible. Spotting scopes and binoculars were used to maximize the distance between the observers and eagles, to minimize possible behavior modifying disturbance (Grier and Fyfe 1987). Eagle foraging technique (either in flight or from a perch), height, species, and condition (good, fair, poor, dead) of perch trees, stand characteristics (cover type, mean DBH, density), slope, aspect, direction of flight from perch to strike point, and distance from shoreline were recorded.

Statistical Analysis

Forage species use were compared statistically by determination method or among geographical regions using the Kruskal-Wallis one-way analysis of variance (NPAR1WAY procedure using SAS/STAT 6.03, SAS Institute Inc. 1991). Differences among geographical regions or prey types were determined using the Kruskal-Wallis

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multiple range test (Miller 1981). To compare differences in prey species utilized among geographical regions within the two major prey classes, fish and birds, we compared the most abundant species with combinations of lesser abundant species of similar trophic levels. For fish, the primary species utilized for comparison were suckers, bullheads, and northern pike, with combinations of other centrachids, game fish, and rough fish utilized for comparison. For birds, the primary species utilized for comparison were Canada geese, and the combinations of ducks, herons, gulls, and all other birds.

RESULTS

Observations of Prey Deliveries to Nests

Bald eagles on the Au Sable and Manistee rivers were observed to feed primarily on fish, 93.0% of all observed prey by both individual and biomass estimates, with suckers (spp.) comprising over 55% of all identified prey items brought to the nest (Table 1). The use of biomass estimates increased the dietary contribution of suckers, bowfin, and walleye and lessened the contribution of bullheads, bass, and other centrachids. No significant differences were found between percent composition of fish species in diet by observation or prey remains determination for numerical (χ^2=7.1268, df=5, P=0.2114) or biomass (χ^2=9.0, df=5, P=0.1091) estimates of prey use.

Prey composition varied seasonally (Table 2) and temporally (Table 3). Use of suckers and bass use increased over time (Table 2). Fish were observed as prey in greater frequency during the early and late time periods (0600-1059, 1600-2059) than during mid-day (Table 3). Prey size varied from < 15 cm to > 45 cm, with most being

Table 1. Bald eagle prey observed during nest observations and recorded from prey remains from 6 nests in northern Michigan, April-July 1990. Prey items collected only during 1990 at these nests. Percent prey in parentheses[1].

Class/Species	n	Observed Biomass (g)[1]	n	Collected Biomass (g)[1]
Fish	240 (93.0)	119489 (93.2)	49 (77.8)	86518 (86.4)
Sucker	48 (46.6)	73920 (57.7)	21 (33.9)	32340 (32.3)
Bullhead	4 (3.9)	1064 (0.8)	10 (16.1)	2660 (2.7)
Bass	14 (13.6)	9030 (7.0)	0	
Northern pike	4 (3.9)	9760 (7.0)	9 (14.5)	21960 (21.9)
Bowfin	3 (2.9)	17872 (13.9)	4 (6.5)	17872 (17.9)
Trout	7 (6.8)	4165 (3.2)	0	
Other Centrachids	6 (5.8)	678 (0.5)	0	
Walleye	1 (0.9)	3000 (2.3)	0	
Carp	0		2 (3.2)	8963 (9.0)
Black Crappie	0		1 (1.6)	170 (0.2)
Catfish	0		1 (1.6)	2440 (2.4)
Bluegill	0		1 (1.6)	113 (0.1)
Unknown Fish[2]	153		0	
Mammals[3]	10 (3.9)	5155 (4.0)	4 (6.3)	5984 (6.0)
Rabbit/Hare	4 (3.9)	2600 (2.0)	2 (3.2)	1300 (1.3)
Red Squirrel	1 (0.9)	181 (0.1)	0	
Chipmunk	1 (0.9)	32 (0.0)	0	
Beaver	0		1 (1.6)	2342 (2.3)
Opossum	0		1 (1.6)	2342 (2.3)
Muskrat	2 (1.9)	2342 (1.8)	0	

Table 1 (cont'd).

Class/Species	n	Biomass (g)	n	Biomass (g)
Birds	4 (1.6)	1798 (1.4)	9 (14.3)	6427 (6.4)
Gull	0		3 (4.8)	1899 (1.9)
Mallard	0		3 (4.8)	3555 (3.6)
Duck	2 (1.9)	1798 (1.4)	1 (1.6)	899 (0.9)
Blue Jay[4]	0		1 (1.6)	74 (0.1)
Unknown[2]	2 (1.9)		1 (1.6)	
Reptiles/ Amphibians[5]	4 (1.2)	1741 (1.3)	1 (1.6)	1171 (1.2)
Snake	3 (2.9)	570 (0.4)	0	
Turtle	1 (0.9)	1171 (0.9)	1 (1.6)	1171 (1.2)
Unknown Prey[2]	67		0	
TOTALS	325	128183	63	100100
Without Unknowns	103		62	

[1]Does not include unknown prey.
[2]Not included in species percentage calculations or totals.
[3] Mammal species: Rabbit (cottontail, *Sylvilagus floridanus*); Hare (snowshoe, *Lepus americanus*); red squirrel (*Tamiasciurus hudsonicus*); chipmunk (*Tamias* spp.); beaver (*Castor canadensis*); opossum (*Didelphis virginianus*); muskrat (*Ondatra zibethica*).
[4]Blue jay (*Cyanocitta cristata*).
[5]Reptile/amphibian species: unknown snake, Class Reptilia ; turtles (painted, *Chrysemys picta*; snapping, *Cheldra serpentina*).

Table 2. Number of prey observed from observation blinds by month at 6 bald eagle nests in northern Michigan, April-June 1990.

Species	April	May	June	Total
Fish	6	45	47	98
Sucker	3	24	28	55
Bullhead		5	1	6
Bass	1	5	8	14
Northern pike		1	3	4
Trout	2	2	3	7
Other Centrachids		6	2	8
Bowfin		2	1	3
Walleye			1	1
Mammals	4	2	2	8
Rabbit	3		1	4
Muskrat	1	1		2
Chipmunk			1	1
Squirrel		1		1
Birds	5	1		6
Duck	2			2
Other	3	1		4
Reptiles/Amphibians		1	3	4
Snake		1	2	3
Turtle			1	1
TOTAL				116

Table 3. Number of prey observed from observation blinds by time period at 6 bald eagle nests in northern Michigan, April-June 1990.

Species	0600-1059	1100-1559	1600-2059	Total
Fish	37	26	35	98
Sucker	25	15	15	55
Bullhead	1		5	6
Bass	7	3	4	14
Northern pike		1	3	4
Trout	1	3	3	7
Other Centrachids	1	2	5	8
Bowfin	2	1		3
Walleye		1		1
Mammals	4	1	3	8
Rabbit	1	1	2	4
Muskrat	1		1	2
Chipmunk	1			1
Squirrel	1			1
Birds	5	1		6
Duck	2			2
Other	3	1		4
Reptiles/Amphibians	1	2	1	4
Snake	1	1	1	3
Turtle		1		1
TOTAL				116

between 15-45 cm in length. The most frequently observed fish were suckers 15-45 cm (Table 4). Only suckers and northern pike were greater than 45 cm in length and were not observed until later in the nesting season. Proportional abundance of size classes was similar between the first and last time periods but prey items 30-45 cm occurred in greater frequency than prey items 15-30 cm in the 1100-1559 time period.

Analysis of Prey Remains

Prey remains from 285 nest collections indicated that fish were the most common prey class (77.3%, Table 5). No significant differences were found between frequency of prey class (Table 5, χ^2=7.1268, df=6, P=0.2114), percent of primary fish species (Table 6, χ^2=7.1268, df=6, P=0.9035), or percent of primary avian species (Table 6, χ^2=2.6421, df=6, P=0.8522) among geographical areas. No significant differences were found between incidence of prey class (Table 7, χ^2=0.81715, df=6, P=0.9722), percent incidence of primary fish species (Table 8, χ^2=0.9452, df=6, P=0.9883), or percent incidence of primary avian species (Table 8, χ^2=1.2903, df=6, P=0.9722) among geographical areas. Within all regions, warm-water species including suckers, northern pike, bullheads, carp, and bowfin comprised the majority of individual fish identified (60.3-77.7% of total diet). These are all shallow water species. The proportion of gulls in the diet was much greater at Great Lakes breeding areas in Michigan (12.8%) and at Voyageurs National Park (10.3%) than at Lake Erie or inland sites (0.6-5.2%).

Significant differences were found for frequency of prey among prey classes

Table 4. Fish observed as prey by size class during observations at 6 bald eagle nests in northern Michigan, 1990.

Species	< 15 cm	15-30 cm	30-45 cm	> 45 cm
Sucker		26	27	3
Bullhead		3	2	
Bass		8	5	
Northern pike		1	2	1
Trout		6	1	
Other Centrachids	3	5		
Bowfin		2	1	
Walleye			1	
TOTAL	3	51	39	4

Table 5. Number of individuals by genus or species identified from prey remains from seven subpopulations[1] of bald eagles in Michigan, Minnesota, Ohio, and Ontario, 1989-1993.

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Fish	81	295	268	276	45	173	321
Suckers	21	78	77	55	6	51	5
Bullheads	21	65	67	92	3	6	184
Northern Pike	15	114	88	106	19	78	15
Bass	3	7	12		3	4	5
Other Centrachids		2	6	13	5	4	1
Walleye	2	6	3	4	6	20	3
Bowfin	11	13	10	2		4	6
Carp	7	8	4	2	1	5	58
Freshwater Drum							41
Yellow Perch							1
Gizzard Shad							2
Unknown Fish	1	2	1	2	2	1	
Birds	25	79	44	46	11	38	42
Gulls	14	15	10	2	3	22	3
Mergansers	2	1	2				2
Mallard Duck		6	9	14		3	5
Other Ducks	2	4	6	17	3	2	13
Common Raven		2	1			2	
Red-tailed Hawk							2
Double-crested Cormorant			3				
Herons		21	2	5	2	3	2
Other Birds	5	11	12	5	3	5	15

Table 5 (cont'd).

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Mammals	2	41	24	6	2	3	12
Muskrat	1	16	7	3	1		6
Squirrels		1	3				1
White-tailed Deer	1	4	4		1	3	1
Cow		2	1				
Mink		2					
Woodchuck		1					
Raccoon		3					
Beaver			1				
Skunk		1					
Otter		1					
Rabbit/Hare		10	8	2			4
Reptiles	1	7	1	4			33
Turtles	1	7	1	4			33
Other		3	1	1			2
Clam		3					2
Snail			1				
Crayfish				1			
TOTALS	109	425	338	333	58	214	210

[1]Subpopulations: Michigan, GLM, within 8.0 km of Lakes Superior, Michigan and Huron, UP, greater than 8.0 km of a Great Lake in the upper peninsula, and LP, greater than 8.0 km of a Great Lake in the lower peninsula; Minnesota, CNF, Chippewa National Forest, SNF, Superior National Forest, and VNP, Voyageurs National Park; and LE, within 8.0 km of Lake Erie.

Table 6. Percent of primary fish and avian prey items identified from prey remains from seven subpopulations[1] of bald eagles in Michigan, Minnesota, Ohio, and Ontario, 1989-1993.

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Fish							
Suckers	25.9	26.4	28.7	19.9	13.3	29.5	1.6
Bullheads	25.9	22.0	25.0	33.3	6.7	3.5	57.3
Northern Pike	18.5	38.6	32.8	38.4	42.2	45.1	4.7
Game Fish	6.2	4.4	5.6	1.4	20.0	13.9	2.5
Rough Fish	23.5	7.8	5.6	2.2	6.7	5.8	33.6
Other Centrachids	0.0	0.7	2.2	4.7	11.1	2.3	0.3
Birds							
Ducks	16.0	13.9	38.6	67.4	27.3	13.2	47.6
Canada Geese	8.0	24.1	4.5	0.0	0.0	2.6	0.0
Herons	0.0	26.6	4.5	10.9	18.2	7.9	4.8
Gulls	56.0	19.0	22.7	4.3	27.3	57.9	7.1
Other Birds	20.0	16.5	29.5	17.4	27.3	18.4	40.5

[1]Subpopulations: Michigan, GLM, within 8.0 km of Lakes Superior, Michigan and Huron, UP, greater than 8.0 km of a Great Lake in the upper peninsula, and LP, greater than 8.0 km of a Great Lake in the lower peninsula; Minnesota, CNF, Chippewa National Forest, SNF, Superior National Forest, and VNP, Voyageurs National Park; and LE, within 8.0 km of Lake Erie.

Table 7. Number of breeding areas prey species identified from prey remains were found in from seven subpopulations[1] of bald eagles in Michigan, Minnesota, Ohio, and Ontario, 1989-1993.

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Fish	49	128	116	113	23	87	99
Suckers	16	39	29	30	5	30	4
Bullheads	10	22	27	25	2	4	30
Northern Pike	9	41	36	40	8	29	12
Bass	3	6	7		2	4	2
Other Centrachids		2	6	8	1	4	1
Walleye	1	6	2	4	2	10	3
Bowfin	5	4	4	2		2	5
Carp	4	6	4	2	1	3	16
Freshwater Drum							23
Yellow Perch							1
Gizzard Shad							2
Unknown Fish	1	2	1	2	2	1	
Birds	18	63	44	37	10	30	35
Gulls	9	14	10	2	2	16	3
Mergansers	2	1	2				2
Mallard Duck		5	9	12		3	4
Other Ducks	2	4	6	12	3	2	12
Common Raven		2	1			2	
Red-tailed Hawk							2
Double-crested Cormorant				1			
Herons		16	2	5	2	1	2
Other Birds	3	10	12	5	3	5	10

Table 7 (cont'd).

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Mammals	2	39	22	6	2	3	10
Muskrat	1	14	7	3	1		4
Squirrels		1	2				1
White-tailed Deer	1	4	4		1	3	1
Cow		2	1				
Mink		2					
Woodchuck		1					
Raccoon		3					
Beaver			1				
Skunk		1					
Otter		1					
Rabbit/Hare		10	7	2			4
Reptiles	1	6	1	3			33
Turtles	1	6	1	3			33
Other		3	1	1			2
Clam		3					2
Snail			1				
Crayfish				1			
Total Nests	25	74	42	46	14	44	40

[1]Subpopulations: Michigan, GLM, within 8.0 km of Lakes Superior, Michigan and Huron, UP, greater than 8.0 km of a Great Lake in the upper peninsula, and LP, greater than 8.0 km of a Great Lake in the lower peninsula; Minnesota, CNF, Chippewa National Forest, SNF, Superior National Forest, and VNP, Voyageurs National Park; and LE, within 8.0 km of Lake Erie.

Table 8. Incidence rate[1] of primary fish and avian species identified from prey remains in nests from seven subpopulations[2] of bald eagles, 1989-1993.

Class/Species	GLM	UP	LP	CNF	SNF	VNP	LE
Fish							
Suckers	64.0	52.7	69.0	65.2	35.7	68.2	10.0
Bullheads	40.0	29.7	64.3	54.3	14.3	9.1	75.0
Northern Pike	36.0	55.4	85.7	87.0	57.1	65.9	30.0
Game Fish	16.0	16.2	21.4	8.7	28.6	29.5	12.5
Rough Fish	36.0	13.5	21.4	13.0	21.4	13.6	85.0
Other Centrachids	0.0	2.7	14.3	17.4	7.1	9.1	2.5
Birds							
Ducks	16.0	13.5	40.5	41.3	21.4	11.4	45.0
Canada Geese	8.0	14.9	4.8	0.0	0.0	2.3	0.0
Herons	0.0	21.6	4.8	10.9	14.3	2.3	5.0
Gulls	28.0	16.2	19.0	0.0	0.0	34.1	2.5
Other Birds	12.0	12.2	31.0	13.0	21.4	11.4	22.5

[1]Incidence rate is the percent of nests each species was found in.
[2]Subpopulations: Michigan, GLM, within 8.0 km of Lakes Superior, Michigan and Huron, UP, greater than 8.0 km of a Great Lake in the upper peninsula, and LP, greater than 8.0 km of a Great Lake in the lower peninsula; Minnesota, CNF, Chippewa National Forest, SNF, Superior National Forest, and VNP, Voyageurs National Park; and LE, within 8.0 km of Lake Erie.

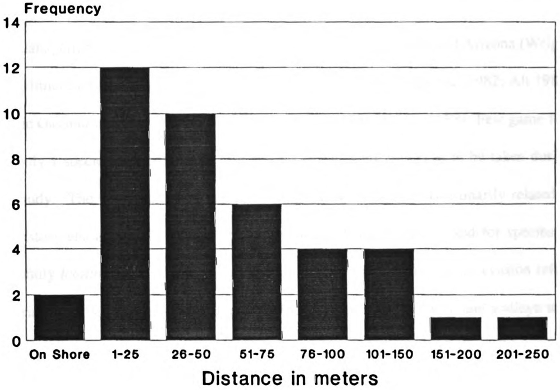
(Table 5, χ^2=30.373, df=4, P=0.0001), percent of primary fish species (Table 6, χ^2=20.141, df=6, P=0.0012), or percent of primary avian species (Table 6, χ^2=13.030, df=6, P=0.0111) among geographical areas. Significant differences were found for incidence rates of prey among prey classes (Table 7, χ^2=30.373, df=4, P=0.0001), percent of primary fish species (Table 8, χ^2=21.863, df=5, P=0.0001), and percent of primary avian species (Table 8, χ^2=12.857, df=4, P=0.0120) among geographical areas.

Foraging Habitat

We observed 41 foraging attempts at the Alcona, Red Bridge, and Monument breeding areas, 33 of which were at Alcona. Bald eagles were more frequently observed in flight (75%) than perched in a tree (25%) prior to initiating a foraging attempt. Bald eagles captured their prey while in continuous flight more frequently, 93%, than landing and grabbing their prey, 7%. Over 50% of all foraging attempts were made within 50 m (164 ft) of shore and 75% were made within 75 m (246 ft) of shore (Figure 5).

Bald eagles were perched greater than 10 m (33 ft) above the surface of the water in all cases and perch height above water ranged up to 110 m (361 ft). Most of the perch trees (9 of 12) were located within 75 m (246 ft) of foraging areas. Bald eagles perched in live conifers in 10 of the 12 instances.

Figure 5. Distance from shore of bald eagle foraging attempts observed in the lower peninsula of Michigan, 1990.


Frequency
14
12
10
8
6
4
2
0
On Shore
1-25
26-50
51-75
76-100
101-150
151-200
201-250
Distance in meters

DISCUSSION

Observations of Prey Deliveries to Nests

Bald eagles typically forage on shallow feeding fish with suckers, bullheads or catfish, and northern pike or pickerel being common across regions and in many diverse habitats (Haywood and Ohmart 1986). Our findings indicate that these species were frequently taken by eagles nesting throughout the midwest. This is consistent with studies in Minnesota, Wisconsin, Maine, Florida, New Brunswick, Chesapeake Bay, Louisiana, Grand Teton and Yellowstone National Parks, California and Arizona (Wright 1953; Imler and Kalmbach 1955; Dunstan and Harper 1975; Todd et al. 1982; Alt 1980; Pacific Gas and Electric 1985; Haywood and Ohmart 1986; Grubb 1988). Few game fish and only 1 species of a cold-water fish species, trout, were observed to be taken during this study. The vulnerability of fish to aerial predation by eagles is primarily related to life history characteristics such as spawning runs and related stress, and for species of the family *Ictaluridae*, a downward orientation of their eyes and lack of an evasion reflex to aerial predation (Dunstan and Harper 1975; Swenson 1978). Trout and walleye tend to be in deeper water during daylight hours and therefore generally inaccessible to bald eagle predation although some may be available due to angler mortality.

The opportunistic nature of bald eagles is indicated by prey from classes other than fish. Mammalian and avian prey were utilized in Michigan early in the breeding period when fish may be less available. Bald eagles in Arizona were found to utilize mammals and birds prior to large runs of Gila suckers (Grubb 1988). In Michigan, as warmer weather increases the temperature of the water of the rivers and ponds, fish become more active and therefore more vulnerable to eagle predation. The two observed nests (North Branch and McKinley) along river stretches were the only ones where reptiles were observed being utilized. This may be an indication that fish prey are not as available in these areas.

Aerial predation by fish-eating birds is divided into two foraging strategies, pursuit divers and surface plungers (Eriksson 1985). Bald eagles are classified as surface plungers and forage primarily within the top 1 m of water. Loss of fish prey density adversely affects surface plungers when the compensatory technique of increasing foraging height or foraging territory no longer offsets the decrease in available prey. Bald eagle productivity has been adversely affected by loss of fish forage in Alaska, Florida and Michigan (Shapiro et al. 1982; Hansen 1987; Bowerman 1991). A proposal to improve trout recruitment by placement of a sucker barrier on the Pit River in California was not implemented because of the potential for decreased bald eagle reproduction due to food stress (Pacific Gas and Electric 1985).

The ability to observe foraging attempts by breeding eagles was directly related to differences in visibility of the surrounding environment at observation points. We selected observation points for the greatest visibility of the nest, with observability of the foraging areas a lesser priority. Breeding areas located along winding riverine sections provided lesser visibility than those associated with open hydroelectric impoundments. While significant differences were not found for comparisons between observations and prey-remains collections in our study for prey composition or biomass estimates, this finding is unusual (Kozie 1985; Mersmann et al. 1992). Most studies find that fish tend to be under-represented in prey remains while classes with more substantial bones, i.e., mammals, birds, and reptiles, tend to be over represented. In the only other comparable study of breeding bald eagles in the midwest (Kozie 1985), it was found that comparison of prey by observation (avian (10%), fish (90%)) vs. prey-remains collections (avian (42%), fish (56%)) overestimated avian prey composition in the diet if only prey remains were used for comparison. This may be typical of Great Lakes breeding areas where prey items were found less frequently than in interior areas (Table 5). No significant differences were found between species composition when comparing observations of golden eagle nests and prey remains collected there (Collopy 1983), but this would be expected since mammals make up the majority of the prey items.

Analysis of Prey Remains

Bald eagles tend to forage on the same species of fish across our study area. The Great Lakes breeding areas and Voyageurs National Park exhibited different preferences in prey, that although not significantly different among regions, may alter management of species within these foraging areas. Eagles nesting along the upper Great Lakes and Voyageurs National Park tended to have a greater percentage of avian prey in prey remains. They also exhibited a low number of individual prey items collected per nest site. This may explain the differences noted. While our interior, observational study area did not differ between observed prey and prey-remains collections, this observation may not be representative throughout the Great Lakes Basin. Determination of prey based on analysis of prey remains tends to underestimate fish prey and overestimate mammalian and avian prey when compared to observational data (Mersmann et al. 1992). Mammalian and avian bones, fur, feathers, and other prey remains are more persistent than fish. This observation is consistent throughout other studies of bald eagle food habits (McEwan and Hirth 1979; Todd et al. 1982; Haywood and Ohmart 1986; Grubb 1988).

Foraging Habitat

Bald eagles at the four nests (Wellston, Alcona, Red Bridge, Monument) were observed to forage primarily in dam ponds. Eagles foraged in areas away from shorelines where there was more room to maneuver and away from potential danger areas. Ponds and river pools may offer better visibility of potential prey than river runs and easier prey capture at lower current velocities (Pacific Gas and Electric 1985). Foraging attempts were primarily in lotic habitats which may reflect shallow shoals where fish would be both accessible and more visible against the sandy bottom.

Bald eagles tended to capture prey in flight rather than ambush their prey while observing a foraging area from a perch. Hunting in flight allows eagles to forage over a large area while searching for available prey (Stalmaster 1987). Hunting from perches allows the eagle exclusive use of a known foraging area where the probability of capturing prey is high. Perch height was great enough to offer good visibility of the foraging areas and also high enough for security and territorial defense (Stalmaster 1987). Conifers offer large open boughs for easy access in and out of the perch tree. Eagles observed in flight prior to a foraging attempt may have been perched in an area not visible to the observer. This would confound our flying versus perching foraging strategy data.

MANAGEMENT IMPLICATIONS

It is apparent from these results that bald eagles across the upper Midwest utilize primarily warm-water fish during the nesting period. The primary species utilized included northern pike, suckers, bullheads, and rough fish including carp, bowfin, and freshwater drum. Previous studies into the loss of forage species during the breeding season and lowered bald eagle reproductive productivity (Shapiro et al. 1982; Hansen 1987; Bowerman 1991) imply that fisheries management should strive to maintain these species within areas identified as bald eagle feeding areas.

Our research identifies how difficult it is to determine on what bald eagles prey during the breeding period. While relative proportions of prey species within a class appear to be reasonable, comparisons among classes appear to be more complex and need to be interpreted on a more site-specific basis. The introduction of video and motion picture cameras to observe eagle foraging may improve this ability, however, the potential impact of researcher activity on adult behavior needs to be accounted for.

LITERATURE CITED

Alt, K.L. 1980. Ecology of the breeding bald eagle and osprey in the Grand Teton-Yellowstone National Parks Complex. unpubl. MS thesis. Montana State Univ., Bozeman.

Bowerman, W.W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. unpubl. M.A. thesis, N. Mich. Univ., Marquette. 113 pp.

Brown, L.H. and D. Amadon. 1968. Eagles, hawks and falcons of the world. Vol. 1. New York:McGraw-Hill.

Carlander, K.D. 1969a. The handbook of freshwater fishery biology. Vol.1. Iowa State Univ. Press, Ames.

Carlander, K.D. 1969b. The handbook of freshwater fishery biology. Vol.2. Iowa State Univ. Press, Ames.

Collopy, M.W. 1983. A comparison of direct observations and collections of prey remains in determining the diet of golden eagles. J. Wildl. Manage. 47(2):360-368.

Dunstan, T. C. and J. F. Harper. 1975. Food habits of bald eagles in north-central Minnesota. J. Wildl. Manage. 39(1):140-143.

Eriksson, M. O. G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. Ornis Scandinavica. 16(1):1-7.

Forbis, L.A., T.G. Grubb, and W.D. Zeedyk. 1983. "Eagle Beagles": A volunteer nest watcher program on Arizona National Forests. pp. 246-254 *in* Proc. Bald Eagle Days, 1983. J.M. Gerrard and T.N. Ingram, eds. The Eagle Foundation, Apple River, IL.

Fraser, J.D., L.D. Frenzel, and J.E. Mathisen. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. J. Wildl. Manage. 49(3):585-592.

Great Lakes Basin Commission. 1975. Report: Great Lakes Basin Framework Study. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Mich.

Grier, J.W. 1980. Modeling approaches to bald eagle population dynamics. Wildl. Soc. Bull. 8(4):316-322.

Grier, J.W., J.B. Elder, F.J. Gramlich, N.F. Green, J.B. Kussman, J.E. Mathisen, and J.P. Mattsson. 1983. Northern states bald eagle recovery plan. USDI-Fish and Wildl. Ser. , Washington, D.C. 105 pp.

Grier, J.W., and R.W. Fyfe. 1987. Preventing research and management disturbance. Pages 173-182 *in* B.A. Giron Pendleton, B.A. Millsap, K.W. Cline, and D.M. Bird, eds. Raptor management techniques manual. Natl. Wildl. Fed., Washington, D.C.

Grubb, T.G. 1988. Results of USDA Forest Service bald eagle research in Arizona. USDA-Forest Service, Tempe, Arizona.

Hansen, A. J. 1987. Regulation of bald eagle reproductive rates in southeast Alaska. Ecology. 68(5):1387-1392.

Haywood, D. D. and R. D. Ohmart. 1986. Utilization of benthic-feeding fish by inland breeding bald eagles. Condor. 88:35-42.

Imler, R.H., and E.R. Kalmbach. 1955. The bald eagle and its economic status. Washington, DC: U.S. Dept. Int., Fish & Wildl. Serv. Circ. No. 30.

Kozie, K.D. 1985. Breeding and feeding ecology of bald eagles in the Apostle Islands National Lakeshore. unpubl. M.S. thesis, Univ. Wisc.-Stevens Point, Stevens Point.

McEwan, L. C. and D. H. Hirth. 1979. Southern bald eagle productivity and nest site selection. J. Wildl. Manage. 43(3):585-594.

Mersmann, T.J., D.A. Buehler, J.D. Fraser, and J.K.D. Seeger. 1992. Assessing bias in studies of bald eagle food habits. J. Wildl. Manage. 56(1):73-78.

Miller, R.G. 1981. Simultaneous Statistical Inference. Springer-Verlag: New York.

Newton, I. 1976. Population limitations in diurnal raptors. Can Field Nat. 90:274-300.

Pacific Gas and Electric. 1985. Final Report: The Pit 3, 4, and 5 Project, bald eagle and fish study. Prepared by BioSystems Analysis, Inc., and Univ. Calif., Davis.

SAS Institute Inc. 1991. SAS/STAT Version 6.06. Carey, North Carolina.

Shapiro, A.E., F. Montabano, III, and D. Mager. 1982. Implications of construction of a flood control project upon bald eagle nesting activity. Wilson Bull. 94:55-63.

Stalmaster, M.V. 1987. The bald eagle. New York:Universe Books.

Steenhof, K. 1983. Prey weights for computing percent biomass in raptor diets. Raptor Res. 17:15-27.

Swenson, J.E. 1978. Prey and foraging behavior of ospreys on Yellowstone Lake, Wyoming. J.Wildl. Manage. 42(1)87-90.

Todd, C. S., L. S. Young, R. B. Owen and F. J. Gramlich. 1982. Food habits of bald eagles in Maine. J.Wildl.Manage. 46(3):636-645.

USFWS. 1991. Compilation of 1991 bald eagle nesting data for the 48 contiguous United States. unpubl. rep., U.S. Fish and Wildl. Serv., Minneapolis, Minnesota.

Wright, B.S. 1953. The relationship of bald eagles to breeding ducks in New Brunswick. J. Wildl. Manage. 17:55-62.

CHAPTER 2:

NEST TREE USE BY BALD EAGLES IN THE UPPER MIDWEST

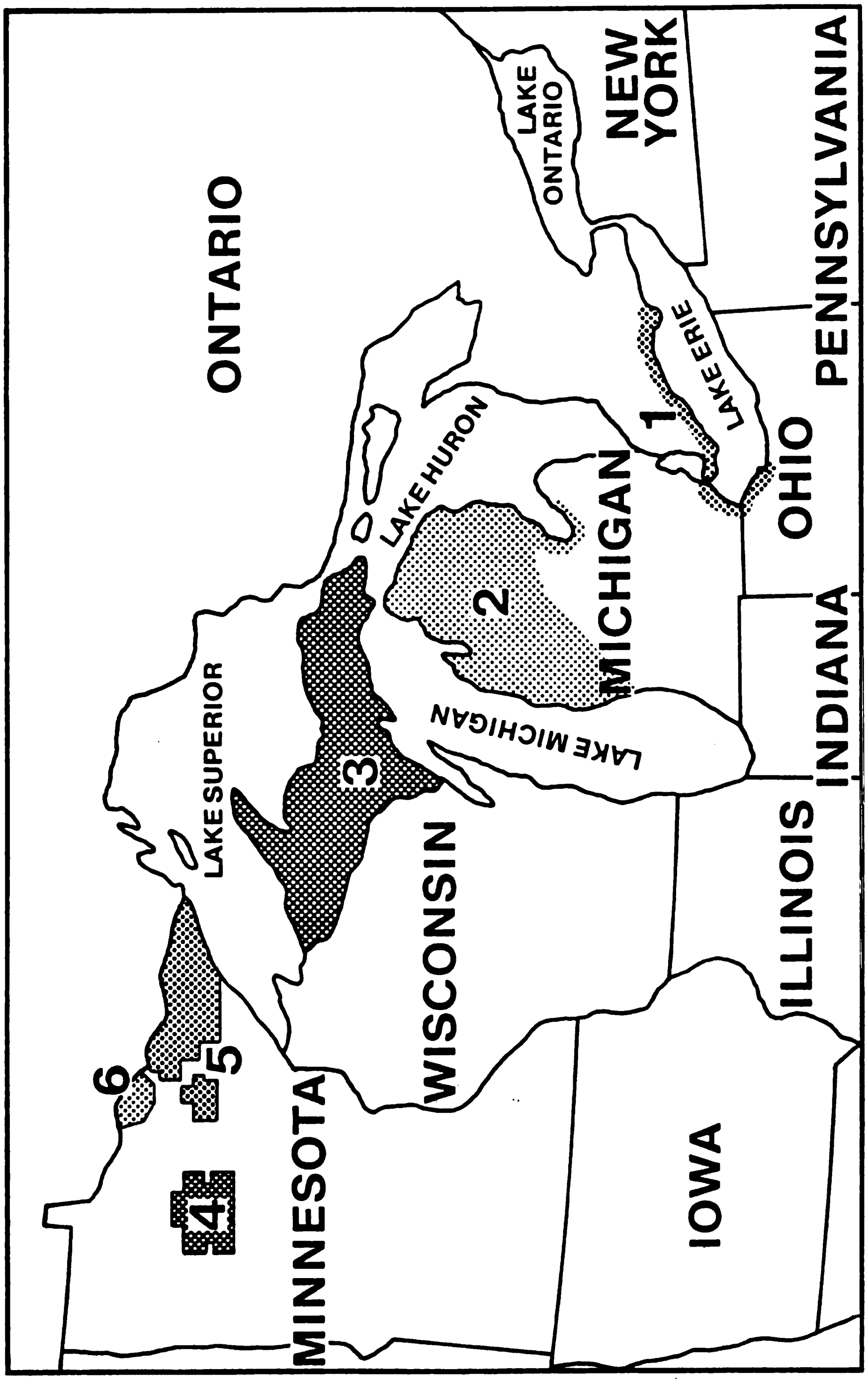
Raptor productivity is primarily regulated by food availability, availability of nesting habitat, and minimal disturbance by humans (Newton 1979). Non-colonial raptors need to have suitable, unoccupied habitat to establish and defend a territory during the breeding season for successful reproduction (Newton 1979). To identify potential nesting habitat within the Great Lakes Basin, we described the characteristics of currently used bald eagle (*Haliaeetus leucocephalus*) nest sites within and adjacent to the Basin. This has allowed us to establish the criteria required to conduct an aerial survey to determine potential breeding habitat along the shorelines and connecting channels of the Great Lakes (Chapter 4). Here we report the physical characteristics of active nest trees and the forested regions surrounding these nests within the state of Michigan, along the shores of Lake Erie in Ohio, and within the Chippewa and Superior National Forests, and Voyageurs National Park in Minnesota, during 1989-1991.

STUDY AREA

Our study area consisted of six areas. These were defined as: 1) the area within 8.0 km of the United States' (U.S.) and Canadian shorelines of the Great Lakes along Lake Erie (LE); 2) the lower peninsula of Michigan (LP); 3) the upper peninsula of Michigan (UP); 4) the Chippewa National Forest (CNF) in Minnesota; 5) the Superior National Forest (SNF) in Minnesota; and 6) Voyageurs National Park (VNP) in Minnesota (Figure 6).

The relative composition of the vegetative cover types varies greatly across the Great Lakes Basin. A northern spruce-fir forest occurs along the north shore of Lake Superior where dominant trees include aspen (*Populus grandidentata, P. tremuloides*),

Figure 6. Six study areas for comparison of bald eagle nest tree characteristics in the midwest. The study areas were: 1) within 8.0 km of the shoreline of Lake Erie; 2) the northern lower and 3) upper peninsulas of Michigan; and 4) the Chippewa and 5) Superior National Forests, and 6) Voyageurs National Park, Minnesota.


ONTARIO
LAKE ONTARIO
NEW YORK
PENNSYLVANIA
LAKE ERIE
LAKE HURON
LAKE SUPERIOR
LAKE MICHIGAN
MICHIGAN
OHIO
INDIANA
ILLINOIS
WISCONSIN
MINNESOTA
IOWA
1
2
3
4
5
6

spruce (*Picea mariana, P. glauca*), and balsam fir (*Abies balsamea*). The central lakes area comprising the south shore of Lake Superior, and northern shores of Lakes Michigan and Huron consists of mixed northern hardwood-pine forest of maple (*Acer rubrum, A. saccharum*), oak (*Quercus rubra, Q. alba*), and pine (*Pinus strobus, P. banksiana, P. resinosa*), southern Lakes Michigan and Huron, and Lake Erie are primarily oak forests (Great Lakes Basin Commission 1975). Vegetative types within the Chippewa and Superior National Forests and Voyageurs National Park include boreal forests of black spruce, eastern tamarack (*Larix laricina*), and eastern arborvitae (*Thuja occidentalis*), and mixed northern hardwood-pine forests of quaking aspen, red, white, and jack pine, balsam fir, maple, and paper birch (*Betula papyrifera*) (Fraser et al. 1985).

METHODS

Nest trees were characterized by determining species, crown class (dominance or codominance in relation to surrounding trees), diameter at breast height (DBH, cm), and height (m). Tree height was measured with a clinometer or altimeter. Percent slope and aspect of the area surrounding the nest was also determined. A clinometer was used to measure slopes of greater than 10%. Diameter at breast height (DBH) was measured with a standard DBH tape. Distances from nests to open water were measured with a 33 m tape or calculated from maps. To characterize the nest stand, a 132-m^2 area was centered on each nest tree with the point-centered quarter method (Cottam and Curtis 1956) and the DBHs of trees $\geq$10.16 cm within this area were recorded for calculating mean DBH and stand density.

Nest tree characteristics were compared statistically among geographical regions using the Kruskal-Wallis one-way analysis of variance, or between coniferous and deciduous trees using the Wilcoxin rank sums tests (NPAR1WAY procedure using SAS/STAT 6.03, SAS Institute Inc. 1991). Differences among nest tree characteristics by geographical regions were determined using the Kruskal-Wallis multiple range test (Miller 1981).

RESULTS

Of the 228 nest trees characterized (Table 9), we identified 15 deciduous and 3 coniferous species (Table 10). Coniferous trees were used 2.8 times as frequently as deciduous trees ($P=0.015$) and, on average, were taller (26.4 m vs. 23.0 m, $P=0.0001$). When nests were located in conifers the average distance from the ground was greater than that for nests located in deciduous trees (22.2 m vs. 17.7 m, $P=0.0001$). Nests in coniferous trees were, on average, located at a greater proportion of total tree height (83.3% vs. 75.1%, $P=0.0001$). Conifers had greater average DBH's (76.7 cm vs. 59.6 cm, $P=0.0001$) and were more likely to be dominant rather than codominant within a stand ($P=0.0001$). Coniferous nest trees were generally located on terrain that had a greater mean slope (8.2% vs. 3.9%, $P=0.0088$). Deciduous trees were generally closer to open water (266.8 m vs. 308.8 m), although this difference was not statistically significant ($P=0.2372$).

The species of trees used as nest trees was not random ($P<0.001$). The most

Table 9. Habitat characteristics of nest trees used by bald eagles in the upper midwest, 1989-1993. (Data are presented as number of trees or mean measurements with standard deviations in parentheses).

Habitat Feature	CNF	SNF	VNP	UP	LP	LE	Sum
Total Trees	39	31	11	68	63	16	228
Tree species (no.)	2	3	2	12	10	5	18
Coniferous	39	25	11	52	41	0	168
Deciduous	0	6	0	16	22	16	60
Dominant crowns	36	29	8	45	41	5	164
Codominant crowns	3	2	3	17	22	11	58
Tree							
DBH (cm)	84.3 (19.2)	71.9 (18.6)	82.8 (16.9)	74.2 (17.2)	61.9 (14.7)	68.5 (19.0)	72.2 (18.8)
Tree height (m)	24.5 (4.9)	29.0 (4.6)	27.4 (7.4)	23.1 (6.2)	25.7 (20.7)	26.9 (13.6)	25.5 (6.8)
Nest height (m)	20.0 (5.0)	23.3 (3.6)	21.7 (5.8)	21.3 (5.4)	20.7 (4.6)	18.3 (4.8)	21.0 (4.9)
Nest height (% of tree ht)	82.1 (10.0)	80.8 (13.7)	76.6 (12.4)	86.5 (10.4)	79.4 (9.5)	73.5 (17.3)	81.1 (11.9)
Stand							
DBH (cm)	22.3 (15.3)	26.6 (9.9)	25.4 (7.5)	27.6 (14.9)	26.7 (14.9)	31.7 (20.4)	27.0 (13.8)
Density (stems/ha)	171.1 (81.1)	247.9 (130.2)	173.4 (68.5)	538.6 (415.3)	496.3 (386.5)	184.3 (131.2)	408.9 (363.5)
Distance to Water (m)	105.1 (109.5)	313.8 (351.5)	127.1 (157.7)	155.1 (302.7)	533.0 (912.3)	320.1 (403.5)	298.0 (554.1)

Table 10. Nest tree species used by nesting bald eagles within the upper midwest, 1989-1993. (Data are presented as number of trees or mean measurements with standard deviations in parentheses).

Species	DBH	Tree Ht. (m)	Nest Ht. (m)	n	CNF	SNF	VNP	UP	LP	LE
Pinus strobus	77.5 (17.6)	26.6 (5.8)	22.3 (4.7)	153	35	24	10	46	38	0
Populous tremuloides	51.3 (8.7)	23.3 (4.3)	17.5 (3.5)	19	0	6	0	2	11	0
Pinus resinosa	69.1 (17.1)	24.2 (5.5)	21.5 (3.2)	14	4	1	1	5	3	0
Populous deltoides	72.5 (21.2)	28.4 (15.9)	18.2 (3.5)	11	0	0	0	0	1	10
Quercus rubra	61.5 (10.1)	22.0 (5.5)	16.5 (5.6)	8	0	0	0	2	3	3
Populous grandidentata	59.6 (20.3)	20.7 (7.7)	18.4 (5.4)	6	0	0	0	4	2	0
Betula alleganiensus	64.6 (22.9)	21.9 (9.4)	17.6 (0.6)	4	0	0	0	2	2	0

Table 10 (cont'd).

Tilia americana	55.4 (9.9)	24.0 (1.4)	21.5 (9.9)	3	0	0	0	2	1	0
Fraxinus nigra	54.1	22.8	16.8	1	0	0	0	1	0	0
Prunus serotina	59.8	18.2	13.2	1	0	0	0	1	0	0
Fagus grandifolia	59.8	21.8	14.8	1	0	0	0	1	0	0
Acer rubrum	61.0	13.7	---	1	0	0	0	1	0	0
Populous balsamifera	57.7	28.3	24.0	1	0	0	0	0	1	0
Fraxinus americana	40.6	21.3	17.7	1	0	0	0	0	0	1
Quercus palustris	61.0	21.3	16.8	1	0	0	0	0	0	1
Platanus occidentalis	95.3	30.5	24.4	1	0	0	0	0	0	1
Fraxinus pennsylvanica	44.4	19.8	13.7	1	0	0	0	0	1	0
Tsuga canadensis	61.3	18.1	11.8	1	0	0	0	0	0	0
Totals				228	39	31	11	68	53	16

frequently used species was white pine (Table 10). Comparing among the characteristics of white pine, red pine, and all deciduous tree species used as nest trees there were found significant differences between the two conifers and the deciduous tree group only for nest location as a proportion of tree height, and between all three groups for average DBH (Table 11). White pines were also found to differ significantly with deciduous trees in tree height and nest height.

DISCUSSION

Bald eagles typically construct nests in large, supercanopy trees which enable easy access to the nest (Stalmaster 1987). Bald eagles tended to choose the trees that are the tallest and have the greatest DBH's in which to build their nests. This is not surprising considering bald eagles have a wingspan of 2 m. Large, open flight paths into the nest are necessary both to deliver prey to the nestlings and for the nestlings during their first flight attempts (Stalmaster 1987). Even though the characteristics of nest trees varied, the availability of a supercanopy tree with an open crown was the key vegetative characteristic that determined the suitability of a stand regardless of dominant species in the stand.

While supercanopy white pine is currently managed to provide potential bald eagle nesting habitat within the National Forests of the Great Lakes region, availability of this species seems to not be required for successful nesting. Thus, should some catastrophic event occur that severely reduces the number of super-canopy white pines available in the future it is probable the eagles will be able to nest successfully. As evidenced by the

Table 11. Differences among mean habitat parameters for trees used for nests by bald eagles in the upper midwest. (Letters signify means within rows which are not significantly different from one another).

Habitat Features	White Pine	Red Pine	Deciduous Species	P
Tree height (m)	26.6 A	24.2 AB	23.0 B	0.0001
Nest height (m)	22.3 A	21.5 AB	17.7 B	0.0001
Nest height/Tree height (%)	83.4 A	83.6 A	75.1 B	0.003
DBH (cm)	77.5 A	69.1 B	59.6 C	0.0001

Lake Erie subpopulation, the availability of conifers is not a prerequisite to successful nesting. The availability of a suitable ecological surrogate for the preeminent supercanopy white pine in the region is all that is necessary for occupancy by nesting eagles. Description of characteristics of habitat for wildlife populations does not necessarily imply that limiting factors for these populations have been identified.

MANAGEMENT RECOMMENDATIONS

We characterized nesting habitat within the Great Lakes region for successfully reproducing bald eagles. The current availability of supercanopy trees in this region is not a limiting factor except along the Lake Erie shoreline (Chapter 4). Based on our study, the need to maintain supercanopy trees with open crowns within active and potential bald eagle breeding areas in the upper Midwest is important to provide suitable habitat for successful reproduction of bald eagles. Human disturbance in areas surrounding nests needs to be controlled during critical periods of incubation and early nestling stages (Grier et al. 1983; Fraser et al. 1985; Grubb et al. 1993). In addition, the density of breeding areas within a population will be controlled primarily by the distribution of prey density (Pitelka et al. 1955; Lack 1964). These considerations need to be incorporated into bald eagle management for current and potential breeding areas within the upper Midwest.

LITERATURE CITED

Cottam, G. and J. Curtis. 1956. The use of distance measures in phyto-sociological sampling. Ecol. 37:451-460.

Fraser, J.D., L.D. Frenzel, and J.E. Mathisen. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. J. Wildl. Manage. 49:585-592.

Great Lakes Basin Commission. 1975. Report: Great Lakes Basin Framework Study. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Mich.

Grier, J.W., J.B. Elder, F.J. Gramlich, N.F. Green, J.V. Kussman, J.E. Mathisen, and J.P. Mattsson. 1983. Northern States Bald Eagle Recovery Plan. U.S. Fish and Wildlife Service, Washington, D.C.

Grubb, T.G., W.W. Bowerman, J.P. Giesy, and G.A. Dawson. 1993. Responses of breeding bald eagles to human activities in northcentral Michigan. In press. Canadian Field Naturalist.

Lack, D. 1964. A long-term study of the great tit (*Parus major*) J. Anim. Ecol. 33(Suppl.):159-173.

Miller, R.G. 1981. Simultaneous Statistical Inference. Springer-Verlag: New York.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, S. Dakota.

Pitelka, F.A., P.Q. Tomich, and G.W. Treichel. 1955. Ecological relations of jaegers and owls as lemming predators near Barrow, Alaska. Ecol. Monogr. 25:85-117.

SAS Institute Inc. 1991. SAS/STAT Version 6.06. Carey, N. Carolina.

Stalmaster, M.V. 1987. The bald eagle. Universe Books, New York.

CHAPTER 3:

POPULATION COMPOSITION AND PERCHING HABITAT OF WINTERING BALD EAGLES IN NORTHCENTRAL MICHIGAN

INTRODUCTION

Bald Eagle *(Haliaeetus leucocephalus)* numbers on wintering grounds are governed by food availability, habitat suitability, and proximity of human disturbance (Vian and Bliese 1974; Stalmaster and Newman 1978). Although wintering eagles have been recorded along the Au Sable, Manistee, and Muskegon Rivers in the northern lower peninsula of Michigan (National Wildlife Federation 1984, Figure 7), details of population size and factors influencing it were unknown. The purpose of this study was to determine the numbers and age composition of Bald Eagles wintering on these rivers and describe the associated perching habitat.

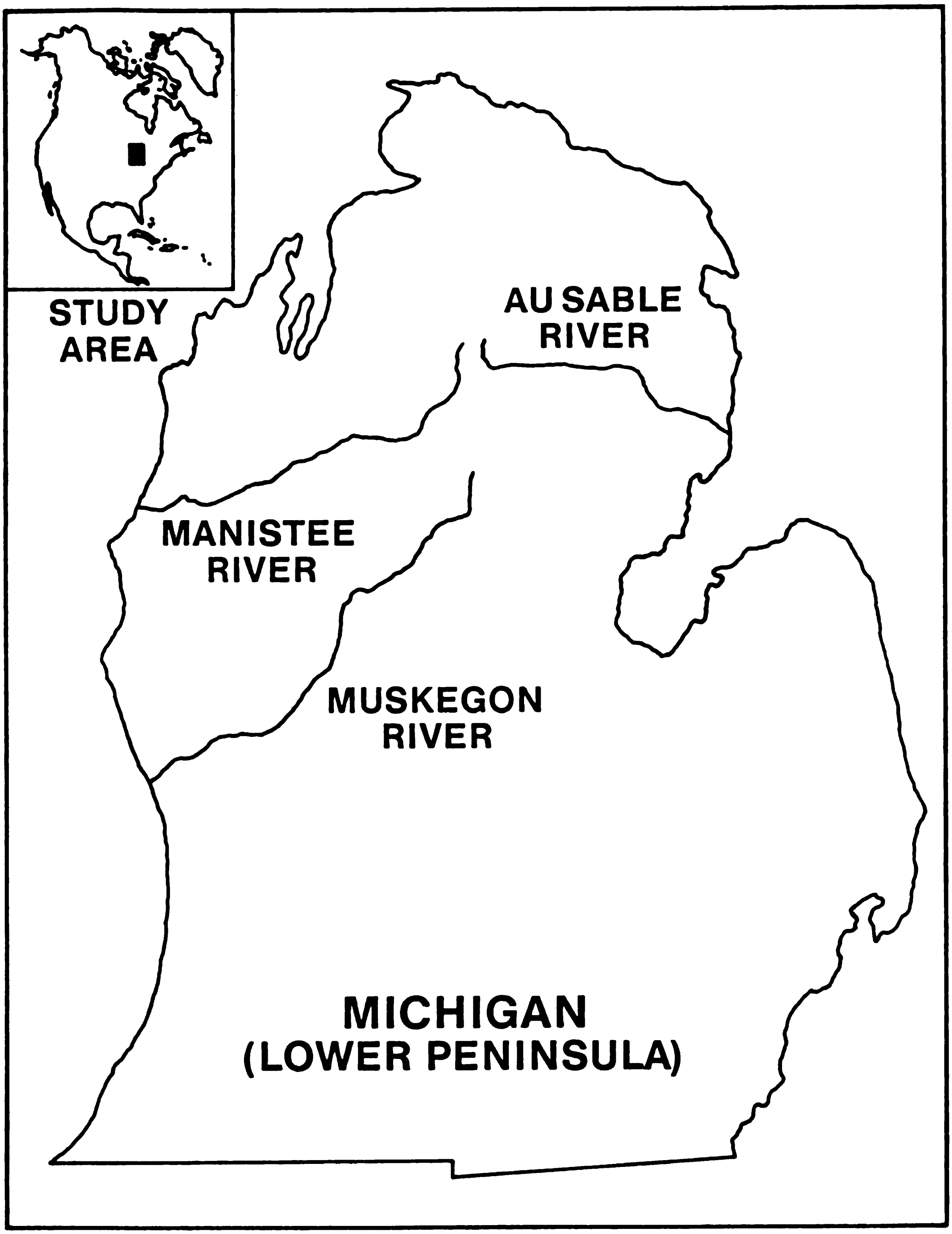
STUDY AREA

Within the study area defined by the 3 rivers (Figure 7), terrain is flat to rolling with occasional hills and an elevational range of 200 to 400 m. Vegetation is predominantly continuous mixed-forest, consisting of White (*Pinus strobus*), Red (*P. resinosa*), and Jack Pine (*P. banksiana*), aspens (*Populus grandidentata* and *P. tremuloides*), oaks (*Quercus rubra* and *Q. nigra*), maples (*Acer rubrum* and *A. saccharum*), and White Birch (*Betula papyrifera*). The area is rural and sparsely populated but supports year-round recreational activity.

METHODS

A pilot and 2 observers conducted surveys every 2 weeks from 15 November 1989 through 15 February 1990, with a Cessna 172 fixed-wing aircraft flown 60-150 m

Figure 7. Location of the Au Sable, Manistee, and Muskegon rivers in the northern lower peninsula of Michigan.


STUDY
AREA
AU SABLE
RIVER
MANISTEE
RIVER
MUSKEGON
RIVER
MICHIGAN
(LOWER PENINSULA)

above ground level at 130-190 km/hr. Each river was flown once during a survey period, and the east-west direction of travel was reversed every survey. The 3 rivers were flown on as nearly consecutive days as weather and scheduling would permit. We flew directly over the rivers to permit simultaneous viewing of both shorelines, and just offshore along the perimeter of the 11 included hydroelectric reservoirs. During aerial surveys, eagles were classified as adults ($\geq$4 years old) or immatures ($<$4 years) by plumage characteristics (McCullough 1989). Eagle perch locations were plotted on United States Geological Service 7.5 minute quadrangle maps. Each perch area was also photographed to facilitate relocation on the ground.

Within 3 weeks of the flights, we measured perch trees to determine species, crown class (dominance or codominance in relation to surrounding trees), diameter at breast height (DBH, cm), and height (m). Tree height was measured with clinometer or altimeter. Percent slope of the perch substrate was also determined with clinometer when slope exceeded 10%. Diameter at breast height (DBH) was measured with a standard DBH tape. Distances from perches to potential disturbance by humans, defined as roadways (primary roads, secondary roads, snowmobile trails) or structures (buildings, power plants, transmission lines) were measured with a 33 m tape or calculated from maps.

We characterized perch surroundings through measurements of 2 additional habitat features. We recorded DBH and height of the nearest-tallest tree to compare perch trees with potential alternate perches (Chester et al. 1990). To characterize the perch stand, a 132-m^2 area was centered on each perch site with the point-centered quarter method

(Cottam and Curtis 1956) and the DBHs of trees ≥ 10.16 cm within this area were recorded for calculating mean DBH and stand density.

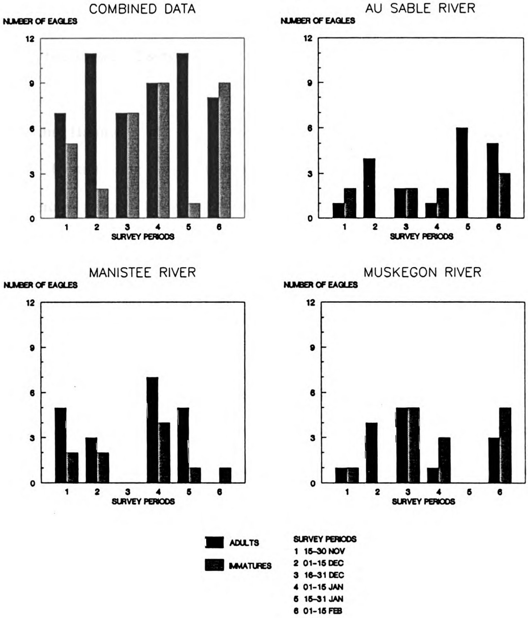
Statistical analyses were performed using SPSS/PC+ Version 4.0 (Norusis/SPSS Inc. 1990a-b). We tested quantitative data (DBHs, heights, distances, and densities) for normality with the Kolmogorov-Smirnov one sample test, and then used either parametric T-tests and ANOVA, or nonparametric binomial (Mann-Whitney *U* and Kruskill-Wallis) tests for further analyses, as appropriate. We also used Chi-square tests with cross - tabulation summaries among variables to evaluate patterns or non-random distributions.

RESULTS

Numbers and Age Composition

Between 15 November and 15 February we recorded 87 Bald Eagles (54 adults and 33 immatures): 28 on the Au Sable River (19,9), 31 on the Manistee (21,10), and 28 on the Muskegon (14,14, Figure 8). The overall ratio of adults to immatures was 1.6:1, but varied among rivers with the 2 northern rivers, Au Sable and Manistee, being 2.1:1 and the Muskegon, 1:1. Adults equalled or outnumbered immatures in all but the final survey period. The greatest number of eagles (18) was observed between 1-15 January. Adult peaks (11) were during 1-15 December and 16-31 January and preceded the peaks for immatures (9) during 1-15 January and 1-15 February. On the Au Sable River, adults were present throughout the study period, while immatures were absent during 2 survey periods. Adults outnumbered immatures on the Manistee River on all

Figure 8. Summary of Bald Eagle numbers and age composition along the Au Sable, Manistee, and Muskegon rivers in northern Michigan, 15 November 1989 to 15 February 1990.


COMBINED DATA
AU SABLE RIVER
MANISTEE RIVER
MUSKEGON RIVER
NUMBER OF EAGLES
0
3
6
9
12
1
2
3
4
5
6
SURVEY PERIODS
ADULTS
IMMATURES
SURVEY PERIODS
1 15-30 NOV
2 01-15 DEC
3 16-31 DEC
4 01-15 JAN
5 15-31 JAN
6 01-15 FEB

but the last survey; whereas on the Muskegon, immatures equalled or outnumbered adults on all but the second survey.

Perching Habitat

In measuring 55 perch trees (Table 12), we identified 13 deciduous and 4 coniferous species (Table 13). Deciduous trees were used twice as frequently as coniferous trees (P=0.015). However, coniferous perch trees were taller (23.2 m vs. 18.9 m, P=0.029), in denser stands (577.6 stems/ha vs. 408.9, P=0.017) and on terrain that had a greater mean slope (40.6% vs. 19.9%, P=0.008) than deciduous trees. Coniferous perches were also less variable in height with a coefficient of variation (s.d./mean X 100%) of 27.4% versus 35.7%. The proportion of coniferous and deciduous perches was similar between crown classes: dominant (37% and 63% respectively); codominant (31% and 69%, P=0.639). Although the frequencies of coniferous perches and dominant crowns were nearly identical, only about a third of the conifers were dominant.

Adults perched nearly equally in coniferous (43%) and deciduous trees (57%), whereas immatures used mostly deciduous perches (85%, P=0.034). We found no difference in crown class (P=0.958) or stand density (P=0.860) among perches used by adult and immature eagles. However, adult perch trees were taller (21.8 m vs. 17.7 m, P=0.036) and on greater slopes (31.6% vs. 17.9%, P=0.046) than were immatures. There was no overall age class preference for perch species (P=0.467), but of the 14 observations of *Pinus strobus* only 1 was of an immature eagle.

Table 12. Habitat features of perch trees used by wintering Bald Eagles along the Au Sable, Manistee, and Muskegon rivers in northcentral Michigan, 15 November 1989 to 15 February 1990. (Data are presented as number of trees or mean measurements with standard deviations in parentheses.)

Habitat Feature	Au Sable River	Manistee River	Muskegon River	Totals
Total Perch Trees	14	22	19	55
Eagle Use				
Adults only	10	13	11	34
Immatures only	4	9	6	19
Both ads. & imms.	0	0	2	2
General Features				
Tree species (no.)	8	9	8	17
Coniferous trees	8	8	2	18
Deciduous trees	6	14	17	37
Dominant crowns	8	8	3	19
Codominant crowns	6	14	16	36
Perch Tree Measures				
DBH (cm)	48.8	39.2	54.1	46.8
	(20.2)	(13.1)	(29.3)	(22.2)
Height (m)	21.4	18.4	21.8	20.3
	(7.9)	(5.8)	(7.0)	(6.9)
Nearest-Tallest Tree				
DBH (cm)	36.1	33.4	43.7	37.6
	(10.2)	(8.8)	(21.9)	(15.4)
Height (m)	18.2	19.9	22.9	20.5
	(4.9)	(4.1)	(8.1)	(6.1)
Stand				
DBH (cm)	25.1	22.1	29.5	25.4
	(7.2)	(7.0)	(11.7)	(9.4)
Density (stems/ha)	527.6	460.4	421.6	464.1
	(310.2)	(269.4)	(224.2)	(264.2)
% Slope				
Mean	45	56	38	50
S.D.	(9.6)	(16.7)	(18.7)	(16.7)
N > 10% slope	9	19	4	32

Table 13. Perch tree species used by wintering Bald Eagles along the Au Sable, Manistee, and Muskegon rivers in northcentral Michigan, 15 November 1989 to 15 February 1990. (Data are presented as number of trees or mean measurements with standard deviations in parentheses.)

Species	DBH (cm)	Height (m)	N	AuS R.	Man R.	Mus R.
Pinus strobus	50.6 (13.7)	25.3 (5.8)	14	5	7	2
Acer rubrum	52.5 (23.7)	18.0 (6.6)	8	0	1	7
Quercus alba	31.7 (9.9)	15.8 (6.2)	5	0	3	2
Acer saccharinum	54.8 (21.0)	23.2 (1.8)	4	0	0	4
Betula papyrifera	35.5 (8.0)	12.3 (2.6)	4	1	3	0
Populus spp.	30.2 (13.2)	17.3 (6.0)	4	0	4	0
Quercus rubra	46.5 (3.3)	18.2 (1.7)	3	2	1	0
Acer saccharum	27.2 (17.1)	16.8 (0.5)	2	1	1	0
Pinus resinosa	41.5 (0.0)	17.0 (0.9)	2	2	0	0
Populus deltoides	39.7 (0.1)	17.7 (3.0)	2	1	0	1
Acer negundo	50.8	19.9	1	0	0	1
Fraxinus spp.	34.6	22.6	1	0	0	1
Pinus banksiana	32.0	15.2	1	1	0	0
Robinia pseudoacacia	147.0	40.0	1	0	0	1
Tilia americana	49.0	25.2	1	0	1	0
Tsuga canadensis	37.8	15.5	1	0	1	0
Ulmus americana	99.1	32.9	1	1	0	0

The distribution of perch use among recorded species was not random ($P<0.001$). The 2 most frequently used species were *Pinus strobus* and *Acer rubrum* (Table 13), which collectively were taller ($P=0.043$) and had greater DBH ($P=0.021$) than the remaining perch species; crown class ($P=0.730$) and stand density did not vary ($P=0.077$). Heights of the nearest-tallest trees, which averaged 5.5 m (s.d.$=3.5$) from perches, were comparable to perch tree heights ($P=0.815$). However, perch DBH was greater than both nearest-tallest DBH ($P=0.003$) and surrounding stand DBH ($P<0.001$). Nearest-tallest DBH was also greater than surrounding stand DBH ($P<0.001$). Only tree type and crown class varied among rivers. The percent of deciduous perch tree use increased across the Au Sable (42.4), Manistee (63.6), and Muskegon rivers (89.5, $P=0.005$). The percent of codominant perch trees followed a similar pattern (42.9, 63.6, and 84.6, respectively; $P=0.049$).

Distance from perch trees to potential human disturbance varied between structures and roadways, and with tree type. Deciduous perch trees were farther from human activity than conifers (655.0 m vs. 353.5 m, $P=0.042$). Perches in the vicinity of structures were farther away (752.9 m vs. 455.2 m, $P=0.026$) and in taller trees (22.4 m vs. 19.5 m, $P=0.029$) than perches near roadways. Mean distance from perch trees to potential disturbances varied among rivers, with the Muskegon showing the greatest mean distance (912.7 m) followed by the Manistee (508.3 m) and the Au Sable (132.4 m, $P<0.001$). Roadways were the predominant human activity along the Au Sable and Manistee rivers, while along the Muskegon structures were most frequent activity ($P<0.001$).

DISCUSSION

Numbers and Age Composition

The high proportion of adults, along with the timing of changes in population composition, are consistent with other studies in the Midwest which indicate that immature Bald Eagles migrate earlier and travel further south than adults (Southern 1963, 1964; Sprunt and Ligas 1966). At wintering areas along the Mississippi River, adults peak between mid-December and early-February, prior to leaving by mid-February. Immatures typically peak after the adults and migrate later (Southern 1964; Vian and Bliese 1974).

Perching Habitat

The patterns of habitat use we recorded may be as much a function of habitat availability as an indication of wintering Bald Eagle perch selection. The scope of this study did not permit an analysis of random sites for a statistical comparison of selected versus available habitat. However, our data are sufficient to characterize typical winter perching habitat along the Au Sable, Manistee, and Muskegon rivers, and in addition, at least partially differentiate perch characteristics among age classes and the 3 rivers. Our results are consistent with the well documented tendency for Bald Eagles throughout their range to seek the highest available perches (Stalmaster and Newman 1979, Gerrard et al. 1980, Steenhof et al. 1980). Chester et al. (1990) also observed a higher proportion of daytime winter perching in leafless hardwoods than in pines ($P<0.005$), and concurred with Stalmaster and Gessaman (1984) that this may be related to less obstructed flight paths, greater range of vision, and possible thermoregulatory advantage from solar radiation. Perches on the Muskegon River, a river more densely populated by humans, were almost twice as far from potential human disturbances than those along the Manistee, and almost 7 times farther than those on the sparsely populated Au Sable.

LITERATURE CITED

Chester, D.N., D.F. Stauffer, T.J. Smith, D.R. Luukkonen, and J.D. Fraser. 1990. Habitat use by nonbreeding Bald Eagles in North Carolina. Journal of Wildlife Management 54:223-234.

Cottam, G. and J. Curtis. 1956. The use of distance measures in phyto-sociological sampling. Ecology 37:451-460.

Gerrard, J.M., P.N. Gerrard, and D.W.A. Whitfield. 1980. Behavior in a non-breeding Bald Eagle. Canadian Field-Naturalist 94:391-397.

McCullough, M. A. 1989. Molting sequence and aging of Bald Eagles. Wilson Bulletin 101: 1-10.

National Wildlife Federation. 1984. Midwinter Bald Eagle Survey. Eyas 7:2-4.

Norusis, M.J./SPSS Inc. 1990a. SPSS/PC+ 4.0 Base Manual. SPSS Inc., Chicago, Illinois.

Norusis, M.J./SPSS Inc. 1990b. SPSS/PC+ Statistics 4.0. SPSS Inc., Chicago, Illinois.

Southern, W.E. 1963. Winter populations, behavior, and seasonal dispersal of Bald Eagles in northwest Illinois. Wilson Bulletin 75:42-55.

Southern, W.E. 1964. Additional observations on winter Bald Eagle populations: including remarks on biotelemetry techniques and immature plumages. Wilson Bulletin 76:121-137.

Sprunt, A., IV and F.J. Ligas. 1966. Audubon Bald Eagle studies, 1960-1966. Proceedings of the 62nd National Audubon Society Meeting, Sacramento, CA, pp. 25-30.

Stalmaster, M.V., and J.A. Gessaman. 1984. Ecological energetics and foraging behavior of overwintering Bald Eagles. Ecological Monograph 54:407-428.

Stalmaster, M.V., and J.R. Newman. 1978. Behavioral responses of wintering Bald Eagles to human activity. Journal of Wildlife Management 42:506-513.

Stalmaster, M.V., and J.R. Newman. 1979. Perch-site preferences of wintering Bald Eagles in northwest Washington. Journal of Wildlife Management 43:221-224.

Steenhof, K., S.S. Berlinger, and L.H. Fredrickson. 1980. Habitat use by wintering Bald Eagles in South Dakota. Journal of Wildlife Management 44:798-805.

Vian, W.E., and J.C.W. Bliese. 1974. Observations on population changes and on behavior of the Bald Eagle in southcentral Nebraska. Nebraska Bird Review 42:46-55.

CHAPTER 4:

IDENTIFICATION OF POTENTIAL BALD EAGLE NESTING HABITAT ALONG THE GREAT LAKES

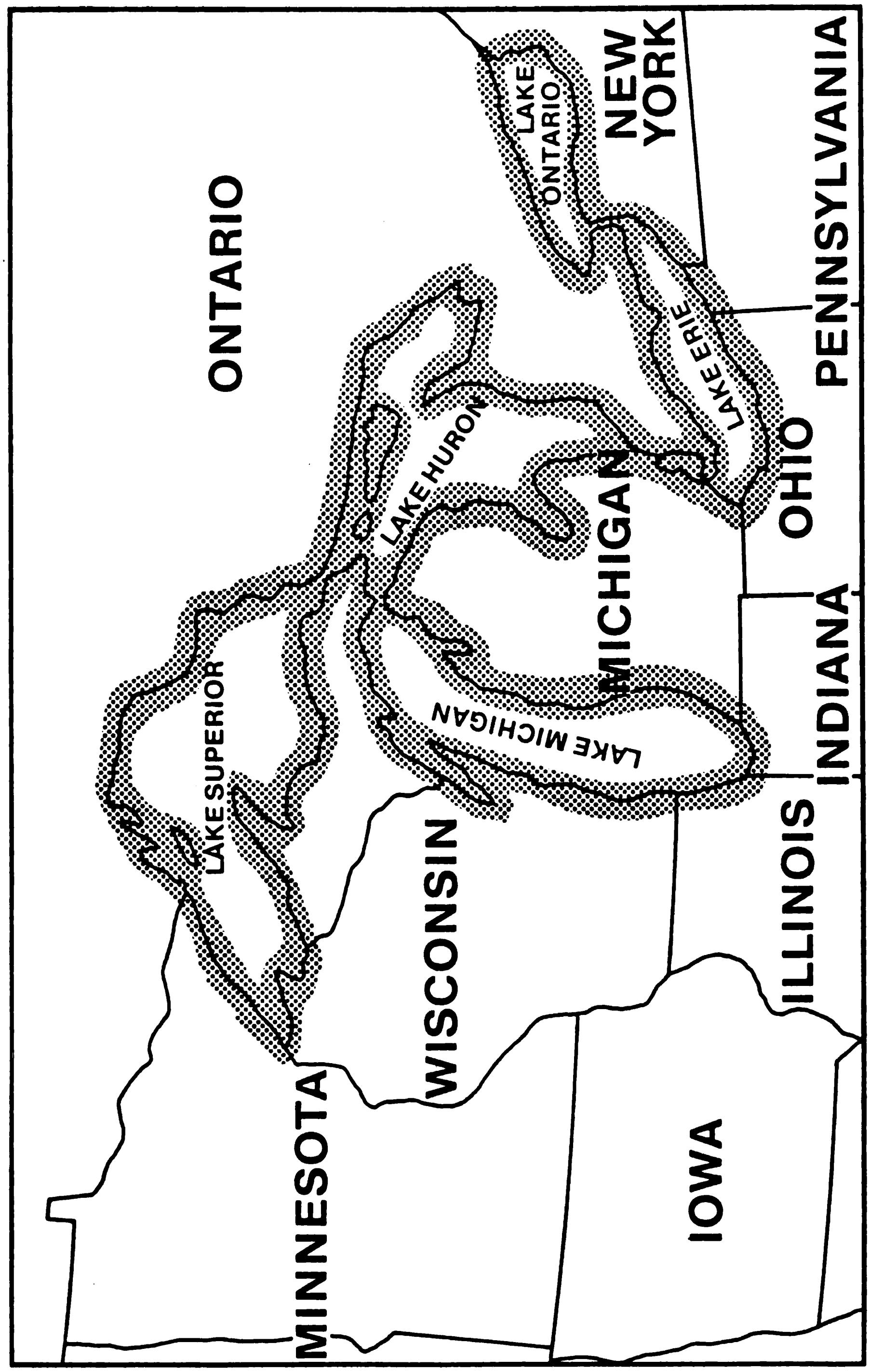
Historically, bald eagles (*Haliaeetus leucocephalus*) nested along the shorelines of all 5 of the Laurentian Great Lakes (Colborn 1991). Bald eagles were extirpated from the islands and shorelines of the Great Lakes in the 1950s and early 1960s, but have recently returned to nest and produce young there (Postupalsky 1985). The primary reason for this localized extirpation was egg shell thinning, caused by p,p'-DDE, the aerobic metabolite of DDT (Colborn 1991). Prior to the widespread use of DDT after World War II, however, eagle populations were already in decline. The loss of nesting habitat, changes in fish populations, and persecution by humans were some of the reasons for their initial decline (Colborn 1991). Although eagles have returned to the Great Lakes islands and shorelines, they still fail to produce young at a level considered to be associated with a healthy population. Concentrations of p,p'-DDE and PCBs within addled eggs and plasma of nestling eagles are sufficiently great to be of concern (Bowerman et al. 1993; Sprunt et al. 1973).

The bald eagle has been proposed as an ecosystem monitor species of Great Lakes water quality by the International Joint Commission (International Joint Commission 1989). Specifically, the sensitivity of the bald eagle to reproductive effects of organochlorine pesticides, primarily p,p'-DDE, and PCBs makes it a good environmental monitor. In order to evaluate effects of organochlorine compounds on eagles it was first necessary to determine the availability of suitable potential nesting habitat along the Great Lakes shorelines. Aerial surveys of the shorelines of all 5 Great Lakes and their connecting channels were conducted during 1992. From these comprehensive aerial surveys we classified and determined the distribution of potential bald eagle breeding habitat along the Great Lakes' shoreline. For both documentation of the current survey and as a step toward standardization of future efforts, we also developed a probabilistic model of the search pattern used in conducting these aerial habitat surveys. We then tested the accuracy of habitat classifications by comparing the locations of active bald eagle nests with the percentages of habitat in each classification.

STUDY AREA

The study area included the shorelines, islands, and connecting channels of all 5 Great Lakes, bounded on the west by the Harbor of Duluth/Superior at the western end of Lake Superior and on the east by the international bridge spanning the St. Lawrence River at Ivy Lea, Ontario. The area within 1.6 km of the United States' (U.S.) and Canadian shorelines of the Great Lakes was surveyed (Figure 9). The surface area of the 5 lakes encompassing the Great Lakes Basin is approximately 754,325 km^2. The elevation of the Lake levels varies from approximately 183 m at Lake Superior to 75 m above sea level at Lake Ontario (Great Lakes Basin Commission 1975a). The vegetative covers vary across the Great Lakes Basin, with a northern spruce-fir forest along the north shore of Lake Superior with dominant trees including aspen (*Populus grandidentata, P. tremuloides*), spruce (*Picea mariana, P. glauca*), and balsam fir (*Abies balsamea*), to the central lakes area comprising the south shore of Lake Superior, and northern shores of Lakes Michigan and Huron of mixed northern hardwood-pine forest of maple (*Acer rubrum, A. saccharum*), oak (*Quercus rubra, Q. alba*), and pine (*Pinus strobus, P. banksiana, P. resinosa*), to the mainly oak forests of southern Lakes

Figure 9. Map of Great Lakes aerial survey area. Shaded areas along lakes indicate flight path.


ONTARIO
NEW YORK
PENNSYLVANIA
LAKE ONTARIO
LAKE ERIE
LAKE HURON
OHIO
MICHIGAN
INDIANA
LAKE MICHIGAN
LAKE SUPERIOR
WISCONSIN
ILLINOIS
MINNESOTA
IOWA

Michigan and Huron, Lake Erie and western Lake Ontario, to the mixed forest cover of eastern Lake Ontario with species similar to the central lakes area (Great Lakes Basin Commission 1977).

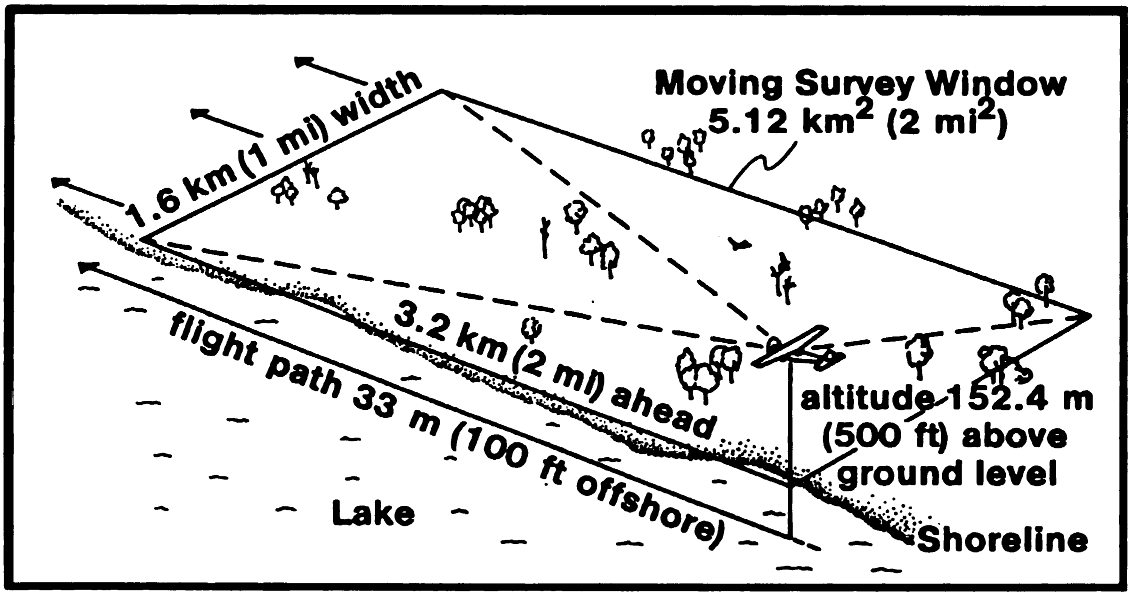
METHODS

Survey Technique

Either a Cessna 177 or Cessna 172 aircraft, flying at approximately 200 km/hr at an average altitude of 152 m was used to survey both the Canadian and U.S. waters/shorelines. Unique to this study, a single observer conducted the entirety of the potential habitat survey and classification. The survey was conducted from the mouth of the Detroit River on Lake Erie, eastward through Lake Erie, the Niagara River, Lake Ontario and the St. Lawrence River to the International Bridge at Ivy Lea, Ontario in January 1992, and from the mouth of the Detroit River on Lake Erie, northward through Lake Huron, the St. Mary's River, westward through Lake Superior and southward through Lake Michigan in April and September 1992. The survey of Lakes Erie and Ontario was conducted during 2-5 January 1992, the eastern shore of Lake Huron during 23 and 27 April 1992, the rest of Lake Huron, Lake Superior, and all but the northeastern shore of Lake Michigan during 12-14 September 1992, and the northeastern shore of Lake Michigan on 28 September 1992.

A moving survey window was utilized to rate habitat for potential eagle nesting use (Figure 10). As the aircraft flew along the shore, a single observer rated the habitat using the following factors: percentage of forested area and proximity to the shoreline;

Figure 10. Flight path and altitude with associated moving survey window used during Great Lakes bald eagle habitat surveys, 1992.


Moving Survey Window
5.12 km^2 (2 mi^2)
1.6 km (1 mi) width
3.2 km (2 mi) ahead
flight path 33 m (100 ft offshore)
altitude 152.4 m
(500 ft) above
ground level
Lake
Shoreline

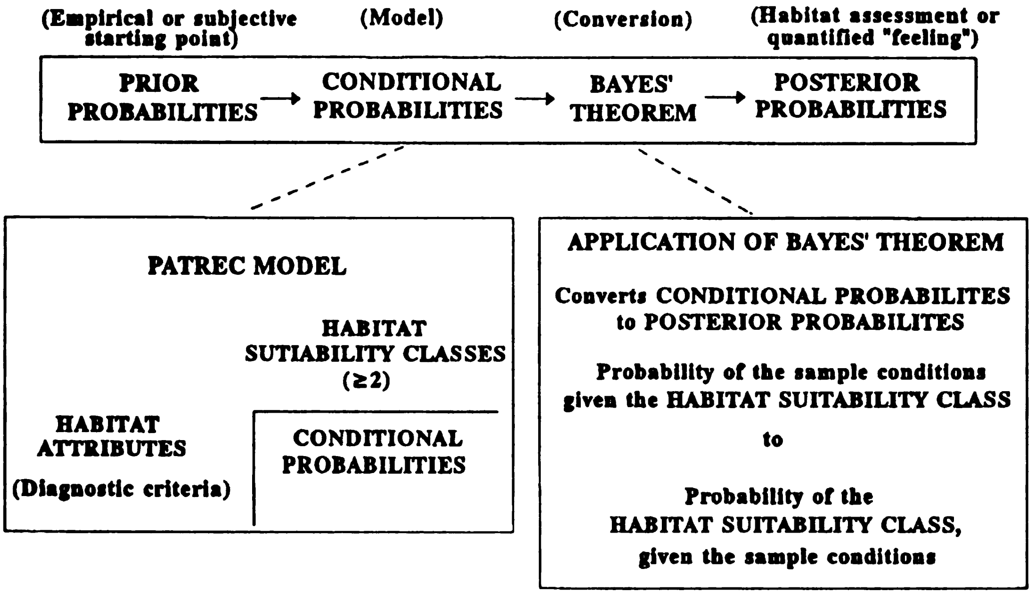
potential human disturbances based on structures, roadways, and signs of human use; shoreline irregularity; available foraging habitat as evidenced by shallow bays, marshes, and still water; and availability of perching and nesting trees within the forest stand. Availability of an adequate prey base along the shoreline was assumed to be present based on proximity to Great Lakes shorelines. Secondary forage area characteristics including the availability of marshes, still water, shallow bays, and degree of shoreline irregularity were used to further refine forage availability. Habitat was classified as either good, marginal, or unsuitable.

Search Image Model

We modeled the search image used in conducting the aerial habitat surveys with Pattern Recognition (PATREC, Figure 11). PATREC is a simple, probabilistic modeling technique that uses Bayes' theorem (Edwards et al. 1963) to estimate the likelihood of a habitat suitability class given a set of sample habitat conditions (Williams et al. 1977, Kling 1980, Grubb 1988). Our PATREC model identified specific habitat attributes and the conditional probabilities of 3 habitat suitability classes associated with each habitat attribute. PATREC also required the estimation or empirical determination of prior probabilities, the likelihood of occurrence for each habitat suitability class. Prior and conditional probabilities were then converted via the following equation to the final habitat assessment, or posterior probability, for each suitability class (Equation 1):

Figure 11. Schematic of the Pattern Recognition (PATREC) habitat modeling process (reprinted from Grubb 1988, with permission).

PATTERN RECOGNITION



$$P(G/ID) = \frac{P(G)\ P(ID/G)}{P(G)\ P(ID/G)\ +\ P(M)\ P(ID/M)\ +\ P(U)\ P(ID/U)} \tag{1}$$

where P(G/ID)	=	posterior probability of good habitat given the inventory data,
P(G)	=	prior probability of good habitat,
P(ID/G)	=	probability of inventory data given good habitat, i.e., the product of all conditional probabilities in this suitability class (if an attribute is not present, then the conditional probability for that attribute is subtracted from 1.00 before being multiplied),
M	=	marginal habitat,
U	=	unsuitable habitat.

We developed the model by first delineating and then refining the habitat attributes comprising the surveyor's search image (Table 14, Figure 12). The area of consideration was a 5.12 km^2 moving survey window (Figure 10). We established prior probabilities by planimetrically measuring the appropriate length of shoreline in each habitat class for each Great Lake, calculating class totals, and determining the relative percentages of each. Since the first 2 steps in the model eliminated an estimated 90% of the unsuitable habitat, the prior probabilities in the model were calculated for the remaining habitat. Because the necessary data were not available and because we were modeling a search image after the surveys, conditional probabilities had to be developed by a combination of 1) estimating the relative proportion of each habitat suitability class for each habitat attribute observed during the surveys, 2) making similar estimates based upon our collective field experience with bald eagles, and 3) adjusting the resultant figures in the model to yield reasonable results consistent with the actual approach used

Table 14. Pattern recognition model of the search image used to identify potential bald eagle breeding habitat during aerial surveys of the Great Lakes' shoreline. Prior probabilities = Good, 0.68; Marginal, 0.27; and Unsuitable, 0.05[1].

Habitat Attributes	Conditional Probabilities		
	Good	Marginal	Unsuitable
1. **Tree Cover**[2] - >10% forested	0.99	0.99	0.01
2. **Nearest Human Disturbance**[3] (Proximity) >1.6 km from heavy human activity or in remote, undeveloped areas (e.g., upper lakes), or >0.8 km from light to moderate human activity or in developed areas (e.g., lower lakes)	0.99	0.99	0.01
3. **Nearest Human Disturbance** (Type/Amount)			
a. Light[4] - trails, unimproved roads or campgrounds	0.55	0.25	0.20
b. Moderate - buildings, paved roads, small docks/launches	0.40	0.45	0.20
c. Heavy - cities, industry, extensive development, marinas	0.05	0.30	0.60
4. **Additional Foraging and/or Shoreline** Presence of shallows, bays, marshes, small lakes, and/or Ratio of linear distance to total shoreline >2.0[5]	0.90	0.60	0.20
5. **Potential Perch Trees** Suitable[6] perch trees ≥30.5 cm DBH, ≤ 400 m from foraging area	0.98	0.60	0.30
6. **Potential Nest Trees** ≥ 3 suitable[7] nest trees, ≥61.0 cm DBH if coniferous or ≥ 45.7 cm DBH if deciduous, Dominant (supercanopy) or near edge (of stand, along shore)	0.98	0.60	0.30

Table 14 (cont'd).

[1] Prior probabilities were determined for the remaining habitat after an estimated 90% of the unsuitable class was removed by Steps 1-2. Prior probabilities were established by planimetrically measuring the approximate length of shoreline in each habitat class for each Great Lake, calculating class totals, and determining the relative percentage of each.

[2] If Tree Cover is > 10%, continue to Step 2 because of the high probability (0.99) of the habitat being Marginal to Good. If Tree Cover is ≤ 10%, do not continue because of the low probability (0.01) that the habitat will be suitable.

[3] If Nearest Human Disturbance is either > 1.6 km from heavy activity or in remote areas, or > 0.8 km from light to moderate activity or in developed areas, continue to Step 3 because of the high probability (0.99) of the habitat being Marginal to Good. If Nearest Human Disturbance is < 1.6 km... or < 0.8 km..., do not continue because of the low probability (0.01) that the habitat will be suitable.

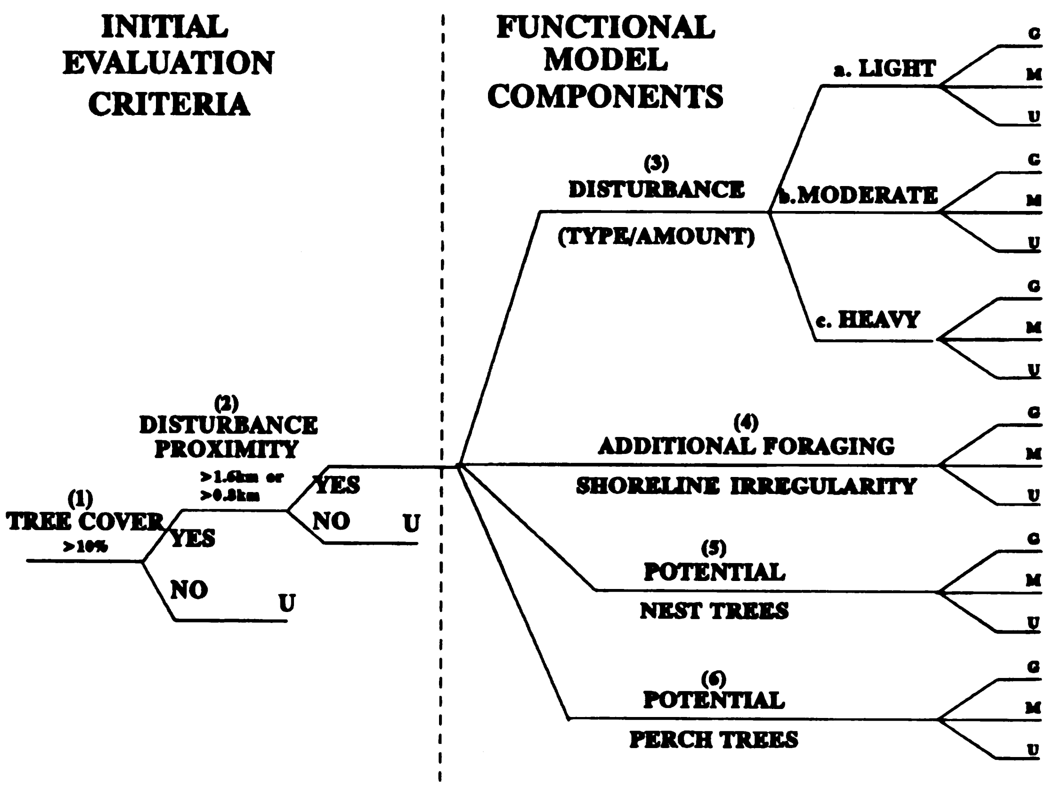
[4] Use the Light category when human activity is totally absent.

[5] Linear distance is the length of a direct flight path across the survey window, i.e., 3.2 km. Total shoreline includes the Great Lakes' shoreline plus that of any islands, bays, marshes, interior lakes, stream or river banks, etc., within the survey window.

[6] Suitable perch trees typically have exposed or open branching with good views and accessibility.

[7] Suitable nest trees have accessible, sufficiently large branching and structure at or above canopy height to support an eagle nest.

Figure 12. Schematic flow chart of PATREC model of the search image used during Great Lakes bald eagle habitat surveys, 1992. Classification abbreviations: G, Good; M, Marginal; and U, Unsuitable.


INITIAL EVALUATION CRITERIA
FUNCTIONAL MODEL COMPONENTS
(1) TREE COVER >10%
YES
NO
U
(2) DISTURBANCE PROXIMITY
>1.6km or >0.8km
YES
NO
U
(3) DISTURBANCE (TYPE/AMOUNT)
a. LIGHT
b. MODERATE
c. HEAVY
(4) ADDITIONAL FORAGING SHORELINE IRREGULARITY
(5) POTENTIAL NEST TREES
(6) POTENTIAL PERCH TREES
G
M
U

in the air. Once the model was complete, we used it to calculate the posterior probabilities for a variety of hypothetical habitat conditions.

Comparison to Known Nesting Areas

Areas where eagles currently breed were compared to the predictions of the classification system to determine the reliability of our predictions of potential breeding habitat. Aerial surveys were conducted at an altitude sufficiently great such that only one bald eagle nest was observed during the survey. A Chi-square test of a 2-way contingency table was used to compare PATREC classifications with the habitat surrounding currently existing nest sites (Ott 1988). We tested for random distribution by categorizing breeding areas active within the period 1988-92 by habitat classification and comparing these observed breeding areas to expected breeding areas using percentages of linear shoreline by habitat classification multiplied by the total number of breeding areas. Lake Ontario data, however, were not included in these analyses since no eagles had been observed to breed along its shoreline since the 1970s (Colborn 1991).

RESULTS

Aerial Survey

A non-random distribution of potential breeding habitat in the Great Lakes Basin was observed. Lake Superior has good habitat along most of its perimeter (Figure 13), Lakes Michigan and Huron have good or marginal habitat clustered along the northern areas (Figures 14, 15), while habitat along the shoreline of Lakes Erie and Ontario was

Figure 13. Areas identified as good or marginal potential bald eagle nesting habitat within 1.6 km of Lake Superior.

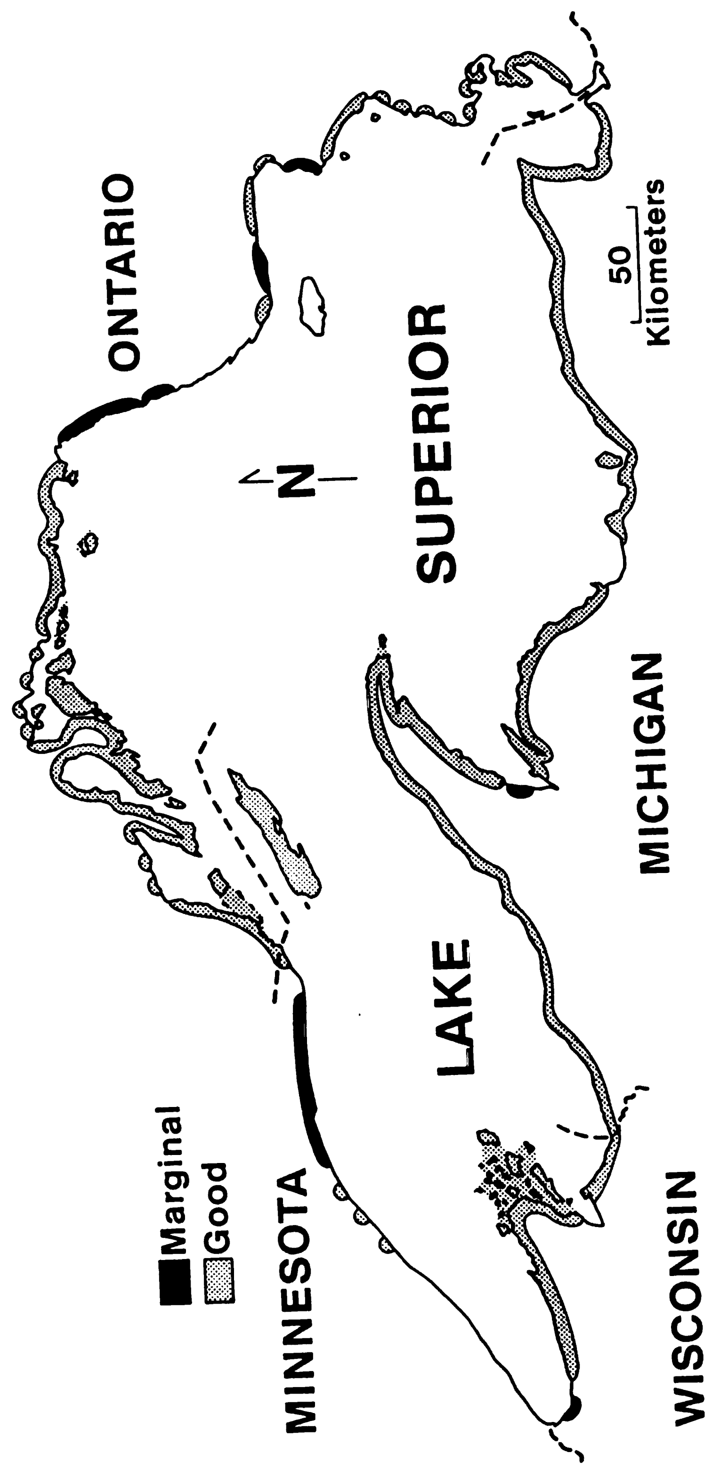

Marginal
Good
MINNESOTA
ONTARIO
LAKE
SUPERIOR
N
MICHIGAN
WISCONSIN
50
Kilometers

Figure 14. Areas identified as good or marginal potential bald eagle nesting habitat within 1.6 km of Lake Michigan.

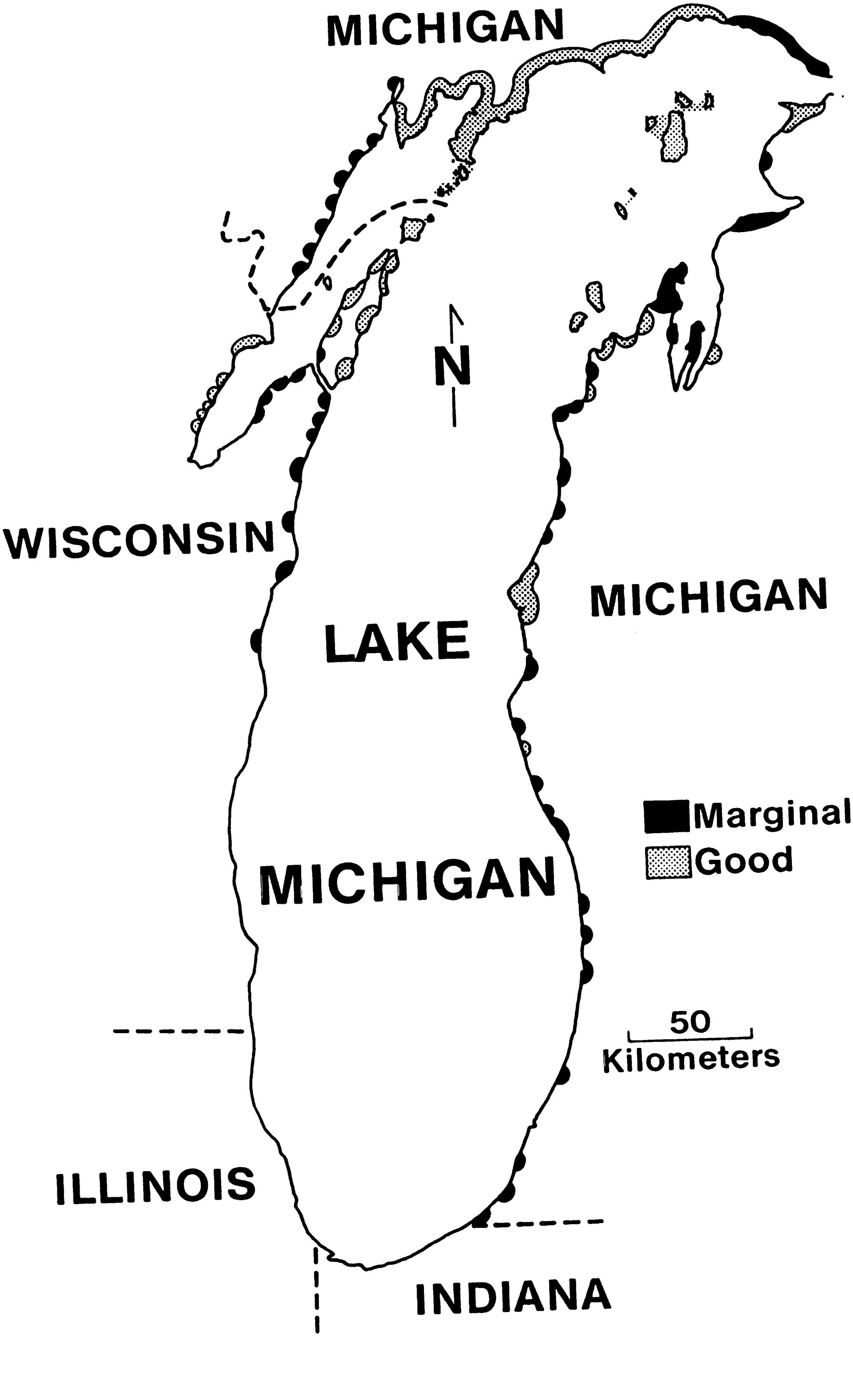
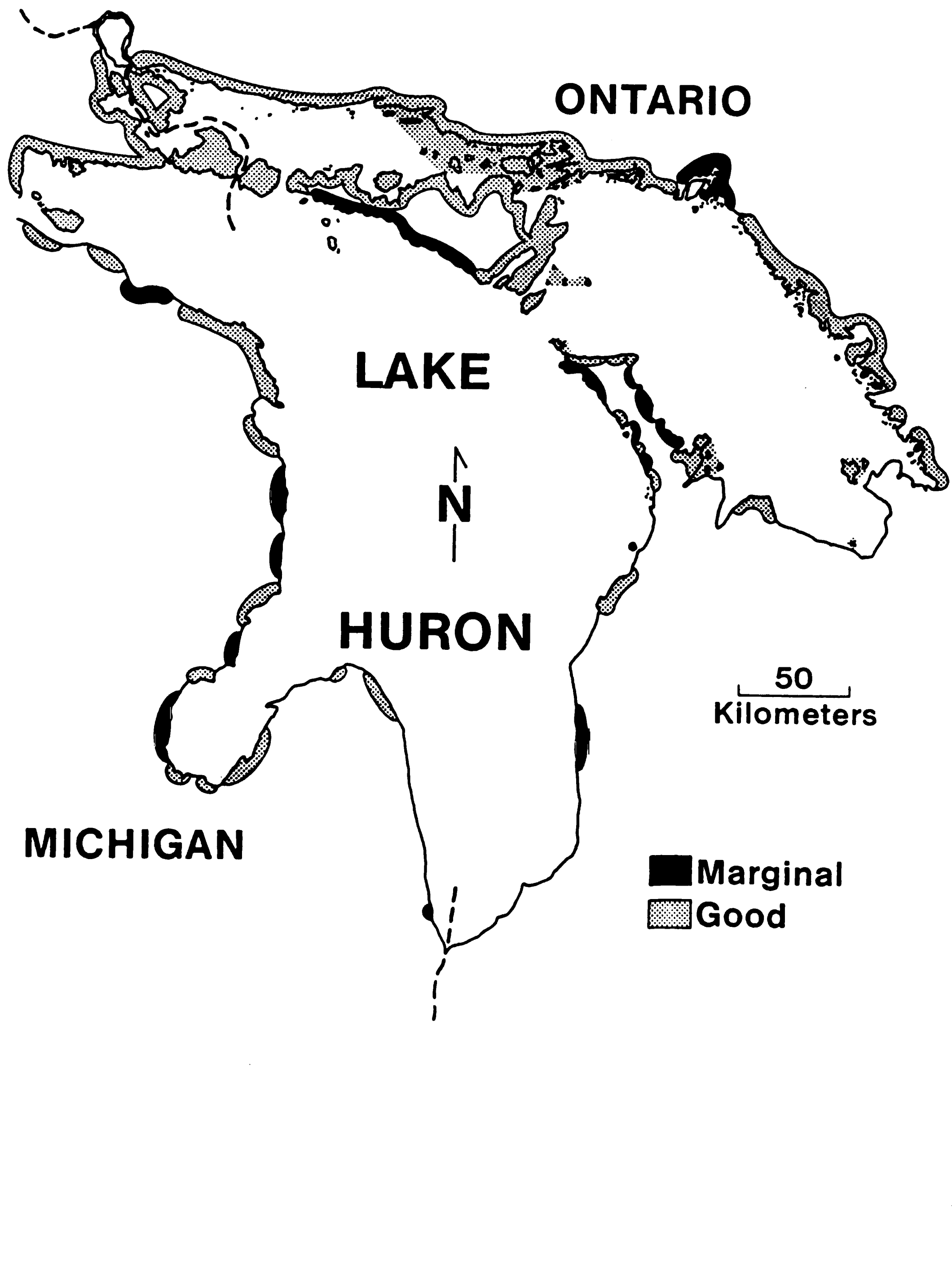

MICHIGAN
N
WISCONSIN
LAKE
MICHIGAN
MICHIGAN
Marginal
Good
50
Kilometers
ILLINOIS
INDIANA

Figure 15. Areas identified as good or marginal potential bald eagle nesting habitat within 1.6 km of Lake Huron.


ONTARIO
LAKE
N
HURON
50
Kilometers
MICHIGAN
Marginal
Good

mostly marginal and scattered along their perimeters (Figures 16 and 17). Total linear distance of suitable (i.e., good and marginal) habitat varied by lake (Table 15) and by governmental jurisdiction (Table 16). Of a total of 10596 km of shoreline surveyed, 66.1% (7006 km) was classified as either good or marginal potential nesting habitat.

Search Image Model

The PATREC model of the search image defined and incorporated 6 habitat attributes relating to tree cover, human disturbance, potential foraging, shoreline irregularity, and availability of suitable trees for perching and nesting (Table 17). The first 2 attributes were initially assessed from the air to determine if further evaluation was appropriate. In the model (Table 14, Figure 12), the thresholds for Attributes 1 and 2 had to be met in order to proceed with further analysis of the habitat using the functional components of the model (Attributes 3 through 6), whose conditional probabilities are then used in calculating the overall likelihood of good, marginal, or unsuitable habitat given the observed conditions. Attributes 3-6 are also organized into the same order that they were assessed from the air, although after Attributes 1 and 2, position in the model does not affect the outcome. Type/amount of Nearest Human Disturbance is partitioned into 3, inclusive levels to reflect the influence of varying amounts of human activity on potential habitat evaluation. The conditional probabilities of good habitat for the last 3 attributes are weighted high to stress the benefit of additional potential foraging areas or the critical importance of having suitable perch or nest trees present.

Posterior probabilities from the PATREC model were calculated for a series of

Figure 16. Areas identified as good or marginal potential bald eagle nesting habitat within 1.6 km of Lake Erie.

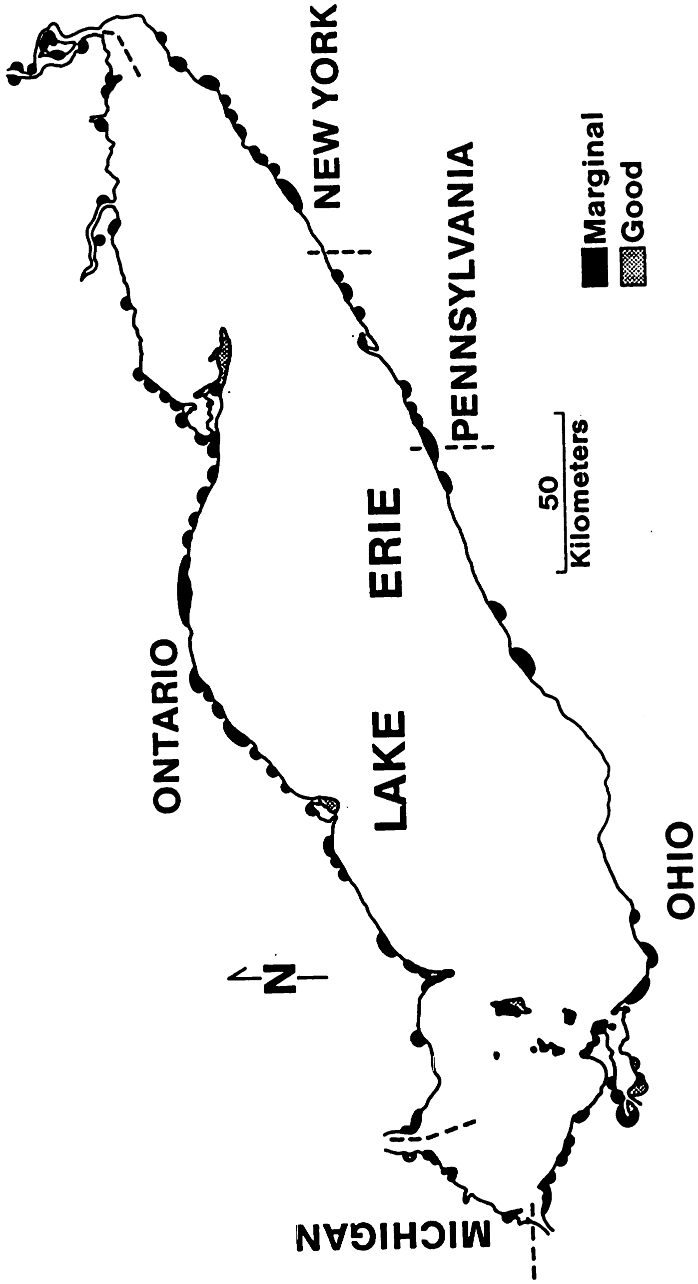

NEW YORK
PENNSYLVANIA
ONTARIO
LAKE
ERIE
OHIO
MICHIGAN
N
50
Kilometers
Marginal
Good

Figure 17. Areas identified as good or marginal potential bald eagle nesting habitat within 1.6 km of Lake Ontario.

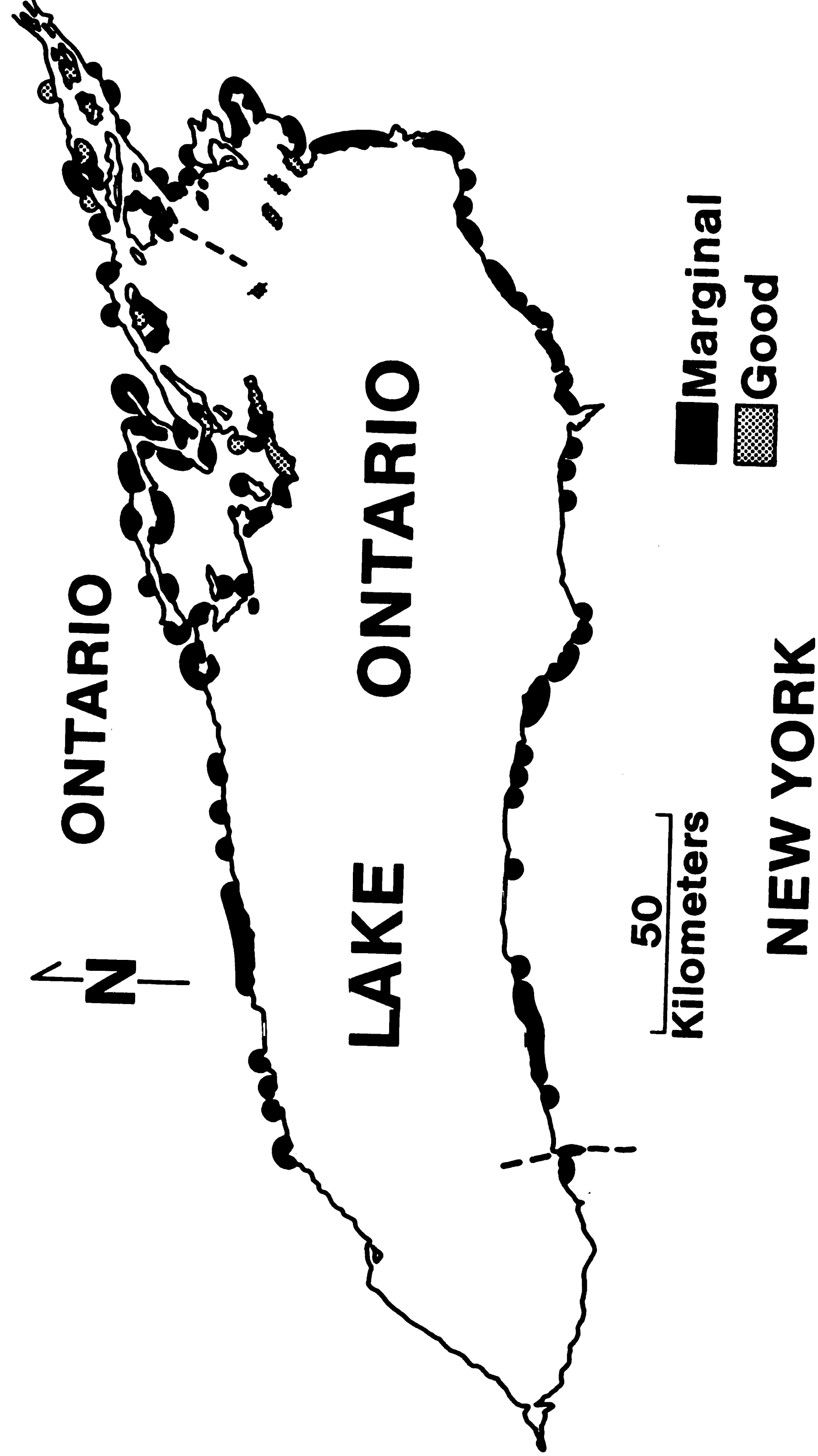

ONTARIO
LAKE ONTARIO
NEW YORK
N
50
Kilometers
Marginal
Good

Table 15. Shoreline (km) by habitat classification for each Great Lake surveyed. Percents are of linear distance in Total Column.

Lake	Good km (%)	Marginal km (%)	Unsuitable km (%)	Total km (%)
Superior	2186 (76.5)	186 (6.5)	487 (17.0)	2859 (27.0)
Michigan	624 (32.5)	353 (18.4)	942 (49.1)	1919 (18.1)
Huron	1975 (65.0)	319 (10.5)	744 (24.5)	3038 (28.7)
Erie	94 (7.0)	543 (40.4)	707 (52.6)	1344 (12.7)
Ontario	112 (7.8)	614 (42.8)	710 (49.4)	1436 (13.5)
TOTAL	4991 (47.1)	2015 (19.0)	3590 (33.9)	10596

Table 16. Shoreline (km) by habitat classification for each political jurisdiction along the shorelines of the Great Lakes. Percents are of linear distance in Total Column.

Region	Good km (%)	Marginal km (%)	Unsuitable km (%)	Total km (%)
Michigan	1837 (60.5)	427 (14.0)	774 (25.5)	3038 (28.7)
Wisconsin	545 (51.7)	89 (8.4)	421 (39.9)	1055 (9.9)
Minnesota	171 (45.1)	74 (19.5)	134 (35.4)	379 (3.6)
Ohio	20 (5.3)	140 (37.2)	216 (57.5)	376 (3.5)
Illinois	0 (0.0)	0 (0.0)	87 (100.0)	87 (0.8)
Indiana	0 (0.0)	0 (0.0)	69 (100.0)	69 (0.6)
Pennsylvania	0 (0.0)	43 (51.2)	41 (48.8)	84 (0.8)
New York	47 (7.2)	331 (50.7)	275 (42.1)	653 (6.2)
United States Subtotal	2620 (45.7)	1104 (19.2)	2017 (35.1)	5741 (54.2)
Ontario, CANADA	2371 (48.8)	911 (18.8)	1573 (32.4)	4855 (45.8)
TOTAL	4991 (47.1)	2015 (19.0)	3590 (33.9)	10596

Table 17. Posterior probabilities resulting from a Pattern Recognition model of the survey image used to identify potential bald eagle breeding habitat during aerial surveys of Great Lakes' shoreline[1].

Conditions/Habitat Attributes (from PATREC Model, Table 1)[2]	Habitat Class		
	Good	Marginal	Unsuitable
1. Best case, all conditions met	0.96	0.04	0.00
2. Moderate disturbance	0.90	0.10	0.00
3. Heavy disturbance	0.62	0.37	0.01
4. No additional foraging	0.78	0.21	0.01
5. No suitable perch trees	0.39	0.58	0.03
6. No suitable nest trees	0.39	0.58	0.03
7. No suitable perch or nest trees	0.02	0.85	0.13
8. No perch trees/no additional foraging/shoreline	0.08	0.73	0.19
9. No foraging/moderate disturbance	0.59	0.39	0.02
10. No foraging/heavy disturbance	0.23	0.62	0.15
11. No perch or nest trees/no foraging	0.0	0.52	0.48
12. Worst case, no conditions met	0.0	0.31	0.69

[1]Adequate tree cover and distance from human disturbance are assumed.

[2]With the exception of cases 1 and 12, only absent or suboptimal habitat attributes are listed; all other attributes or conditions were met, i.e., optimal.

hypothetical habitat conditions (Table 17). The probability of a habitat being classified as good was great (95.6%) when all attributes are optimal, and nonexistent (0.0%) when none of the model attributes are present, even though at an acceptable distance the type/amount of disturbance significantly affects the amount of habitat classified as good and marginal. Although irregular shoreline and obvious potential foraging areas are not critical along the Great Lakes' shoreline, they are important components in evaluating habitat as good; their absence drops the probability of good habitat nearly 20%. Lack of sufficient potential perching and nesting trees, considered separately or in combination, has the greatest impact on the classification of habitat by the PATREC model. All combinations of absent attributes depressed the probability of good habitat and raised the probabilities of marginal and unsuitable habitat significantly more than when the same attributes were treated individually. All posterior probabilities calculated with the PATREC model describe the probability of classifying a habitat among the three habitat classifications for all habitat remaining after the initial habitat criteria (Attributes 1 and 2) had eliminated approximately 90% of the unsuitable habitat from further analysis.

Comparison to Known Nesting Areas

The number of bald eagle breeding areas was determined: Lake Superior 60; Lake Huron 25; Lake Erie 24; Lake Michigan 8; and Lake Ontario 0 (Table 18). The distribution of breeding areas among habitat classifications was not random within and among Lakes (Table 19). For all Lakes, nests were located within good habitat in a

Table 18. Numbers of bald eagle breeding areas by habitat classification within 1.6 km of a Great Lake 1988-92. Percentage in parentheses.

Lake	Good	Marginal	Unsuitable	Total
Superior	59 (98.3)	1 (1.7)	0 (0.0)	60 (51.3)
Michigan	7 (87.5)	1 (12.5)	0 (0.0)	8 (6.8)
Huron	23 (92.0)	2 (8.0)	0 (0.0)	25 (21.5)
Erie	7 (29.2)	13 (54.2)	4 (16.6)	24 (21.4)
TOTAL	96 (82.1)	17 (14.5)	4 (3.4)	117

Table 19. Test of random selection of habitat type by breeding bald eagles in the Great Lakes Basin.

Region	χ^2 Value	D.F.	P
Lake Superior	284.49	2	<0.001
Lake Michigan	35.02	2	<0.001
Lake Huron	83.45	2	<0.001
Lake Erie	113.60	2	<0.001
ALL LAKES	2970.11	2	<0.001

greater proportion than expected and nests were located within unsuitable habitat at a lesser proportion than expected. For all Lakes except Lake Erie, nests were located within marginal habitat at a lesser proportion than expected. Most of the breeding areas (82.1%) along the Great Lakes were located in good habitat, with breeding areas located in unsuitable habitat only along Lake Erie (Table 18).

DISCUSSION

Aerial Survey

Potential nesting habitat was found along all 5 Great Lakes but was more concentrated and contiguous in the northern lakes, Superior, Michigan, and Huron. The more populated and industrialized southern portions of Lakes Michigan and Huron, and the areas surrounding Lakes Erie and Ontario, contained fewer and more disjoint regions of suitable habitat.

The survey only quantified suitable physical habitat and those potential human disturbances that could be discerned from a moving aircraft. Forage was assumed to be present in quantities needed to raise young to fledging. Additional foraging attributes assessed in the model identified secondary foraging characteristics which would tend to increase prey availability near the potential breeding habitat. No direct measure of foraging availability, however, was determined nor does the data necessary to analyze the potential availability of fish forage in all of the survey areas exist.

Survey Image Model

The primary intent of using the PATREC model was to more objectively quantify the essentially subjective, experience-based search image that made the present exhaustive surveys possible. The PATREC model is species-, seasonally-, geographically-, and survey technique-specific. The model was calibrated to evaluate bald eagle, breeding season (i.e., nesting) habitat, within 1.6 km of the Great Lakes' shoreline, during low-level, aerial surveys. Because the model was designed for use on all 5 Great Lakes, and the prior probabilities were similarly calculated, it will tend to underestimate the probability of good habitat on the upper lakes where good habitat is abundant, and overestimate good habitat on the lower lakes where such habitat is limited. The model, much like any aerial surveyor covering great lengths of unfamiliar habitat, will not pick up the isolated or unusual pockets of good habitat, such as an isolated, relatively undisturbed, lone nest tree in a coastal marsh. Nonetheless, this model documents the approach used in these first, exhaustive aerial surveys of the Great Lakes, and thus provides a baseline standard for comparison, modification, and replication with future efforts.

Comparison to Known Nesting Areas

The comparison between PATREC classifications and current bald eagle breeding areas showed that the model was sensitive and correctly classified currently used habitat. More refinement of parameters is needed, however, to further identify and quantify specific areas along the Great Lakes shoreline which would be suitable for bald eagle breeding habitat. The PATREC model failed to identify 4 areas along Lake Erie where single nest trees or small woodlots were used for nesting within large marshes; because of the lack of forest cover, we classified the areas as unsuitable. All 4 breeding areas have been established since 1986 and since then the Lake Erie population increased from 14 to 31 occupied breeding areas.

The number of breeding areas for raptors are set by availability of food or nest sites, whichever is in shorter supply (Newton 1979). Indications of density dependant factors for partitioning of bald eagle territories near Lake Erie include adult mortality within territories due to territorial battles, movement of nesting areas when a new breeding area nearer the shoreline precludes a more interior nest's corridor to the lake, and movement to a new nest site after the first year a breeding area is occupied when human disturbance of the breeding pair occurs within the exclusionary zone during the breeding season (unpubl. data, P. Hunter and M. Shieldcastle). The greater forage productivity of Lake Erie in comparison to the northern lakes (Great Lakes Basin Commission 1975b) may also make forage more available and increase the number of breeding areas that can be successful in marginal habitat (Hansen 1987). Primary productivity is greatest in the western basin of Lake Erie, lesser in the central basin, and least in the eastern basin (Great Lakes Basin Commission 1975c). The majority (21 of 31) of breeding areas occupied in 1993 were within the western basin.

The observance of potential human disturbance was also greater along the Lake Erie shoreline than along the other lakes and decreased the quality of breeding habitat using our classification system. Only Lake Erie breeding areas had greater than expected occurrence within all suitable habitat (i.e., good and marginal) in contrast to the northern lakes where breeding areas in marginal habitat were less than expected. The large number of breeding areas within marginal habitat may be partially explained by the aggressive management strategies of the Ohio Department of Natural Resources and Ontario Ministry of Natural Resources. Both agencies have cooperative management plans with private landowners, monitor nest sites using volunteers, and maintain at minimum, a 400 m human exclusionary zone during the breeding season (Grier et al. 1983). The management of human activities in areas surrounding these nests may improve the suitability of suboptimal habitat for bald eagles. This, however, could not be discerned from an aerial survey.

MANAGEMENT IMPLICATIONS

The majority (80.5%) of areas identified as suitable (i.e., good or marginal) breeding habitat lie within the 3 northern lakes. Only 9.1% of the suitable habitat is located along Lake Erie, however, Lake Erie has a greater density of breeding eagles than any of the other lakes, and greater human disturbance potential, but its greater primary productivity and aggressive management of human presence near nests during the breeding season may compensate at present for its lack of habitat within the good classification. Additional silvicultural management of areas identified as marginal or unsuitable for increased stand density of supercanopy trees may increase the available habitat in the future. Proposed recreational facilities along Lake Erie need to accommodate the limited habitat for eagles that currently exists there.

The identification and protection of historic breeding areas needs to be incorporated into management of potential breeding habitat. We have collectively observed the reoccupation of nest trees along the 4 lakes which had been used historically. Land management decisions that could alter these habitats along any of the lakes by either decreasing forested areas or increasing human disturbance could decrease the potential reoccupation of areas where eagles were extirpated in the 1950s and 1960s. Most of the current breeding areas along the lakes are far from human presence. Loss of historic or currently occupied habitats not only decreases the recovery of eagles within the Great Lakes ecosystem, but also could lessen their importance as an ecosystem monitor species of Great Lakes water quality by precluding their presence in large areas of the basin.

The primary management challenge in the Great Lakes region is to preserve large enough tracts of breeding habitat along the shores of Lake Erie to maintain the breeding population there, manage for improvement of additional habitat, and protect the remaining shorelines of the Great Lakes from large-scale landscape changes that would render these areas less likely to support breeding eagles.

LITERATURE CITED

Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. J. Toxicol. Environ. Health 33:395-453.

Bowerman, W. W., D. A. Best, J. P. Giesy, T. J. Kubiak, and J.G. Sikarskie. 1993. The influence of environmental contaminants on bald eagle populations in the Laurentian Great Lakes, North America. IV World Conf. on Birds of Prey, Berlin.

Edwards, W., H. Lindman, and L. J. Savage. 1963. Bayesian statistical inference for psychological research. Pysch. Rev. 70:193-242.

Great Lakes Basin Commission. 1975a. Report: Great Lakes Basin Framework Study. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Mich.

Great Lakes Basin Commission. 1975b. Report: Great Lakes Basin Framework Study. Appendix 4 Limnology of Lakes and Embayments. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Mich.

Great Lakes Basin Commission. 1975c. Report: Great Lakes Basin Framework Study. Appendix 8 Fish. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Mich.

Grier, J. W., J. B. Elder, F. J. Gramlich, N. F. Green, J. V. Kussman, J. E. Mathisen, and J. P. Mattsson. 1983. Northern states bald eagle recovery plan. U. S. Fish & Wildlife Service, Washington, D.C.

Grubb, T. G. 1988. Pattern recognition--a simple model for evaluating wildlife habitat. Res. Note RM-487. USDA For. Serv., Rocky Mount. For. & Rang. Exper. Sta., Ft. Collins, CO. 5 p.

Hansen, A. J. 1987. Regulation of bald eagle reproductive rates in southeast Alaska. Ecol. 68(5): 1387-1392.

International Joint Commission. 1989. Proceedings of the Expert Consultation Meeting on bald eagles. International Joint Commission, Windsor, Ontario.

Kling, C. L. 1980. Pattern recognition for habitat evaluation. unpubl. M.S. thesis. CO. St. Univ., Ft. Collins. 244 p.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, South Dakota. 397 pp.

Ott, L. 1988. An introduction to statistical methods and data analysis, Third Edition. PWS-Kent Publishing Co., Boston.

Postupalsky, S. 1985. The bald eagles return. Natural History 87:62-63.

Sprunt, A., IV, W. B. Robertson, S. Postupalsky, R. J. Hensel, C. E. Knoder, and F. J. Ligas. 1973. Comparative productivity of six bald eagle populations. Trans. No. Am. Wildl. Nat. Res. Conf. 38:96-106.

Williams, G. L., K. R. Russell, and W. K. Seitz. 1977. Pattern recognition as a tool in the ecological analysis of habitat. Pp. 521-531 in Classification, inventory, and analysis of fish and wildlife habitat: proceedings of a national symposium, Phoenix, AZ. Office of Biol. Serv., U.S. Fish and Wild. Serv., Washington, D.C.

SECTION II:

TOXICOLOGICAL ASPECTS

CHAPTER 5:

PCBs AND DDE CONCENTRATIONS IN PLASMA OF NESTLING EAGLES IN THE UPPER MIDWEST

Bald eagle (*Haliaeetus leucocephalus*) populations in North America have increased since the ban of DDT and the lessening of egg-shell thinning effects of its metabolite, p,p'-DDE (Grier 1980; Postupalsky 1985; Colborn 1991). However, the recovery has not been uniform and several regions where populations are not reproducing at a level considered to be healthy continue to exist (Colborn 1991). One of these areas is the Great Lakes Basin, where p,p'-DDE and PCBs have been linked to poor reproductive success (Kozie and Anderson 1991; Bowerman 1991; Best et al. 1993). With recent proposals to alter the status of the eagle under the Federal Endangered Species Act (Federal Register 1990) focusing primarily on the increasing numbers of breeding pairs in the contiguous United States, it is important to understand the dynamics of the population recovery and the role of PCBs and p,p'-DDE, as part of this decision.

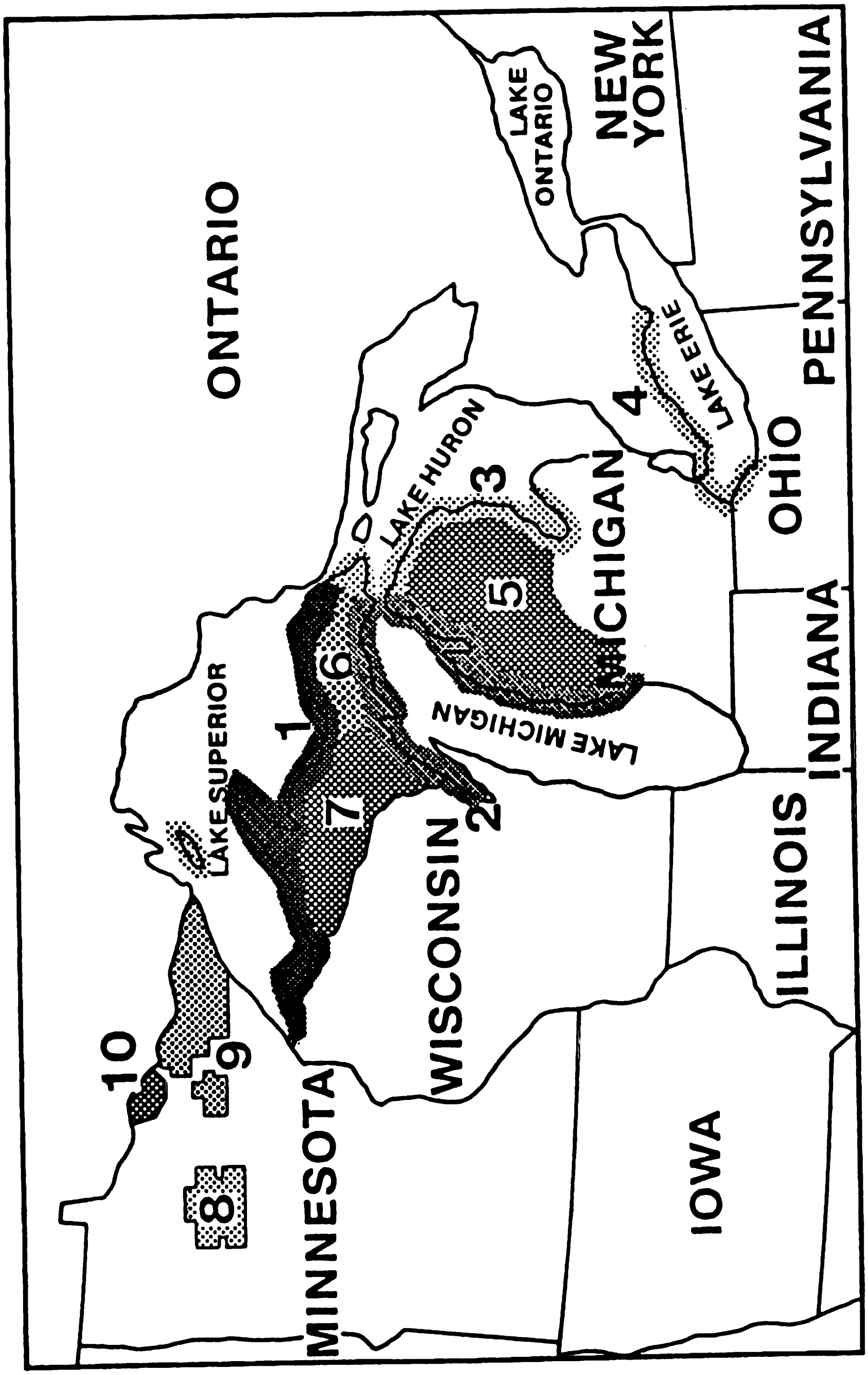
Bald eagles are sensitive to some types of chlorinated hydrocarbons compounds. For instance, the ability to produce viable eggs is impaired by exposure to some of these compounds while others are teratogenic (Wiemeyer et al. 1984; Kubiak et al. 1989; Gilbertson et al. 1991; Chapter 8). It has been argued that the bald eagle is a good biological indicator species of toxic effects of organochlorine compounds for fish eating wildlife and the effects of bioaccumulation and biomagnification in the Great Lakes (Gilbertson pers. comm.). Eagles forage primarily on fish and other vertebrates associated with coastal, riverine and interior aquatic systems. Concentrations of p,p'-DDE and PCBs in the plasma of nestlings reflect their exposure to these compounds from the prey species within their breeding area (Frenzel 1985). In order to determine the current relationships between concentrations of PCBs and p,p'-DDE in bald eagles and reproductive success, we measured concentrations of these compounds as well as several other organochlorine insecticides in plasma of nestling bald eagles and compared concentrations with bald eagle productivity between 1977 and 1993 in 10 subpopulations within and adjacent to the Great Lakes Basin.

STUDY AREA

Our study area consisted of ten subpopulations (Figure 18). These were defined as: the area within 8.0 km of the United States' (U.S.) and Canadian shorelines of the Great Lakes and anadromous fish accessible areas along 1) Lake Superior (LS), 2) Lake Michigan (LM), 3) Lake Huron (LH), and 4) Lake Erie (LE); areas in Michigan greater than 8.0 km from the shorelines of the Great Lakes and not along anadromous fish accessible areas in 5) the lower peninsula (LP), 6) the eastern upper peninsula (EUP) east of U.S. Highway 41, and 7) the western upper peninsula (WUP) west of U.S. Highway 41; and 8) the Chippewa National Forest (CNF), 9) the Superior National Forest (SNF), and 10) Voyageurs National Park (VNP) in Minnesota (Figure 18).

The relative composition of the vegetative cover types varies greatly across the Great Lakes Basin. A northern spruce-fir forest occurs along the north shore of Lake Superior where dominant trees include aspen (*Populus grandidentata, P. tremuloides*), spruce (*Picea mariana, P. glauca*), and balsam fir (*Abies balsamea*). The central lakes area comprising the south shore of Lake Superior, and northern shores of Lakes Michigan and Huron consists of mixed northern hardwood-pine forest of maple (*Acer rubrum, A. saccharum*), oak (*Quercus rubra, Q. alba*), and pine (*Pinus strobus, P.*

Figure 18. Ten subpopulations used for comparison of PCB and p,p'-DDE concentrations in plasma of nestling bald eagles in the midwest. Subpopulations were: within 8.0 km of Lakes 1) Superior, 2) Michigan, 3) Huron, and 4) Erie; interior areas within 5) the northern lower, 6) eastern upper, and 7) western upper peninsulas of Michigan; and 8) the Chippewa and 9) Superior National Forests, and 10) Voyageurs National Park, Minnesota.


ONTARIO
NEW YORK
LAKE ONTARIO
PENNSYLVANIA
LAKE ERIE
OHIO
4
LAKE HURON
3
MICHIGAN
5
INDIANA
LAKE MICHIGAN
6
1
LAKE SUPERIOR
7
2
WISCONSIN
ILLINOIS
IOWA
10
9
8
MINNESOTA

banksiana, P. resinosa), southern Lakes Michigan and Huron, and Lake Erie are primarily oak forests (Great Lakes Basin Commission 1975). Vegetative types within the Chippewa and Superior National Forests and Voyageurs National Park include boreal forests of black spruce, eastern tamarack (*Larix laricina*), and eastern arborvitae (*Thuja occidentalis*), and mixed northern hardwood-pine forests of quaking aspen, red, white, and jack pine, balsam fir, maple, and paper birch (*Betula papyrifera*) (Fraser et al. 1985).

METHODS

Blood Plasma Collection, Sex and Age Determination

Blood was collected from 309 nestling bald eagles in Michigan, Minnesota, Ohio, Ontario, and Wisconsin between 1987 and 1992. Sterile techniques were used to collect blood from the brachialus vein with heparinized glass syringes fitted with 22 or 24 gauge needles. The syringes had previously been washed with hexanes and acetone. Samples of whole blood were transferred to heparinized vacuum tubes, kept on ice in coolers, and centrifuged within 48 hours of collection. Blood plasma was decanted and transferred to vacuum tubes and frozen (Morizot et al. 1985). We determined the age and sex of nestlings by measuring the eighth primary feather and foot pad of nestlings and using these measurements in mathematical growth rate and sexual dimorphism equations (Bortolotti 1984).

Quantification of Chlorinated Hydrocarbons

Samples were analyzed by two different laboratories with two comparable methods. Samples collected in 1987 through 1989 were analyzed by the Environmental Laboratory of the Michigan Department of Public Health (MDPHL). Samples collected after 1989 were analyzed by the Aquatic Toxicology Laboratory at Michigan State University (MSU-ATL). The MSU-ATL method was an alteration of the MDPHL method. Comparison between methods was accomplished using spiked bovine serum provided by MDPHL. Recoveries of organochlorine pesticides and Aroclor 1254 from reference material was previously reported as averaging 92% and 87%, respectively (Mora et al. 1993).

At MDPHL, individual 2-4 ml samples of plasma were dissolved in methanol and extracted twice with 5 ml of a 1:1 mixture of hexane-ethyl ether by agitating on a rotary mixer for 20 minutes at 50-55 rpm. Extracts were concentrated on a hot water bath to a volume of 0.5 ml. Clean-up was done on a 7 mm Chromaflex column packed with 2.5 g of Florisil using 10 ml of hexane. Elution of polycholorinated biphenyls (PCBs) and chlorinated hydrocarbon pesticides from the Chromaflex column was accomplished with 20 ml of 6% ethyl ether/hexane. Elution of dieldrin from the column was accomplished with 20 ml of 20% ethyl ether/hexane. Separation of PCB from the chlorinated hydrocarbon pesticides was accomplished with a Chromaflex column packed with Silica Gel 60. The fraction containing hexachlorobenzene (HCB) and mirex was eluted with 15 ml hexane. Aroclor 1260, Aroclor 1016, and polybrominated biphenyl (PBB) were eluted with an additional extraction with 20 ml hexane. Elution of Aroclor 1016 and chlorinated hydrocarbon pesticides was accomplished with 20 ml of benzene (Michigan Department of Public Health 1987). Concentrations of organochlorine pesticides and PCBs were determined by gas chromatography with confirmation of pooled samples by mass spectrometry (Price et al. 1986; Michigan Department of Public Health 1987). Gas chromatography was performed on a Varian 3700 gas chromatograph equipped with small volume pulsed ^{63}Ni electron capture detector, Varian 8000 Auto Sampler, and CDS-111 microprocessor. A 1.83 m x 0.64 cm x 2 mm i.d. glass column packed with 3% SE-30 was used. Nitrogen flow rate was 30 ml/min through the column during operation. Total PCB concentrations were determined on the basis of mean weight percent factors (Webb and McCall 1973). The following compounds: 1,1'-(2,2,2-Trichloroethylidene)bis[4-chlorobenzene] (p,p'-DDT), and its metabolites p,p'-DDD and p,p'-DDE, HCB, heptachlor epoxide, cis-nonachlor, trans-nonachlor, oxychlordane, dieldrin, PBB, toxaphene, mirex, alpha-chlordane, and gamma-chlordane, were identified by reference to the relative retention time of p,p'-DDE x 100 and quantified by comparison to authentic standards (Michigan Department of Public Health 1987).

MSU-ATL analytical methods were described previously (Mora et al. 1993). Extraction was by the method of Burse et al. (1990) using hexane and ether as solvents. Cleanup was by the method of Ribick et al. (1982). The internal standard for GC analysis was 50 μl of PCB #30 (11.4 ng/ml). Gas chromatography was performed on a Perkin Elmer 8500 gas chromatograph, with a ^{63}Ni electron capture detector, and a fused silica capillary column DB-5 (J&W Scientific, Folsom, CA), 30 m x 0.25 mm i.d., 0.25 μm film thickness. The injector was operated in splitless mode with helium as a carrier gas. A Perkin Elmer 8300 autosampler was used to inject the samples. The chromatographic data were transferred directly to a computer. Total concentrations of PCBs were determined by congener summing. Individual PCB congener concentration response factors and a gravimetric calibration mixture obtained from Columbia National Fisheries Contaminant Laboratory. The calibration standard consisted of a 1:1:1:1 mixture of Aroclors 1242, 1248, 1254, and 1260. Relative response factors were calculated relative to an internal standard, PCB #30 (3,4,5-trichlorobiphenyl). Several congeners eluted from the GC as unresolved peak pairs. In these cases, the combined congener mass was used to calculate the response factor for the peak pair. Total concentrations of PCBs were determined by summing individual masses of the congeners. The following compounds: p,p'-DDT, and its metabolites p,p'-DDD and p,p'-DDE, HCB, heptachlor epoxide, cis-nonachlor, trans-nonachlor, oxychlordane, dieldrin, PBB, toxaphene, mirex, alpha-chlordane, and gamma-chlordane, were identified by reference to the relative retention time of p,p'-DDE x 100 and quantified by comparison to authentic standards (Michigan Department of Public Health 1987).

Reproduction Analysis

We calculated reproductive productivity (i.e., total number of fledged young per occupied nest) and success rate (percent of nests producing at least one fledged young) for bald eagles for all breeding areas within ten subpopulations (Figure 1), 1977-1993 using the method of Postupalsky (1974). Subpopulations were analyzed two ways: by mean of yearly productivity or success rate; and by overall productivity or success rate for the entire time period. Information on the productivity of eagles also exists for central Wisconsin, inland Ohio, and the northern shores of Lakes Huron and Superior in Ontario. These data, however, were not used since they included a classification of "some degree of activity" (Wisconsin) which caused an overestimate of productivity from these areas; were based on information from a geographically isolated subpopulation <5 breeding areas (Ohio); or on information from nests producing fledged young but without information on nest failures (Ontario). Productivity within each region was determined by dividing the total number of young by the number of occupied breeding areas for each year (Postupalsky 1974). Success was determined by dividing the number of nests producing fledged young by the number of occupied breeding areas for each year (Postupalsky 1974). Annual productivities or success rates as well as the overall productivity or success rate for the period 1977-1993, were correlated with concentrations of chlorinated hydrocarbons.

Data Analysis

All concentrations of chlorinated hydrocarbons were converted to geometric means for statistical analyses. Concentrations of p,p'-DDE and PCBs were compared statistically among geographical regions or nestling ages using the Kruskal-Wallis one-way analysis of variance, or between sexes using the Wilcoxin rank sums test (NPAR1WAY procedure, SAS/STAT 6.03, SAS Institute Inc. 1991). Differences among individual locations or ages were determined using the Kruskal-Wallis multiple range test (Miller 1981).

Relationships between geometric mean concentrations of PCBs or p,p'-DDE in plasma of nesting eagles and means of annual productivities or success rates or overall productivity or success rate for the 10 subpopulations were determined using general linear models for regression analysis (PROC GLM, SAS/STAT 6.03, SAS Institute Inc. 1991). Analyses for PCBs were run without the Lake Erie subpopulation due to a preponderance of nestlings sampled that were greater than eight weeks of age which were significantly greater in concentrations of PCBs in blood plasma than younger nestlings, a ratio of PCBs:p,p'-DDE which was over two times greater than any other subpopulation, and observations of adult replacement within breeding areas every five years.

RESULTS

Concentrations of PCBs and p,p'-DDE varied among subpopulations (Table 20). Geometric mean concentrations of PCBs in plasma of nestlings from Great Lakes breeding areas (LS, LM, LH, and LE) were significantly greater ($\chi^2=199.91$, df=9, P=0.0001) than those from Voyageurs National Park, or from interior regions of Michigan and Minnesota. Geometric mean concentrations of p,p'-DDE in plasma of nestlings from Great Lakes (LS, LM, LH, and LE) and Voyageurs National Park breeding areas were significantly greater ($\chi^2=141.07$, df=9, P=0.0001) than those from interior regions of Michigan and Minnesota. Geometric mean concentrations of PCBs and p,p'-DDE were significantly greater in plasma of nestlings which were older than 8 weeks of age (PCBs, $\chi^2=16.737$, df=5, P=0.0050; p,p'-DDE, $\chi^2=12.883$, df=5,

Table 20. Geometric mean, standard deviation, range, and frequency of detectable concentrations of Total PCBs and p,p-DDE in plasma of 309 nestling bald eagles from 10 subpopulations in the upper midwest, 1987-1993.

		Total PCBs				p,p'-DDE			
Area[1]	n	Geometric Mean (ug/kg)	S.D.	Range	Frequency (%)	Geometric Mean (ug/kg)	S.D.	Range	Frequency (%)
CNF	43	7	2	<10-67	23	3	2	<5-29	19
SNF	15	5	1	<10-18	7	3	1	<5-8	13
VNP	21	47	4	<10-1615	91	20	3	<5-206	95
LP	49	31	2	<10-200	96	10	2	<5-193	86
EUP	16	32	2	<10-146	94	12	2	<5-24	94
WUP	48	25	3	<10-177	88	10	3	<5-245	79
LS	45	127	2	12-640	100	25	3	<5-306	89
LM	25	154	2	14-628	100	35	2	<5-235	100
LH	12	105	3	5-928	100	25	3	<5-78	92
LE	35	199	2	81-1325	100	22	3	<5-429	100

[1]Areas were: Chippewa (CNF) and Superior (SNF) National Forests, and Voyageurs National Park (VNP), Minnesota; lower (LP), eastern upper (EUP), and western upper (WUP) peninsulas of Michigan; and Lakes Superior (LS), Michigan (LM), Huron (LH), and Erie (LE).

P=0.0245; Table 21) compared to concentrations in plasma of younger nestlings. Geometric mean concentrations of PCBs and p,p'-DDE in plasma of nestling eagles were not related to sex (PCBs, P=0.3340; p,p'-DDE, P=0.6362 ; Table 22).

All productivity measurements were significantly and inversely correlated with geometric mean concentrations of PCBs and p,p'-DDE in plasma of nestling eagles. Overall productivity within subpopulations was significantly and inversely correlated with geometric mean concentrations of PCBs (P=0.0003, R^2=0.869, Figure 19) and p,p'-DDE (P=0.0001, R^2=0.945, Figure 20). Mean annual productivity within subpopulations was significantly and inversely correlated with geometric mean concentrations of PCBs (P=0.0005, R^2=0.839, Figure 21) and p,p'-DDE (P=0.0001, R^2=0.950, Figure 22). Overall success rates within subpopulations were significantly and inversely correlated with geometric mean concentrations of PCBs (P=0.0005, R^2=0.840, Figure 23) and p,p'-DDE (P=0.0001, R^2=0.923, Figure 24). Mean annual success rates within subpopulations were significantly and inversely correlated with geometric mean concentrations of PCBs (P=0.0009, R^2=0.812, Figure 25) and p,p'-DDE (P=0.0001, R^2=0.927, Figure 26) .

DISCUSSION

Increased concentrations of PCBs and p,p'-DDE are known to be related to decreased productivity in bald eagles (Wiemeyer et al. 1984). Reproduction of bald eagles is considered to be impaired when productivity, measured as young/occupied nest, is less than 1.0. A productivity of 0.7 is necessary to maintain population stability

Table 21. Geometric mean, standard deviation, and range of Total PCBs and p,p-DDE in plasma of nestling bald eagles by age in weeks, 1987-1993. Letters signify significant differences among ages.

		Total PCBs			p,p'-DDE		
Age[1] (weeks)	n	Geometric Mean (ug/kg)	S.D.	Range	Geometric Mean (ug/kg)	S.D.	Range
<5	24	46 C	127	<10-628	8 C	11	<5-52
5	24	40 C	48	<10-160	12 B	13	<5-41
6	22	41 C	64	<10-206	11 B	12	<5-12
7	26	39 C	48	<10-196	11 B	16	<5-73
8	16	72 B	48	<10-158	19 A	12	<5-43
>9	6	175 A	241	<10-640	18 A	13	<5-35

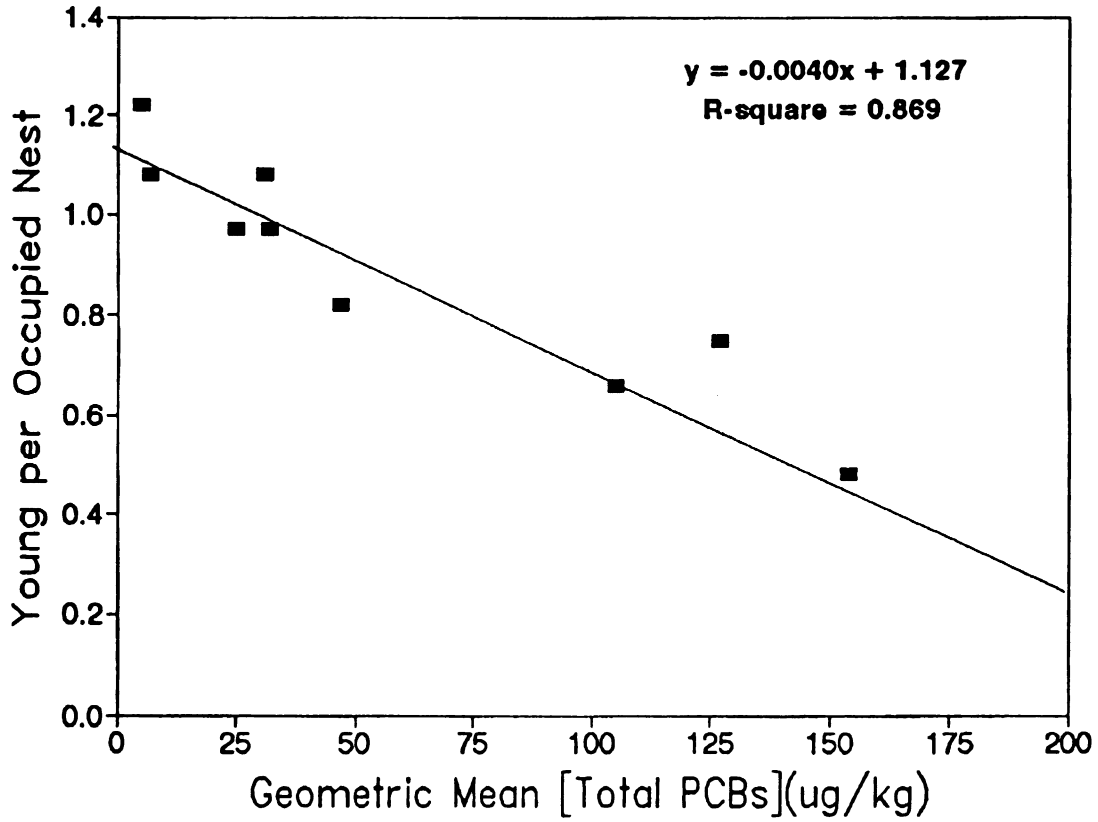
[1]Age determined using 8th primary feather measurements (Bortolotti 1984)

Table 22. Geometric mean, standard deviation, and range of Total PCBs and p,p-DDE in plasma of nestling bald eagles by sex, 1987-1993.

		Total PCBs			p,p'-DDE		
Sex[1]	n	Geometric Mean (ug/kg)	S.D.	Range	Geometric Mean (ug/kg)	S.D.	Range
Male	56	53	93	<10-628	13	14	<5-52
Female	51	82	132	<10-640	14	14	<5-73

[1]Sex determined using morphological measurements (Bortolotti 1984)

Figure 19. Relationship between overall productivity, 1977-1993, and geometric mean concentrations of Total PCBs (ug/kg wet wt) in plasma of nestling bald eagles within nine subpopulations in the upper midwest.



y = -0.0040x + 1.127
R-square = 0.869
Young per Occupied Nest
Geometric Mean [Total PCBs](ug/kg)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
25
50
75
100
125
150
175
200

Figure 20. Relationship between overall productivity, 1977-1993, and geometric mean concentrations of p,p'-DDE (ug/kg wet wt) in plasma of nestling bald eagles within ten subpopulations in the upper midwest.

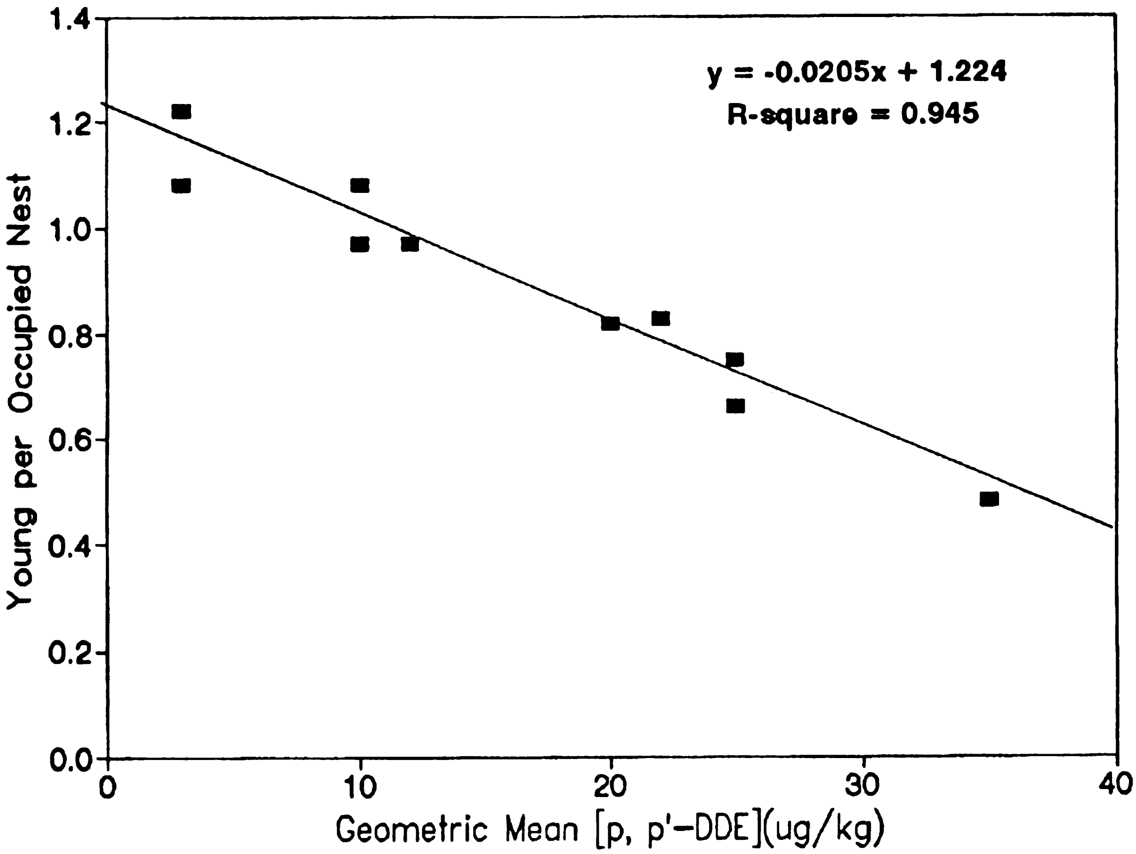

y = -0.0205x + 1.224
R-square = 0.945
Young per Occupied Nest
Geometric Mean [p, p'-DDE](ug/kg)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
10
20
30
40

Figure 21. Relationship between mean annual productivity, 1977-1993, and geometric mean concentrations of Total PCBs (ug/kg wet wt) in plasma of nestling bald eagles within nine subpopulations in the upper midwest. Error bars are one standard deviation from the mean.

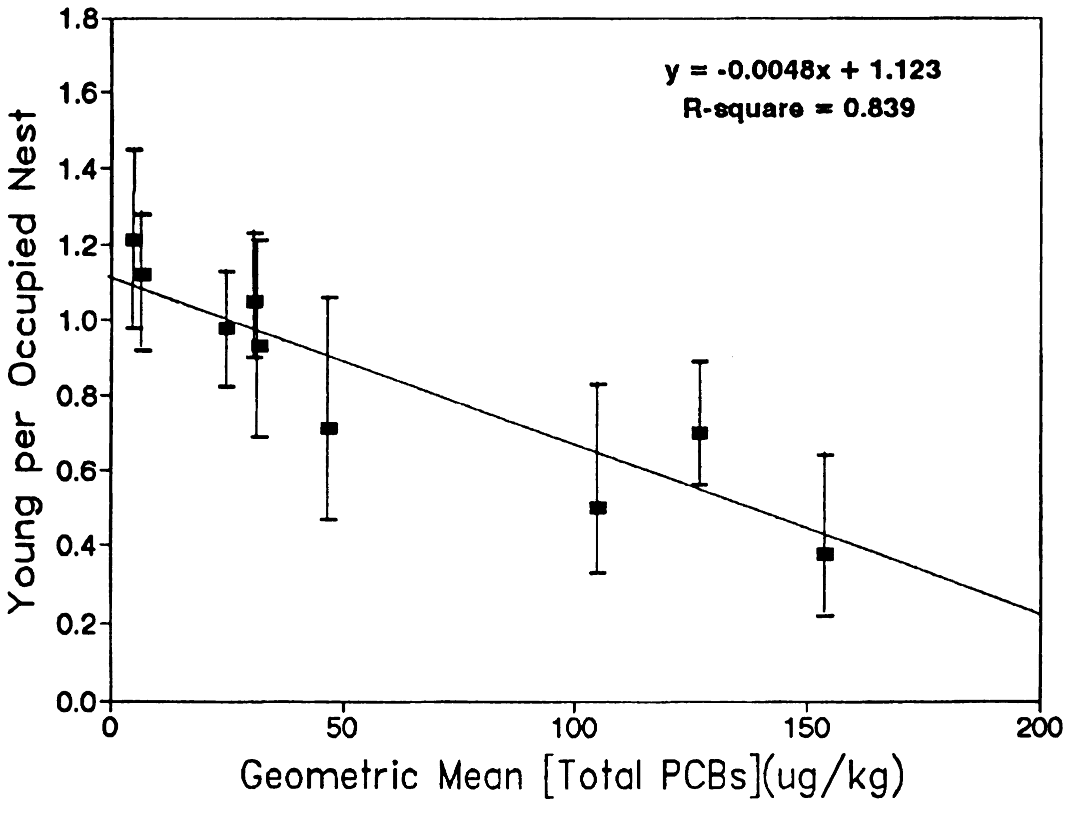

y = -0.0048x + 1.123
R-square = 0.839
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Young per Occupied Nest
0
50
100
150
200
Geometric Mean [Total PCBs](ug/kg)

Figure 22. Relationship between mean annual productivity, 1977-1993, and geometric mean concentrations of p,p'-DDE (ug/kg wet wt) in plasma of nestling bald eagles within ten subpopulations in the upper midwest. Error bars are one standard deviation from the mean.

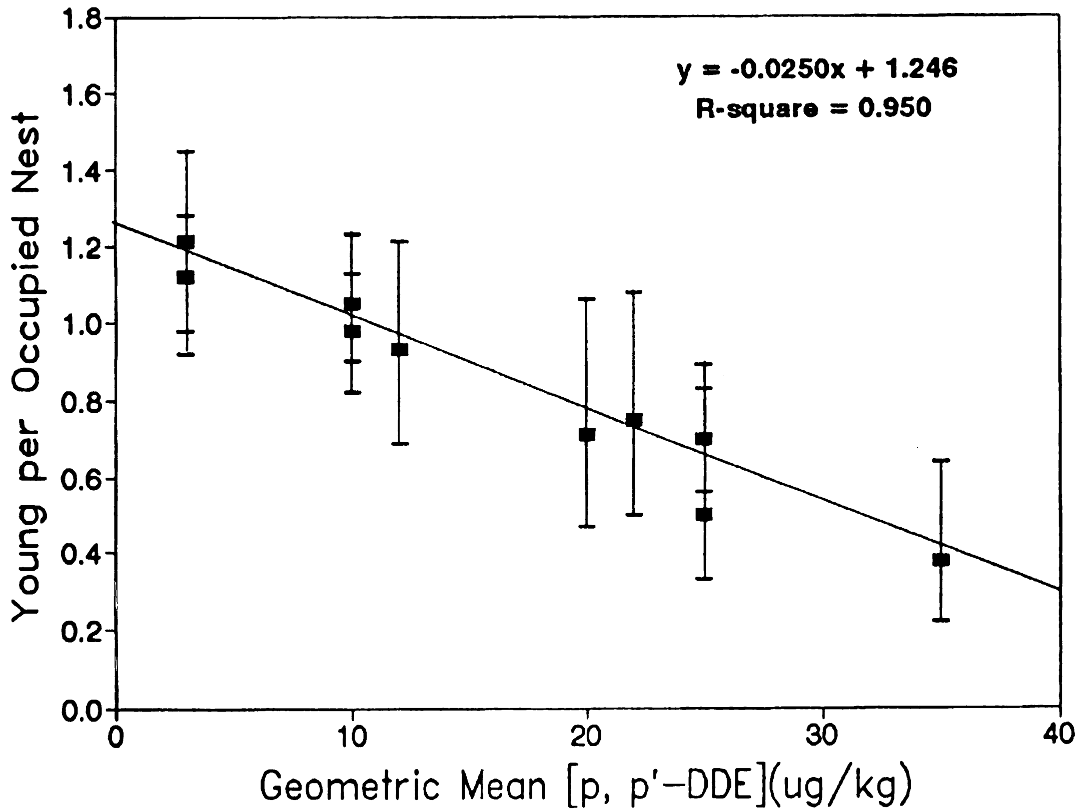

y = -0.0250x + 1.246
R-square = 0.950
Young per Occupied Nest
Geometric Mean [p, p'–DDE](ug/kg)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40

Figure 23. Relationship between overall success rate, 1977-1993, and geometric mean concentrations of Total PCBs (ug/kg wet wt) in plasma of nestling bald eagles within nine subpopulations in the upper midwest.

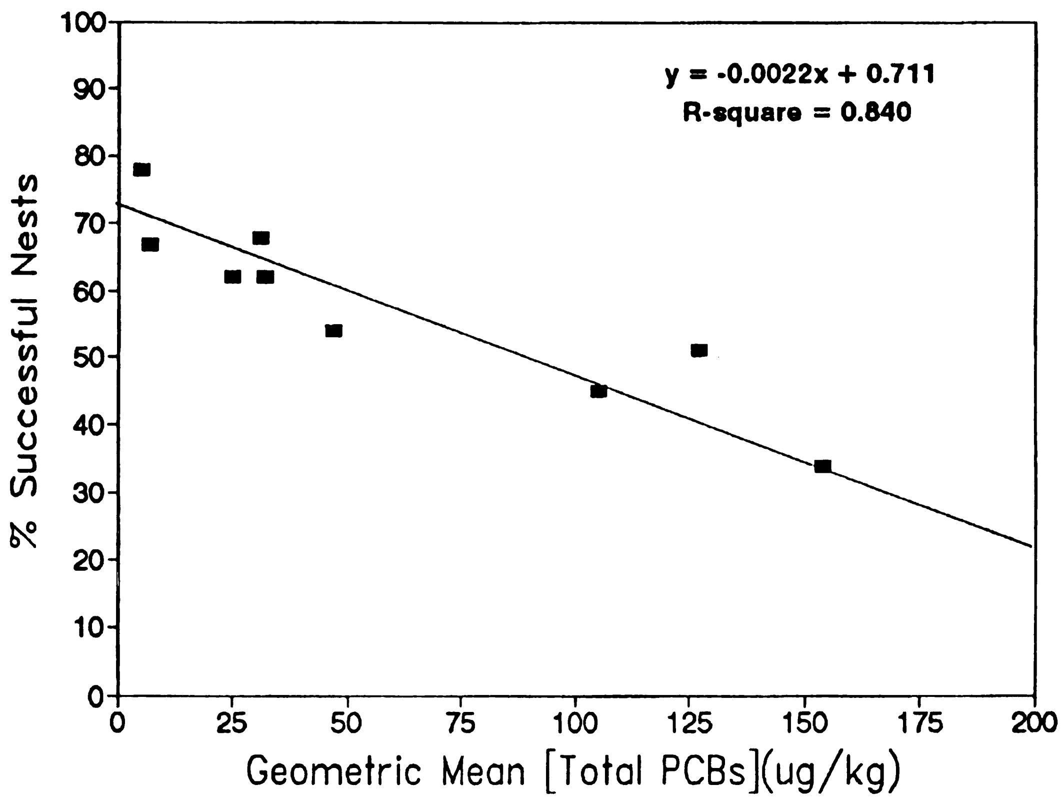

y = -0.0022x + 0.711
R-square = 0.840
% Successful Nests
100
90
80
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
Geometric Mean [Total PCBs](ug/kg)

Figure 24. Relationship between overall success rate, 1977-1993, and geometric mean concentrations of p,p'-DDE (ug/kg wet wt) in plasma of nestling bald eagles within ten subpopulations in the upper midwest.

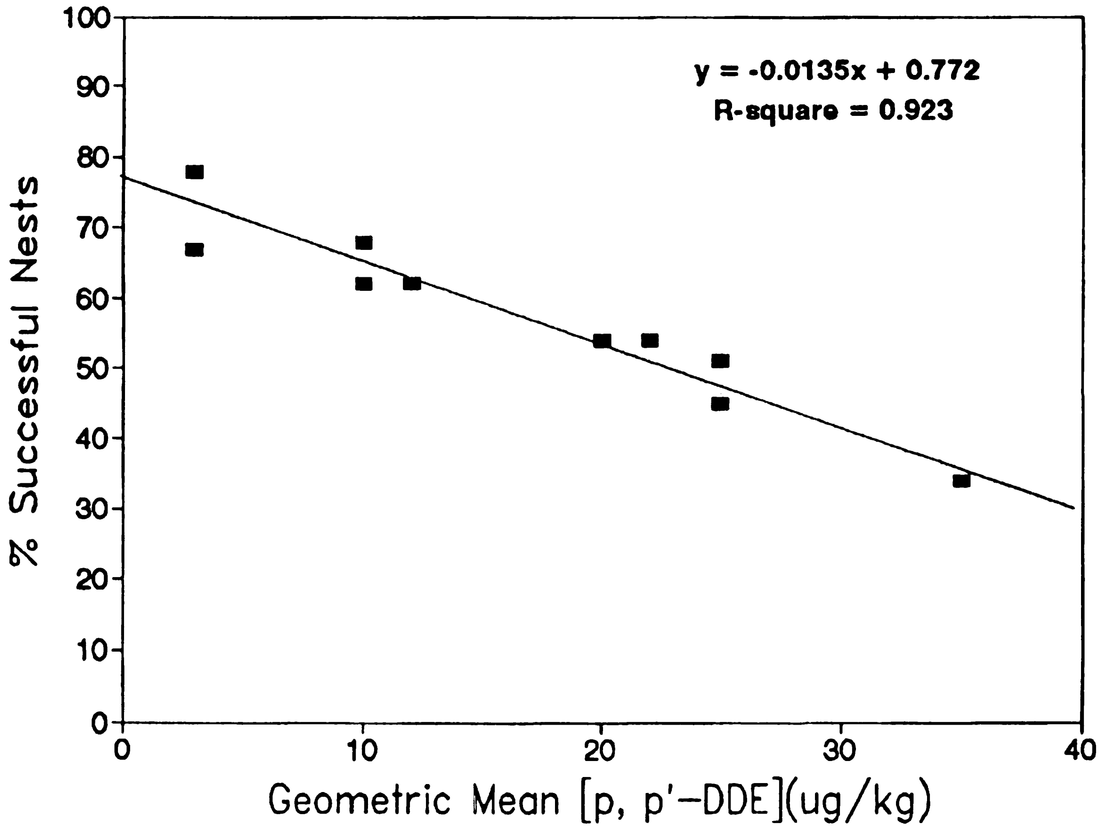
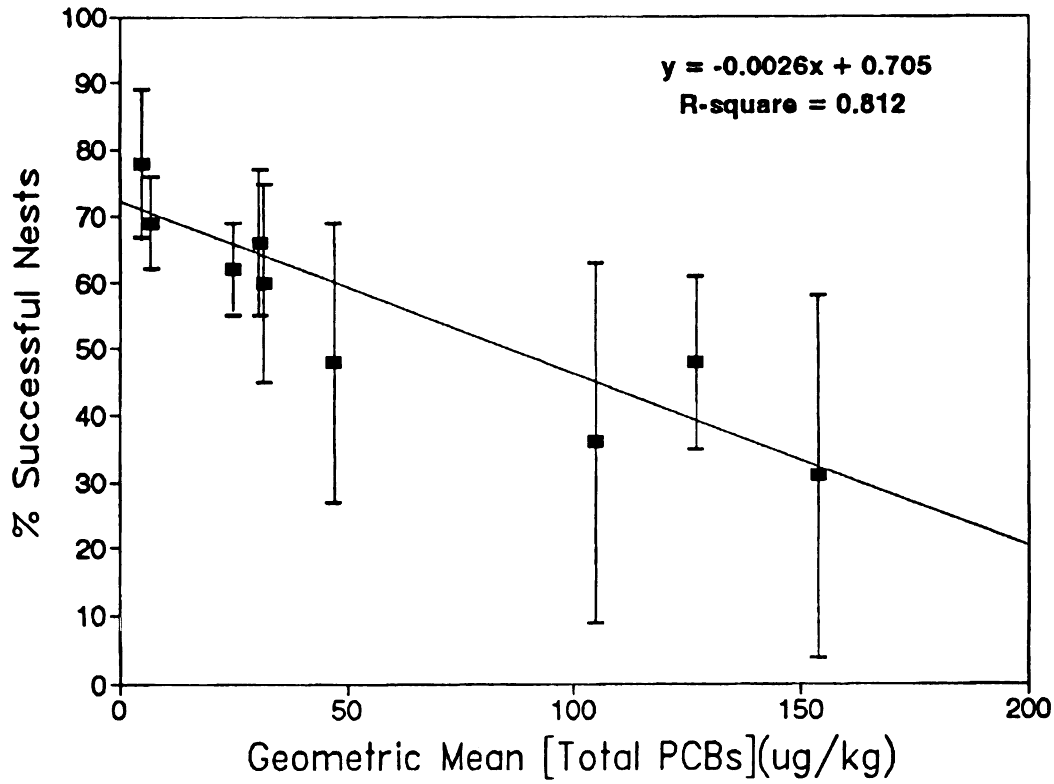
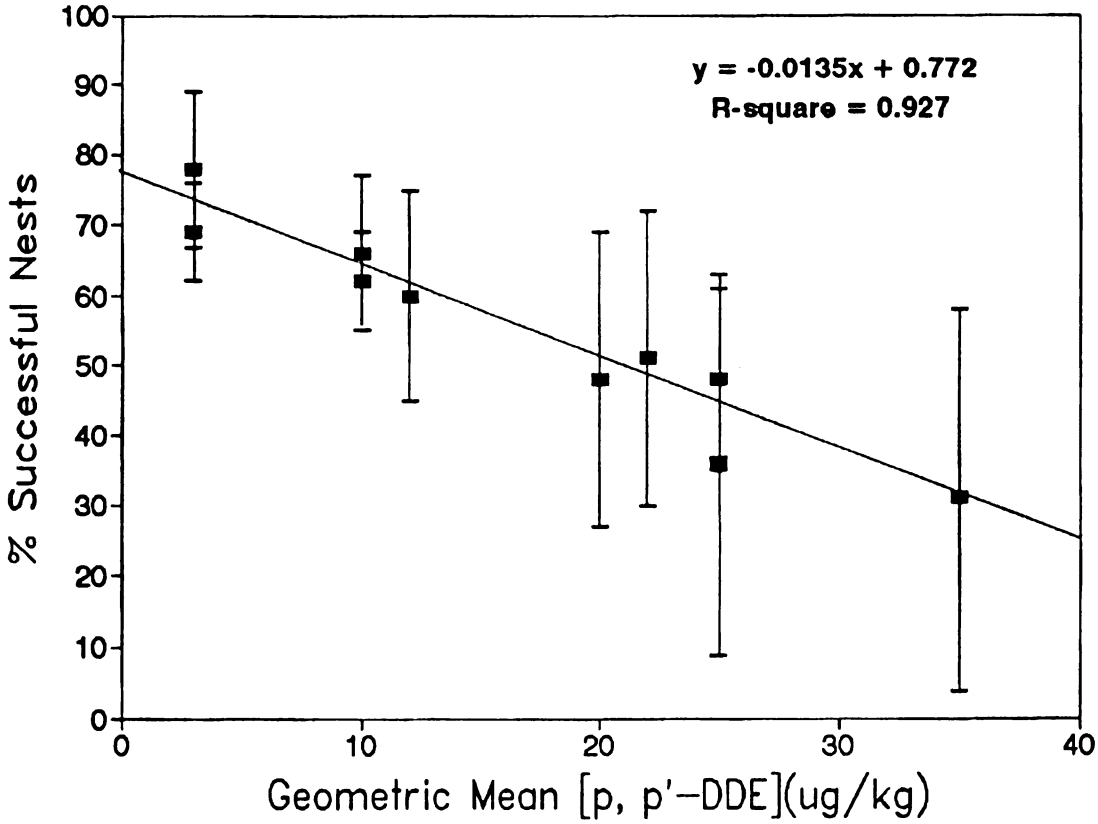

y = -0.0135x + 0.772
R-square = 0.923
% Successful Nests
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
Geometric Mean [p, p'-DDE](ug/kg)

Figure 25. Relationship between mean annual success rate, 1977-1993, and geometric mean concentrations of Total PCBs (ug/kg wet wt) in plasma of nestling bald eagles within nine subpopulations in the upper midwest. Error bars are one standard deviation from the mean.



y = -0.0026x + 0.705
R-square = 0.812
% Successful Nests
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
Geometric Mean [Total PCBs](ug/kg)

Figure 26. Relationship between mean annual success rate, 1977-1993, and geometric mean concentrations of p,p'-DDE (ug/kg wet wt) in plasma of nestling bald eagles within ten subpopulations in the upper midwest. Error bars are one standard deviation from the mean.


y = -0.0135x + 0.772
R-square = 0.927
% Successful Nests
Geometric Mean [p, p'–DDE](ug/kg)
0
10
20
30
40
50
60
70
80
90
100

(Sprunt et al. 1973). Bald eagles using Great Lakes nests and Voyageurs National Park breeding areas are significantly less productive than eagles using interior nests in Michigan or Minnesota (Chapter 9). The relationship between PCBs and productivity, however, is not as strong as for p,p'-DDE. This is believed to be influenced primarily by samples collected within the Lake Erie subpopulation which is influenced by three factors: the majority of nestling eagles greater than eight weeks of age are within this sample; there is documentation that adult turnover rate within five years of beginning nesting within this region is greater than other regions (pers. comm. P. Hunter and M. Shieldcastle); the Lake Erie population of nestling eagles is exposed to greater concentrations of PCBs than p,p'-DDE.

The lesser productivity of bald eagles nesting near the Great Lakes or anadromous accessible rivers is believed to be due to the effects of PCBs and p,p'-DDE. Bald eagle productivity has previously been demonstrated to be inversely correlated with concentrations of PCBs and p,p'-DDE in addled eggs (Wiemeyer et al. 1984). Greater mortality of adult bald eagles has been observed along shores of Lakes Superior, Michigan, and Erie (Kozie 1986; Bowerman 1991; pers. comm., P. Hunter and M. Shieldcastle). Concentrations of PCBs in blood plasma from nestling bald eagles from Great Lakes nests were greater than from those nestlings in Oregon and Washington (Chapter 8). Low reproductive success coupled with high egg and plasma concentrations of p,p'-DDE and PCBs has been noted on the Lower Columbia River (Garrett et al. 1988).

It appears from this study that plasma from nestling bald eagles is an accurate index of PCB and p,p'-DDE of prey within breeding territories (Giesy et al. 1993b). It has previously been shown that blood can be used to measure p,p'-DDE in other species. A significant correlation was found between p,p'-DDE uptake, brain concentrations, and egg concentrations to plasma concentrations for American kestrels (*Falco sparverius*), northern goshawks (*Accipiter gentalis*), Cooper's hawks (*Accipiter cooperii*), and sharp-shinned hawks (*Accipiter striatus*) (Henny and Meeker 1981). It was found that p,p'-DDE concentrations in blood serum was highly correlated with concentrations in fat and breast muscle lipids of the white-faced ibis (*Plegadis chihi*) (Capen and Leiker 1979).

MANAGEMENT IMPLICATIONS

The importance of a vulnerable, relatively uncontaminated, forage base for bald eagle reproduction is imperative for the species ability to successfully reproduce. Effects of environmental contaminants on bald eagle productivity are well known (Wiemeyer et al. 1972, 1984; Frenzel and Anthony 1992; Bowerman 1991). Management techniques that control populations of prey species utilized by bald eagles need to take into account the effect that increases or decreases in contaminated species will have on the bald eagle reproductive success. The need to maintain populations of primarily warm-water fish in interior foraging areas for inland eagles in the midwest is imperative for maintaining the continuing recovery of this species. The fact that concentrations of PCBs and DDT remain at concentrations which are still associated with lesser average productivities presents continuing management issues, even though production of these compounds has ceased in North America and concentrations of most halogenated hydrocarbons in the prey of eagles has decreased in the Great Lakes Region (Giesy et al. 1993a). Current concentrations of both PCBs, p,p'-DDE, and TCDD-EQ (dioxin equivalents) are sufficiently great to cause adverse effects in birds (Wiemeyer et al. 1972, 1984; Frenzel and Anthony 1989; Bowerman 1991; Giesy et al. 1993a). Our results verify that poor productivity of eagles is inversely correlated with exposure to both PCBs and p,p'-DDE, but not with mercury (Chapter 6). Furthermore, we have observed congenital deformities in bald eagles nestlings (Bowerman et al. 1993). Developmental deformities have been observed in the populations where the greatest concentrations of PCBs have been found in the blood of nestling eagles. The results of laboratory and field studies indicate that the lethality of and deformities in embryos of colonial, fish-eating water birds of the Great Lakes are due to the toxic effects of multiple compounds, primarily those coplanar PCBs, PCDDs, and PCDFs, which express their effects through a common mode of action, the Ah receptor (Giesy et al. 1993a). The concentration of total PCBs and TCDD equivalents (Safe 1984), converted from congener specific data, in two addled bald eagle eggs collected near Lakes Michigan and Huron were 83 and 98 ug/g total PCBs and 21,369 and 30,894 pg/g as TCDD-EQ, respectively (Bowerman et al. 1990). In chicken feeding studies, conversion of Aroclor/congener concentrations in feed explained the toxic reproductive effects on laying hens (Brunstrom and Anderson 1988). Concentrations of TCDD-EQ in bald eagle eggs are greater than known effect levels in poultry experiments, either by total PCB concentration or by conversion of individual PCB congeners (Platonow and Reinhart 1973; Brunstrom and Anderson 1988; Kubiak et al. 1989).

Our results suggest that exposure of eagles to Great Lakes fishes should be minimized. Thus, it would be premature to begin hacking programs to reestablish populations of eagles or improve their genetic diversity along the Great Lakes shoreline, especially Lake Erie. Furthermore, management practices that increase the potential exposure of eagles to chlorinated hydrocarbons in Great Lakes fishes, such as passage of fishes around dams on tributaries to Lakes Michigan, Huron, and Erie, could have adverse effects on productivity of bald eagles in regions which are currently sufficiently productive to act as a source of eagles to colonize other areas. Only by maintaining a vulnerable, relatively uncontaminated, food source for eagles during the breeding season can we continue to experience the population recovery of this species in the midwest.

This method is a relatively non-invasive technique that has several advantages for endangered species including minimal harm to the bird, yearly time trends can be established by taking samples in the same area over time, and uptake rates can be determined to observe trends in concentrations in individuals in the field (Henny and Meeker 1981). It does not appear that this type of survey needs to occur each year, however. A schedule of surveying the population once every 5 to 10 years could be used to monitor trends in organochlorine concentrations.

LITERATURE CITED

Best, D.A., W.W. Bowerman, T.J. Kubiak, S.R. Winterstein, S. Postupalsky, M.C. Shieldcastle, and J.P. Giesy. 1993. Reproductive impairment of bald eagles along the Great Lakes shorelines of Michigan and Ohio. Proc. IV World Conf. on Birds of Prey and Owls, Berlin, Germany. In Press.

Bortolotti, G.R. 1984. Criteria for determining age and sex of nestling bald eagles. J. Field Ornithology., 55(4):467-481.

Bowerman, W.W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. unpubl. M.A. thesis, Northern Michigan University, Marquette, 113pp.

Bowerman, W.W., D.A. Best, E.D. Evans, S.Postupalsky, M.S. Martell, K.D. Kozie, R.L. Welch, R.H. Scheel, K.F. Durling, J.C. Rogers, T.J. Kubiak, D.E. Tillit, T.R. Schwartz, P.D. Jones, and J.P. Giesy. 1990. PCB concentrations in plasma of nestling bald eagles from the Great Lakes Basin, North America. pp. 203-206 *in* O. Hutzinger and H. Fieldler, eds., Volume IV, Proceedings of Dioxin '90, Eco-Informa Press, Bayreuth, Germany.

Brunstrom, B. and L. Anderson. 1988. Toxicity and 7-ethoxyresorufin O-deethylase-inducing potency of coplanar polychlorinated biphenyls (PCBs) in chick embryos. Arch. Toxicol., 62:263-266.

Burse, V.W., S.L. Head, M.P. Korver, P.C. McClure, J.F. Donahue, and L.L Needham. 1990. Determination of selected organochlorine pesticides and polychlorinated biphenyls in human serum. J. Anal. Toxicol. 14:137-142.

Capen, D.E. and T.J. Leiker. 1979. DDE residues in blood and other tissues of white-faced ibis. Environ. Pollut. (19):163-171.

Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. J. Toxicol. Environ. Health 33:395-453.

Federal Register. 1990. 50 CFR Part 17, Endangered and Threatened Wildlife and Plants; Advance Notice of a Proposal to Reclassify or Delist the Bald Eagle (*Haliaeetus leucocephalus*). 55(38):4209-4212.

Fraser, J.D., L.D. Frenzel, and J.E. Mathisen. 1985. The impact of human activities on breeding bald eagles in northcentral Minnesota. J. Wildl. Manage. 49:585-592.

Frenzel, R.W. 1985. Environmental contaminants and ecology of bald eagles in southcentral Oregon. Oregon State University, Corvallis, unpubl. Ph.D. thesis.

Frenzel, R.W. and R.J. Anthony. 1989. Relationship of diets and environmental contaminants in wintering bald eagles. J.Wildl. Manage. 53(3):792-802.

Garrett, M., R.G. Anthony, J.W. Watson, and K. McGarigal. 1988. Ecology of bald eagles on the lower Columbia River. Final Report to U.S. Army Corps of Engineers, Contract No. DACW57-84-C-0071, Oregon Coop. Wildl. Res. Unit, Oregon State Univ., Corvallis.

Giesy, J.P., J.P. Ludwig, and D.E. Tillitt. 1993a. Embryolethality and deformities in colonial, fish-eating waterbirds of the Great Lakes region: Assigning causality. Environ. Sci. Technol. In Press.

Giesy, J.P., D.A. Verbrugge, R. Othout, W.W. Bowerman, M.A. Mora, P.D. Jones, J.L. Newsted, C. Vandervoort, S.N. Heaton, R.J. Aulerich, S.J. Bursian, J.P. Ludwig, M. Ludwig, G.A. Dawson, T.J. Kubiak, D.A. Best, and D.E. Tillitt. 1993b. Contaminants in Fishes from Great Lakes-Influenced Sections and Above Dams on Three Michigan Rivers: III Implications for the Health of Fish-eating Birds. Arch. Environ. Toxicol. Chem. Submitted.

Gilbertson, M., T.J. Kubiak, J.P. Ludwig, and G.A. Fox. 1991. Great Lakes embryo mortality, edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: Similarity to chick-edema disease. J. Toxicol. Environ. Health 33(4):455-520.

Great Lakes Basin Commission. 1975. Report: Great Lakes Basin Framework Study. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Michigan.

Grier, J.W. 1980. Modeling approaches to bald eagle population dynamics. Wildl. Soc. Bull. 8(4):316-322.

Henny, C.J. and D.L. Meeker. 1981. An evaluation of blood plasma for monitoring DDE in birds of prey. Environ. Poll. (Series A) 25:291-304.

Kozie, K.D. 1986. Breeding and feeding ecology of bald eagles in the Apostle Islands National Lakeshore. unpubl. M.S. thesis, Univ. Wis.-Stevens Point, Stevens Point.

Kozie, K.D., and R. K. Anderson. 1991. Productivity, diet, and environmental contaminants in bald eagles nesting near the Wisconsin Lake Superior shoreline. Arch. Environ. Contam. Toxicol. 20:41-48.

Kubiak, T.J., H.J. Harris, L.M. Smith, T. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D. Docherty, and T.C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forster's tern in Green Bay, Lake Michigan - 1983. Arch. Envir. Contam. Toxicol., 18:706-727.

Michigan Department of Public Health. 1987. Analytical Method No.7, Cntr. Environ. Hlth. Sci., Epid. Stud. Lab., Lansing, MI.

Miller, R.G. 1981. Simultaneous Statistical Inference. Springer-Verlag, New York.

Mora, M.A., H.J. Auman, J.P. Ludwig, J.P. Giesy, D.A. Verbrugge, and M.E. Ludwig. 1993. Polychlorinated biphenyls and chlorinated insecticides in plasma of Caspian terns: Relationships with age, productivity, and colony site tenacity in the Great Lakes. Arch. Environ. Contam. Toxicol. 24:320-331.

Morizot, D.C., R.G. Anthony, T.G. Grubb, S.W. Hoffman, M.E. Schmidt, and R.E. Ferrell. 1985. Clinal genetic variation at enzyme loci in bald eagles (*Haliaeetus leucocephalus*) from the western United States. Biochem. Gen. 23(3/4):337-345.

Platonow, N.S. and B.S. Reinhart. 1973. The effects of polychlorinated biphenyls (Aroclor 1254) on chicken egg production, fertility and hatchability. Can. J. Compar. Med., 37:341-346.

Postupalsky, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. pp. 21-31 in F.N. Hamerstrom, Jr., B.E. Harrell, and R.R. Ohlendorff (eds.), Management of Raptors. Proc. Conf. Raptor Conserv. Tech., Raptor Res. Report No. 2.

Postupalsky, S. 1985. The bald eagles return. Natural History 87:62-63.

Price, H.A., R.L. Welch, R.H. Scheel, and L.A. Warren. 1986. Modified multiresidue method for chlordane, toxaphene, and polychlorinated biphenyls in fish. Bull. Environ. Contam. Toxicol. 37:1-9.

Ribick, M.A., G.R. Dubay, J.D. Petty, D.L. Stalling, and C.J. Schmidt. 1982. Toxaphene residues in fish: identification, quantification, and conformation at part per billion levels. Environ. Sci. Technol. 16:310-318.

SAS institute Inc. 1991. SAS/STAT User's Guide, Release 6.03 Edition.

Safe, S. 1984. Polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs): biochemistry, toxicology, and mechanism of action. CRC Crit. Rev. Toxicol., 13:319-393.

Sprunt, A., IV, W.B. Robertson, Jr, S. Postupalsky, R.J. Hensel, C.E. Knoder, and F.J. Ligas. 1973. Trans. N. Am. Wildl. Nat. Resour. Conf., 38:96-106.

Webb, R. G. and A. C. McCall. 1973. Quantitative PCB standards for electron capture gas chromatography. J. Chromgr. Sci. 11:366-373.

Wiemeyer, S.N., B.M. Mulhen, F.J. Ligas, R.J. Hensel, J.E. Mathisen, F.C. Robards, and S. Postupalsky. 1972. Pestic. Monit. J., 19:50-55.

Wiemeyer, S.N., T.J. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser, and M.A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs--1969-1979--and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

CHAPTER 6:

RISK ASSESSMENT OF MERCURY AND SELENIUM ON BALD EAGLE REPRODUCTION IN THE UPPER MIDWEST

Introduction

Some species of birds are sensitive to the adverse effects of mercury and selenium. For mercury, reproductive failure and altered nesting behavior have been documented in Common Loons, *Gavia immer*, (Barr, 1986), and laboratory feeding studies have shown acute lethality, neurotoxicity, and altered nesting behavior related to mercury concentrations in food for the Goshawk, *Accipiter gentilis*, and Red-tailed Hawk, *Buteo jamaicensis*, (Borg *et al.*, 1970; Fimreite and Karstad, 1971). Selenium has been shown to produce embryolethality and teratogenicity in waterfowl (Ohlendorf *et al.*, 1986; Hoffman *et al.*, 1988).

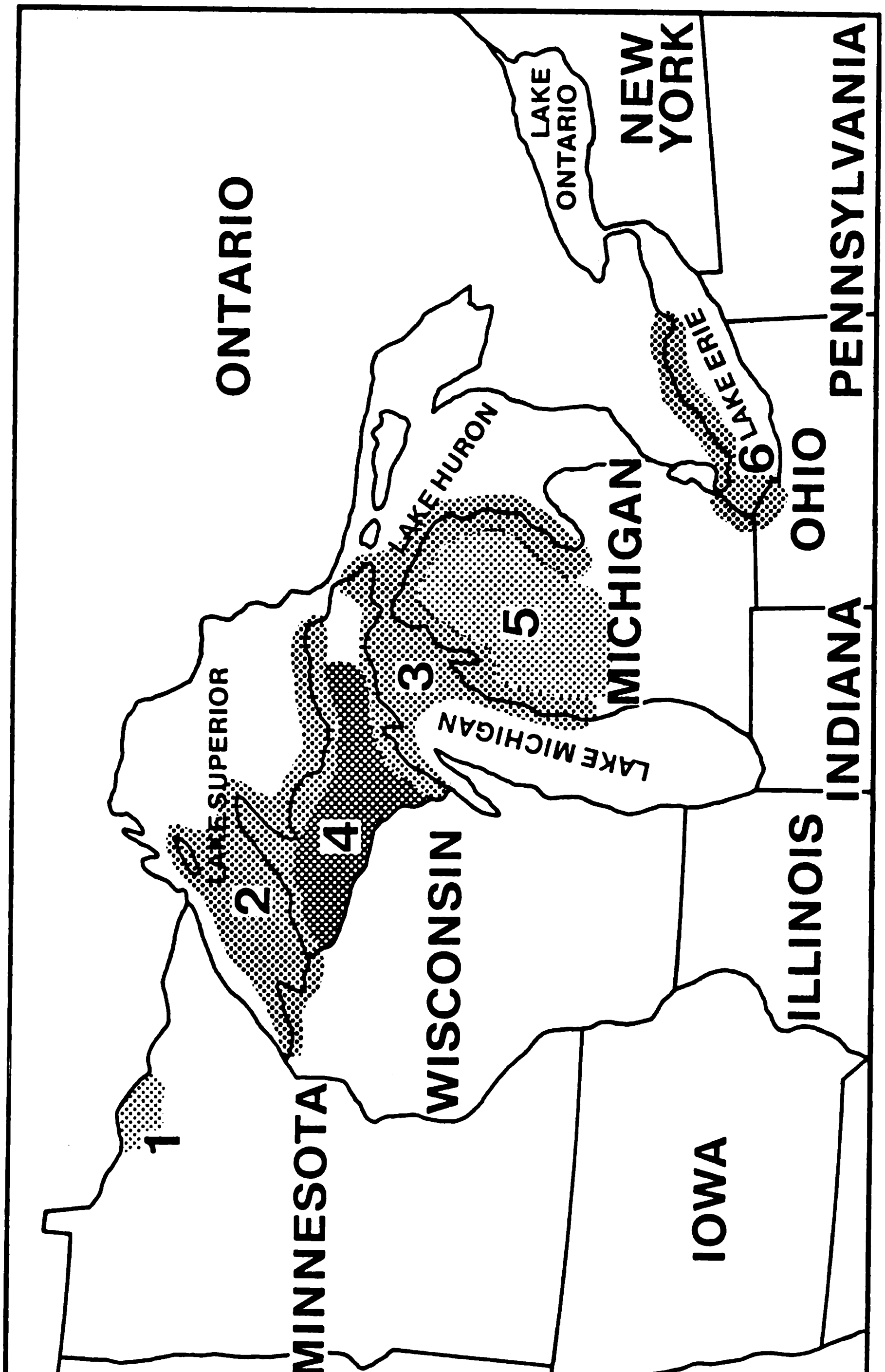
Concentrations of mercury have increased in the aquatic environment throughout eastern North America primarily due to atmospheric deposition (Norton *et al.*, 1981; Nriagu *et al.*, 1990; Wong *et al.*, 1984; Johnson, 1987). Mercury concentrations in fish of inland lakes in Michigan have also been increasing (Evans *et al.*, 1991). The Bald Eagle, *Haliaeetus leucocephalus*, is a tertiary avian predator in the Great Lakes Basin aquatic food web. Because of its position in the food web, it is susceptible to bioaccumulation of xenobiotics. It is therefore, a good sentinel species in which to measure tissue concentrations of xenobiotics. The use of feathers to monitor environmental exposure of birds to heavy metals is a common method (Westermark *et al.* 1975; Bühler and Norheim 1982; Bruane and Gaskin 1987). Here we report on the concentrations of mercury and selenium in the feathers of nestling and adult Bald Eagles in the Great Lakes Basin. We investigate the relationship between mercury, selenium, and mean five-year reproductive measures in breeding areas in Michigan, Minnesota, Wisconsin, Ohio, and Ontario.

Methods

Molted adult feathers were collected in areas surrounding nests and two to three breast feathers were plucked from nestlings during normal population monitoring of the Bald Eagle population within the Great Lakes Basin, for the period 1985 through 1989. In Michigan, feathers were collected from 132 of 196 breeding areas. Feathers from 6 Minnesota, 3 Ohio, 5 Ontario, and 8 Wisconsin breeding areas were obtained as part of studies conducted to determine organochlorine pesticide and PCB concentrations in the blood of nestlings throughout the Basin (Chapter 5). The study area was subdivided into six regions for statistical comparison: Voyageurs National Park; Lake Superior; Lakes Michigan and Huron; Interior Upper Peninsula of Michigan; Interior Lower Peninsula of Michigan; and Lake Erie (Figure 27).

Feathers from adult bald eagles were classified as either primaries, secondaries, tail, or body. Feathers of nestlings were primarily breast feathers and were not further subdivided. Feathers were cleaned of any obvious debris and air dried. The apical portion of the feather was removed for analysis for large feathers while smaller feathers were completely digested. Sample preparation and analysis followed U.S. EPA approved methodologies, as outlined in detail in the Michigan Department of Natural Resources (MDNR) laboratory Analytical Methods Manual (MDNR, 1981) and Quality Assurance Manual (MDNR, 1987). Analysis for mercury (Hg) was completed using the Cold Vapor Atomic Absorption method with a reportable detection limit of 0.1 mg/kg.

Figure 27. Six geographical regions where feather samples of bald eagles were collected for Hg and Se analysis in the Great Lakes Basin, 1985-1989. Geographical regions are: 1) Voyageurs National Park, Minnesota; within 8.0 km of 2) Lake Superior, and 3) Lakes Michigan and Huron in Michigan; interior areas in the 4) upper, and 5) northern lower peninsulas of Michigan; and 6) within 8.0 km of Lake Erie.


ONTARIO
LAKE ONTARIO
NEW YORK
PENNSYLVANIA
LAKE ERIE
LAKE HURON
LAKE SUPERIOR
LAKE MICHIGAN
MICHIGAN
OHIO
INDIANA
ILLINOIS
WISCONSIN
MINNESOTA
IOWA
1
2
3
4
5
6

Analysis for selenium (Se) was completed using the Hydride Atomic Absorption method with a reportable detection limit of 0.5 mg/kg.

Statistical analyses were completed using SAS NPAR1WAY (SAS Institute, Inc., 1991) procedure for the Kruskal-Wallis one-way analysis of variance test to determine difference between feather types, adults, nestlings, and geographical regions for either mercury or selenium. The Kruskal-Wallis simultaneous rank procedure was then applied to differentiate between mean ranks (Miller, 1981). Differences were considered to be significant if $P \leq 0.05$. Geometric mean concentrations of Hg and Se were used for statistical comparison between breeding areas if more than one value for each feather type (i.e., adult primary, secondary, tail, body or nestling) had been obtained for that breeding area.

Relationship between logarithmic geometric mean concentrations of Hg in adult feathers among breeding areas and mean five-year reproductive measures were determined compared using general linear methods for regression analysis (PROC GLM; SAS, 1991). Reproductive measures used were those developed by Postupalsky (1974). *Productivity* was defined as the number of young per occupied nest for each breeding area. *Success* was defined as the percent of occupied breeding areas successfully fledging at least one young. Five-year productivity was determined using the method of Wiemeyer *et al.* (1984) by calculating the mean value for the period of three years prior to collection, the year of collection, and the year following collection. Success was determined for the years within this five year span that the breeding area was occupied. When mercury data spanned more than one year, the year of collection was defined as the year corresponding to the average year of feathers collected within that breeding area.

Results

Adult Feathers

All feathers collected were analyzed for Hg and a subsample of these were also analyzed for Se. All feathers analyzed had measurable concentrations of Hg and Se. In adult feathers, no significant differences were found among feather groups for either Hg or Se ($X^2=1.276$, d.f.=3, $p=0.0735$ Hg; $X^2=1.406$, d.f.=3, $p=0.692$ Se; Table 23).

In comparing among geographic regions using geometric means of feather concentrations by breeding area, no significant differences were found for Hg ($X^2=3.640$, d.f.=4, $p=0.457$) or Se ($X^2=0.549$, d.f.=3, $p=0.908$; Table 24).

Nestling Feathers

All feathers collected were analyzed for Hg and a subsample of these were also analyzed for Se. All feathers analyzed had measurable concentrations of Hg and Se. In comparing adult and nestling feathers, significant differences were found between adult feather groups and nestling feathers for Hg ($X^2=122.15$, d.f.=4, $p=0.0001$) but no significant differences were found for Se ($X^2=1.963$, d.f.=4, $p=0.743$)(Table 23).

In comparing among geographic regions using geometric means of feather concentrations by breeding area, significant differences were found among Lake Erie, Voyageurs National Park, and all other regions for Hg ($X^2=25.178$, d.f.=5, $p=0.0001$),

Table 23. Mean and range for Hg and Se concentrations in feathers of adult and nestling Bald Eagles in the Great Lakes Basin, 1985-1989. Same letters within columns do not differ significantly.

		Concentrations in Feathers		
	Years	**Hg (mg/kg)**	**Se (mg/kg)**	**nSe/n[1]**
Adult Primaries	1985-89	21.2 A (3.6-48.1)	1.9 A (1.6-3.2)	25/53
Adult Secondaries	1985-89	23.4 A (5.3-66.2)	1.8 A (1.2-3.0)	8/39
Adult Tail	1985-89	19.2 A (5.1-46.2)	1.7 A (0.6-2.7)	14/57
Adult Body	1985-89	21.4 A (0.2-47.7)	1.6 A (1.1-2.2)	11/71
Nestling[2]	1985-89	9.0 B (1.5-27.0)	1.9 A (0.8-2.9)	19/115

[1]nSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg.

[2]Nestling includes all feathers collected; primarily breast feathers.

Table 24. Geometric mean and range for Hg and Se concentrations in feathers of adult Bald Eagles in the Great Lakes Basin, North America, between 1985 and 1989. Same letters within columns do not differ significantly.

		Concentrations in Feathers		
	Years	**Hg (mg/kg)**	**Se (mg/kg)**	**nSe/n[1]**
Interior Lower Peninsula	1985-89	21.2 A (6.1-62.0)	1.9 A (1.1-3.2)	12/31
Interior Upper Peninsula	1985-89	20.6 A (0.2-66.2)	1.8 A (1.0-2.9)	18/51
Lake Superior	1985-89	22.1 A (5.9-37.5)	1.6 A (1.1-2.2)	3/14
Lakes Michigan and Huron	1985-89	19.6 A (7.2-40.0)	1.7 A (1.5-1.9)	4/13
Lake Erie	1989	12.9 B (9.0-18.6)		0/3

[1]nSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg.

but no significant differences were found among regions for Se ($X^2=2.729$, d.f.=2, p=0.256; Table 25).

Effects on Reproduction

Neither productivity (young per occupied nest) nor success (percent of successful breeding attempts) was significantly correlated with logarithmic concentrations of Hg, produced significant correlations for either adult or nestling feathers (Table 26).

Discussion

Hg and Se were detected in all feathers analyzed. Concentrations of Hg and Se in feathers in the Great Lakes Basin were elevated above background concentrations previously determined for feathers of Bald Eagles in Alaska from 1988 and feathers collected from Museum specimens of eagles from Michigan for the period 1953-57 (Evans, 1993). Concentrations in feathers may reflect either the blood concentration (Westermark *et al.*, 1975; Scanlon *et al.*, 1980) and/or the tissue concentration (Braune and Gaskin, 1987) at the time the feather was developed. Birds excrete metals and other elements in feathers and this may comprise a significant route of metal detoxification. Feathers in some instances have contained 49 to 93 percent of the body burden of metals, most notably as methyl mercury (Tejning, 1967; Hakkinen and Hasanen, 1980; Bühler and Norheim, 1982; Braune and Gaskin, 1987).

Marine mammals possess enzyme systems capable of demethylating methyl mercury with the result that most of the mercury (97-98%) stored in their liver and

Table 25. Geometric mean and range for mercury and selenium concentrations in feathers of nestling Bald Eagles in the Great Lakes Basin, 1985-1989. Same letters within columns do not differ significantly.

		Concentrations in Feathers		
	Years	Hg (mg/kg)	Se (mg/kg)	nSe/n[1]
Interior Lower Peninsula	1985-89	8.8 A (4.6-13.8)		0/28
Interior Upper Peninsula	1985-89	8.1 A (3.5-16.0)	1.8 A (0.8-2.8)	15/44
Lake Superior	1985-89	8.7 A (2.7-18.0)	2.7 A (2.5-2.8)	2/19
Lakes Michigan and Huron	1985-89	8.0 A (4.1-14.0)	2.0 A (1.0-2.9)	2/10
Lake Erie	1989	3.7 B (1.5-7.4)		0/6
Voyageurs National Park	1989	20.2 C (5.2-27.0)		0/8

[1]nSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg.

Table 26. Relationship between annual measures of productivity and geometric mean concentrations of Hg in feathers of adult and nestling Bald Eagles in the Great Lakes Basin, 1985-1989; n= 93 for adults and n= 95 for nestlings.

	F	p
MEAN ADULT FEATHER Hg		
Productivity (Young/Occupied Nest)	0.66	0.906
Success (%)	0.73	0.836
MEAN NESTLING FEATHER Hg		
Productivity (Young/Occupied Nest)	1.64	0.070
Success (%)	1.09	0.299

Figure 28. The relationship between Hg concentration (mg/kg) in feathers of adult Bald Eagles and mean five-year productivity. Hg is the logarithmic value of the geometric mean of all feathers collected from the breeding area. Productivity is the mean number of young per occupied nest.

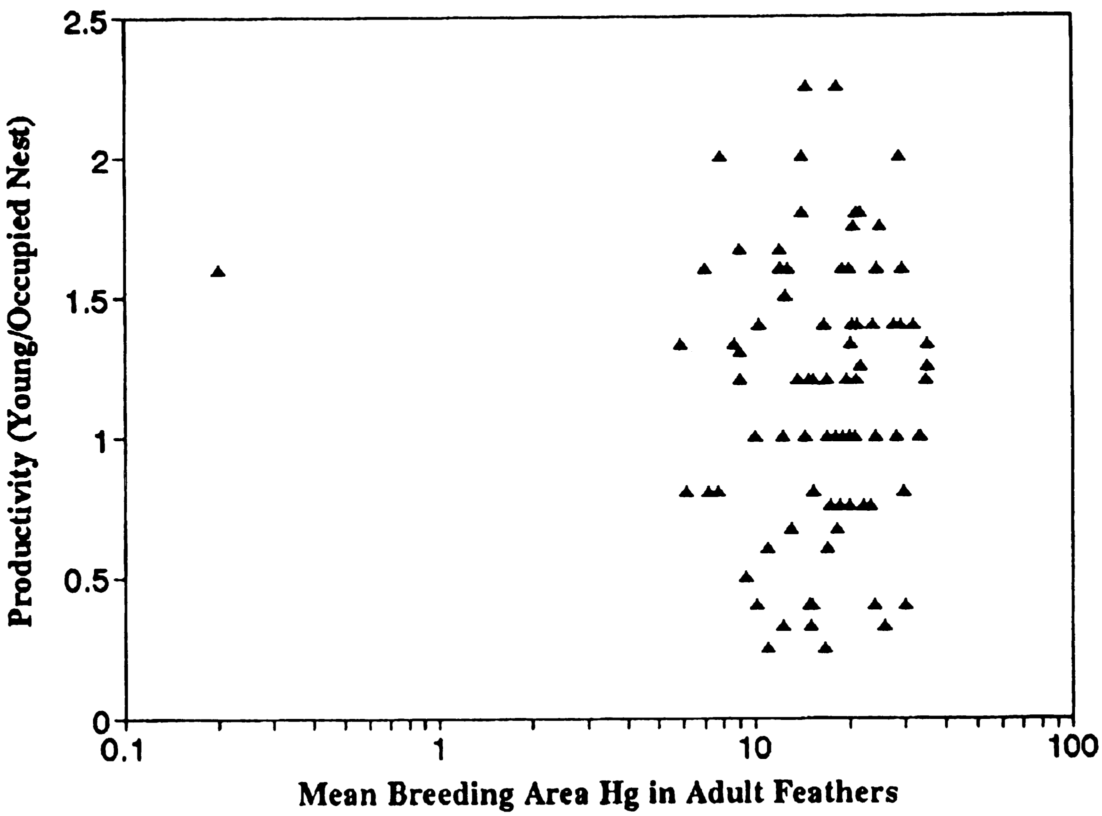

2.5
2
1.5
1
0.5
0
0.1
1
10
100
Productivity (Young/Occupied Nest)
Mean Breeding Area Hg in Adult Feathers

Figure 29. The relationship between Hg concentration (mg/kg) in feathers of adult Bald Eagles and mean five-year success. Hg is the logarithmic value of the geometric mean of all feathers collected from the breeding area. Success is the percentage of active years producing fledged young.

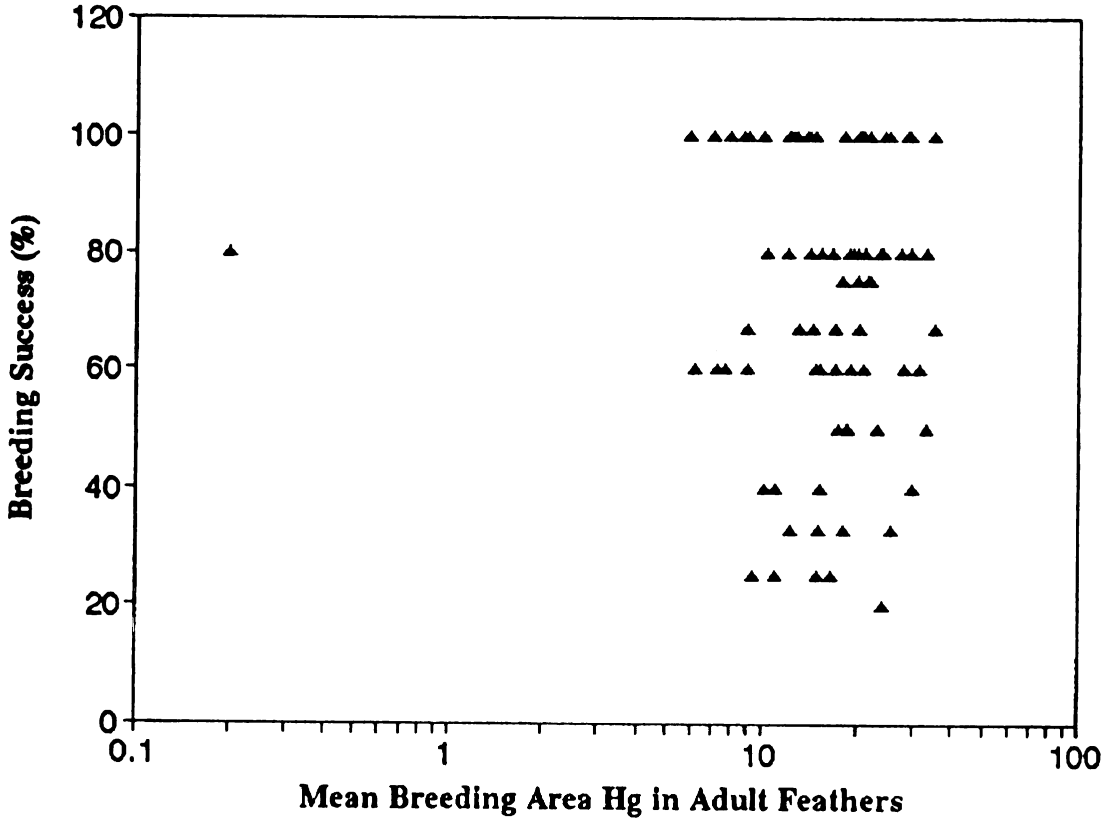

120
100
80
60
40
20
0
Breeding Success (%)
0.1
1
10
100
Mean Breeding Area Hg in Adult Feathers

Figure 30. The relationship between Hg concentration (mg/kg) in feathers of nestling Bald Eagles and mean five-year productivity. Hg is the logarithmic value of the geometric mean of all feathers collected from the breeding area. Productivity is the mean number of young per occupied nest.

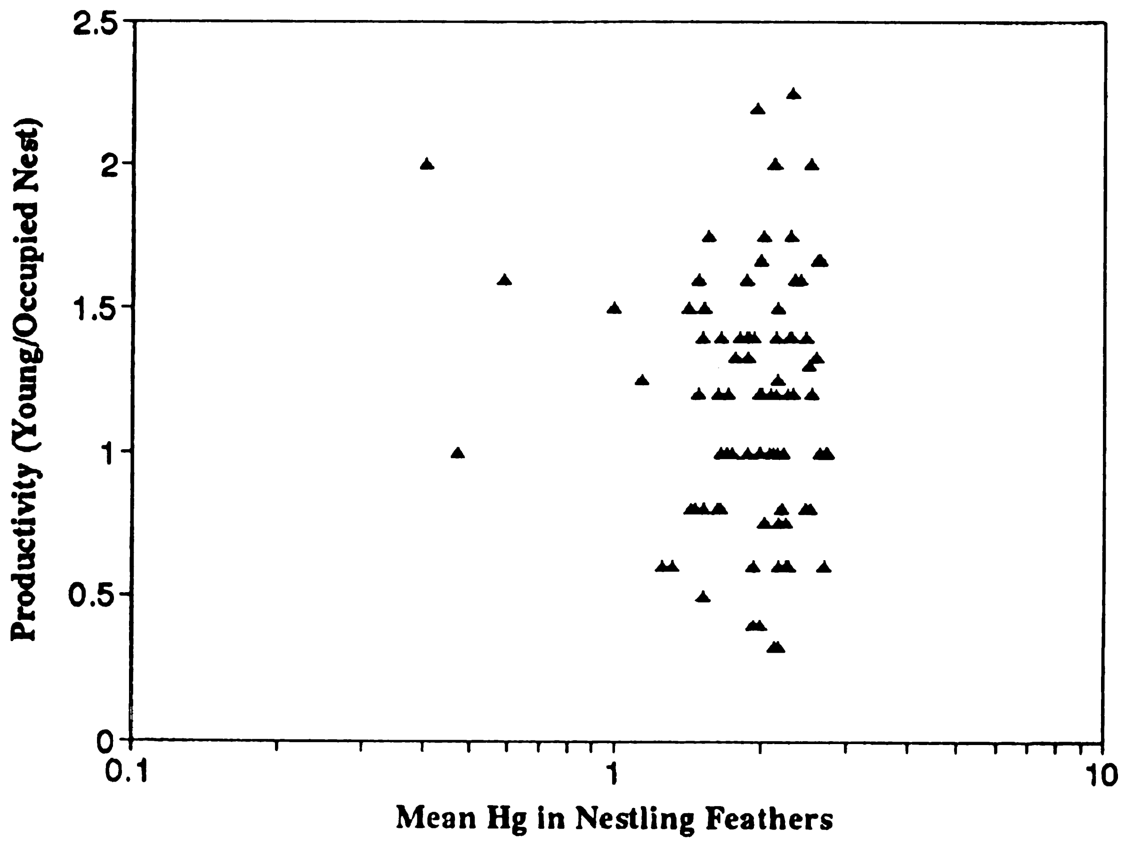
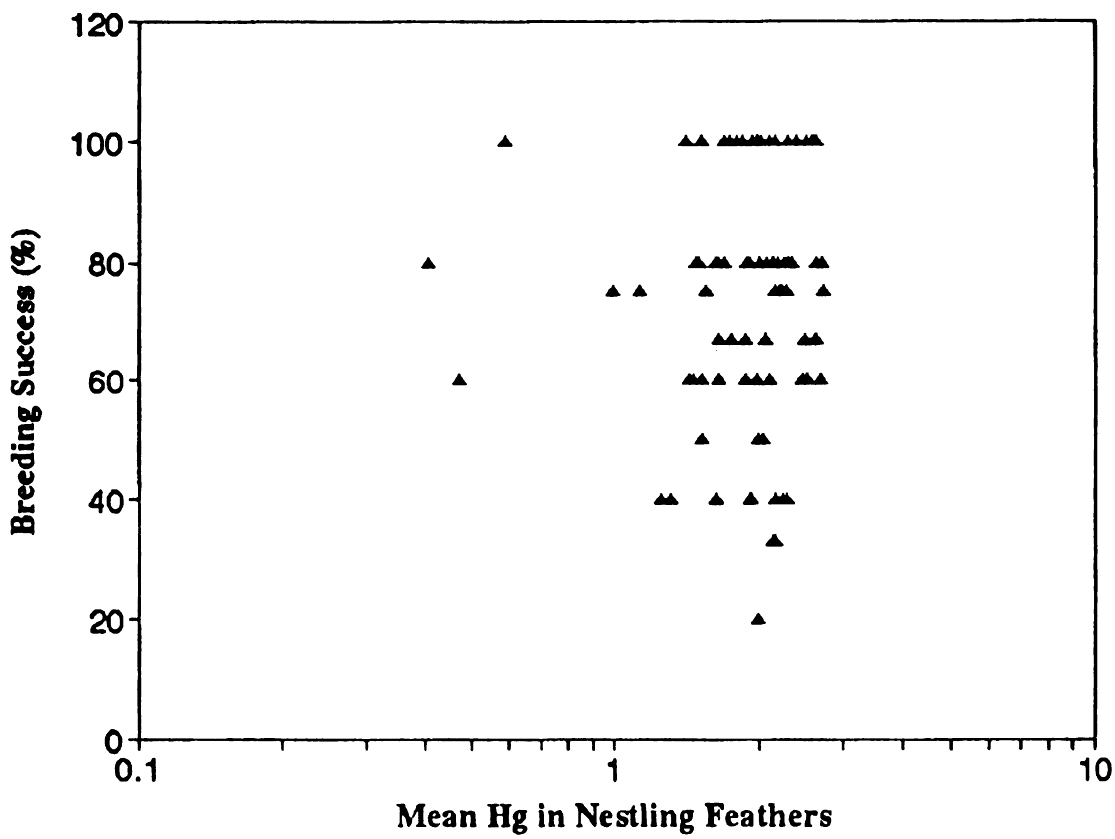

2.5
2
1.5
1
0.5
0
0.1
1
10
Productivity (Young/Occupied Nest)
Mean Hg in Nestling Feathers

Figure 31. The relationship between Hg concentration (mg/kg) in feathers of nestling Bald Eagles and mean five-year success. Hg is the logarithmic value of the geometric mean of all feathers collected from the breeding area. Success is the percentage of active years producing fledged young.


120
100
80
60
40
20
0
Breeding Success (%)
0.1
1
10
Mean Hg in Nestling Feathers

kidneys is in inorganic form. Fish-eating birds are comparable to marine mammals in respect to food and tissue distribution of methyl mercury and it seems reasonable to extend this capability to these birds (Fimreite, 1979). Honda *et al.*, (1990) suggested that coaccumulation of toxic metals and zinc in seabirds may be a detoxification and regulatory mechanism. Demethylation of methyl mercury seems to be a significant detoxification route for methyl mercury in bird of prey (Norheim and Froslic, 1978).

The lack of association between Bald Eagle reproduction and mercury concentrations is not surprising based on previous studies (Wiemeyer *et al.*, 1984; Frenzel, 1984; Anthony *et al.*, 1993). A theoretical NOAEL for mercury concentration in the egg of Bald Eagles is given as 0.5 mg/kg (Wiemeyer *et al.*, 1984) with this value derived from a Mallard, *Anas platyrhynchos*, feeding study where dietary dose was 0.5 mg/kg (Heinz, 1979). The concentration of p,p'-DDE contained in eggs of Bald Eagles from Wiemeyer's studies where mercury concentrations were above 0.5 ppm however were greater than the p,p'-DDE concentration associated with greater than a 50% decline in productivity. In the White-tailed Eagle, *Haliaeetus albicilla*, no indication of effects of mercury on reproduction has been observed (Helander *et al.*, 1982). A theoretical concentration for effect in eggs was given as 1.0 mg/kg in eggs, although no direct linkage to adverse effects were noted (Helander *et al.*, 1982). Berg *et al.*, (1966) observed that White-tailed Eagles in the Baltic that had mercury concentrations in feathers from 40 to 65 mg/kg seldom had eggs that hatched. It is noted, however, that no organochlorine pesticide analysis had been completed as of the time of publication for these data. Subsequent papers refute the mercury/reproduction theory of Berg *et al.*

(1966) and link White-tailed Eagle reproductive problems primarily to p,p'-DDE and PCBs (Koivusaari *et al.* 1980; Helander *et al.* 1982).

It has been stated that the effects of mercury on wild populations of nesting Bald Eagles is hard to access since there is nearly always organochlorine contamination present (Frenzel 1984). This is also true in the Great Lakes Basin where p,p'-DDE and PCBs have been found to cause reproductive effects in Bald Eagles (Best *et al.*, 1993).

Another factor that may also decrease the effect of mercury on Bald Eagle productivity is the basic life history of the eagle. The greatest exposure to mercury in the eagle's yearly diet would come from Walleye, *Stizostedion vitreum*, and Northern Pike, *Esox lucius*, based on fish concentrations in inland lakes in Michigan (Evans *et al.*, 1991). Although Walleye are rarely taken, Northern Pike are a major source of prey for nesting eagles in the Basin (Table 5, Chapter 1) and their consumption is almost exclusively during the period of time corresponding with molting and replacement of feathers by the adults. This may be a natural mechanism that lessens the adverse effects of mercury to nesting eagles. The effects of mercury may become more evident with the decreasing organochlorine concentrations in the environment (Frenzel 1984).

Data pertaining to concentrations of selenium in feathers of birds dependant on freshwater ecosystems are sparse and none is cited for fish eating birds in the reviews of Jenkins (1980) and Eisler (1985). Johnson (1987) found loadings of selenium to be related to increased concentrations in fish flesh in Ontario and suggested that it was in limited supply as a micronutrient. Relative to Bald Eagle prey in the region, selenium in Walleye, Northern Pike, Yellow Perch, *Perca flavescens*, White Sucker, *Catostomus* *commersoni*, Lake Trout, *Salvelinus namaycush*, and Lake Whitefish, *Coregonus clupeaformis*, from Ontario lakes had mean concentrations from 0.25 to 0.84 mg/kg (Johnson, 1987). By comparison, Mosquitofish, *Gambusia affinis*, from ponds at Kesterson Reservoir in California, contaminated with great levels of selenium from irrigation underdrainage, had from 26 to 31 mg/kg selenium, but fish from a nearby reference site had only 0.39 mg/kg (Ohlendorf *et al.*, 1986). The similarity between selenium concentrations in adult and eaglet feathers are in contrast with the marked differences in mercury concentrations. Selenium is apparently in adequate supply in Bald Eagle diets in the Basin and as an essential nutrient, is within the regulatory capability of these animals at this time.

References

Anthony, R.G., Garrett, M.G., and Schuler, C.A.. 1993. Environmental contaminants in Bald Eagles in the Columbia River Estuary. *Journal of Wildlife Management* 57(1):10-19.

Barr, J.F. 1986. Population dynamics of the Common Loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Occasional Paper No. 56, *Canadian Wildlife Service,* Ottawa.

Berg, W., Johnels, A., Sjostrand, B., and Westermark, T. 1966. Mercury content in feathers of Swedish birds from the past 100 years. *Oikos* 17:71-83.

Best, D.A., Bowerman, W.W., Kubiak, T.J., Winterstein, S.R., Postupalsky, S., and Shieldcastle, M. 1993. Reproductive impairment of Bald Eagles along the Great Lakes shorelines of Michigan and Ohio. In Press. *IV World Conference on Birds of Prey and Owls*, Berlin, Germany.

Borg, K., Erne, K., Hanko, E., and Wanntrop, H. 1970. Experimental secondary methyl mercury poisoning in the Goshawk (*Accipiter gentilis*). *Environmental Pollution* 1:91-104.

Braune, B.M., and Gaskin, D.E. 1987. Mercury levels in Bonaparte's Gulls (*Larus philadephia*) during autumn molt in the Quoddy Region, New Brunswick, Canada. *Archives of Environmental Contamination and Toxicology* 16:539-549.

Bühler, U., and Norheim, G. 1982. The mercury content in feathers of the Sparrowhawk *Accipiter nisus* in Norway. *Fuana norv. Ser. C. Cinclus* 5:43-46.

Eisler, R. 1985. Selenium hazards to fish, wildlife and invertebrates: a synoptic review. *U.S. Fish and Wildlife Service*, Biological Report 85(1.10), Washington, DC.

Evans, E., Wilson, M., and Creal, W. 1991. Assessment of mercury contamination in selected Michigan lakes, 1987-90: historical trends, environmental correlates, and potential sources. *Michigan Department of Natural Resources*. Staff Report. Surface Water Quality Division, Great Lakes Environmental Assessment Section, Water Quality Appraisal Unit, Lansing, Michigan.

Evans, E. 1993. Mercury and other metals in Bald Eagle feathers and other tissues from Michigan, nearby areas of Minnesota, Wisconsin, Ohio, Ontario, and Alaska 1985-1989. *Michigan Department of Natural Resources*. Staff Report. Wildlife Division, Natural Heritage Program, Lansing, Michigan.

Fimreite, N., and Karstad, L. 1971. Effects of dietary methylmercury on Red-tailed Hawks. *Journal of Wildlife Management* 35(2):293-300.

Fimreite, N. 1979. Accumulation and effects of mercury on birds. In J.O. Nriagu (ed), *The Biogeochemistry of Mercury in the Environment*, pp. 602-627. Elsevier/North Holland Press: Amsterdam.

Frenzel, R.W. 1984. Environmental contaminants and ecology of Bald Eagles in southcentral Oregon. unpubl. Ph.D. thesis, *Oregon State University*, Corvallis.

Hakkinen, I., and Hasanen, E. 1980. Mercury in eggs and nestling of the Osprey, *Pandion haliaetus*, in Finland and its bioaccumulation from fish. *Annuals Zoologia Fennnici* 17:131-139.

Heinz, G.H. 1979. Methylmercury: reproductive and behavioral effects on three generations of Mallard ducks. *Journal of Wildlife Management* 43:394-401.

Helander, B., Olsson, M., and Reutergårdh, L. 1982. Residue levels of organochlorine and mercury compounds in unhatched eggs and the relationship to breeding success in White-tailed Sea Eagles *Haliaeetus albicilla* in Sweden. *Holarctic Ecology* 5:349-366.

Hoffman D.J., Ohlendorf, H.M., and Aldrich, T.W. 1988. Selenium teratogenicity in natural populations of aquatic birds in central California. *Archives of Environmental Contamination and Toxicology* 17:519-525

Honda, K., Marcovecchio, J., Kan, S., Tatsukawas, R., and Ogi, H. 1990. Metal concentrations in pelagic seabirds from the north Pacific Ocean. *Archives of Environmental Contamination and Toxicology* 19:704-711.

Jenkins, D. 1980. Biological monitoring of toxic trace metals. Volume 2, Toxic trace metals in plants and animals of the world. *U.S. Environmental Protection Agency*, Las Vegas, Nevada, EPA-600/3-80-091.

Johnson, M. 1987. Trace element loadings to sediments of fourteen Ontario lakes and correlations with concentrations in fish. *Canadian Journal of Fisheries and Aquatic Sciences* 44:3-13.

Koivusaari, J., Nuuja, I., Palokangus, R. and Finnlund, M. 1980. Relationships between productivity, eggshell thickness and pollutant contents of addled eggs in the population of White-tailed Eagles *HALIAËTUS ALBICILLA L.* in Finland during 1969-1978. *Environmental Pollution (Series A)* 23:41-52.

MDNR. 1981. Quality assurance for water and sediment sampling. Environmental Protection Bureau, *Michigan Department of Natural Resources*, Lansing. Publication Number 3730-0028.

MDNR. 1987. Analytical methods for environmental samples. Environmental Protection Bureau, *Michigan Department of Natural Resources*, Lansing.

Miller, R.G. 1981. *Simultaneous Statistical Inference*. Springer-Verlag: New York.

Norheim, G. and Froslic, A. 1978. The degree of methylation and organ distribution in some birds of prey in Norway. *Acta Pharmacologia et Toxicologia* 43:196-204.

Norton, S., Hess, C., and Davis, R. 1981. Rates of accumulation of heavy metals in pre- and post-European sediments in New England lakes. In S. Eisenreich (ed) *Atmospheric Pollutants in Natural Waters*. Ann Arbor Science Publishers: Ann Arbor, Michigan.

Nriagu, J.O. 1990. Global metal pollution: poisoning the biosphere? *Environment* 32(7):7-11, 28-33.

Ohlendorf, H., Hoffman, D., Saiki, M., and Aldrich, T. 1986. Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irrigation drainwater. *Science of the Total Environment* 52:49-63.

Postupalsky. S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. In F.N. Hamerstrom, Jr., B.E. Harrell, and R.R. Ohlendorff (eds), *Management of Raptors*, pp. 21-31. Proceedings of a Conference on Raptor Conservation Techniques, Raptor Research Report No. 2.

SAS Institute Inc. 1991. SAS/STAT Version 6.06. Carey, North Carolina.

Scanlon, P.F., Oderwald, R.G., Dietrick, T.J., and Coggin, J.L. 1980. Heavy metal concentrations in feathers of Ruffed Grouse shot by Virginia hunters. *Bulletin of Environmental Contamination and Toxicology* 25:947-949.

Tejning, S. 1967. Biological effects of methyl mercury diacyaniamide-treated grain in the domestic fowl *Gallus gallus L.*. *Oikos Supplemental* 8:1-116.

Westermark, T., Odsjo, T., and Johnels, A. 1975. Mercury content of bird feathers before and after Swedish ban on alkyl mercury in agriculture. *Ambio* 4(2):87-92.

Wiemeyer, S.N., Lamont, T.G., Bunck, C.M., Sindelar, C.R., Gramlich, F.J., Fraser, J.D., and Byrd, M.A. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in Bald Eagle eggs--1969-79--and their relationships to shell thinning and reproduction. *Archives of Environmental Contamination and Toxicology* 13:529-549.

Wong, T., Nriagu, J., and Coker, R. 1984. Atmospheric input of heavy metals chronicled in lake sediments of the Algonquin Provincial Park, Ontario, Canada. *Chemical Geology* 44:187-201.

CHAPTER 7:

HEMATOLOGY AND SERUM CHEMISTRIES OF NESTLING BALD EAGLES (*HALIAEETUS LEUCOCEPHALUS*)

INTRODUCTION

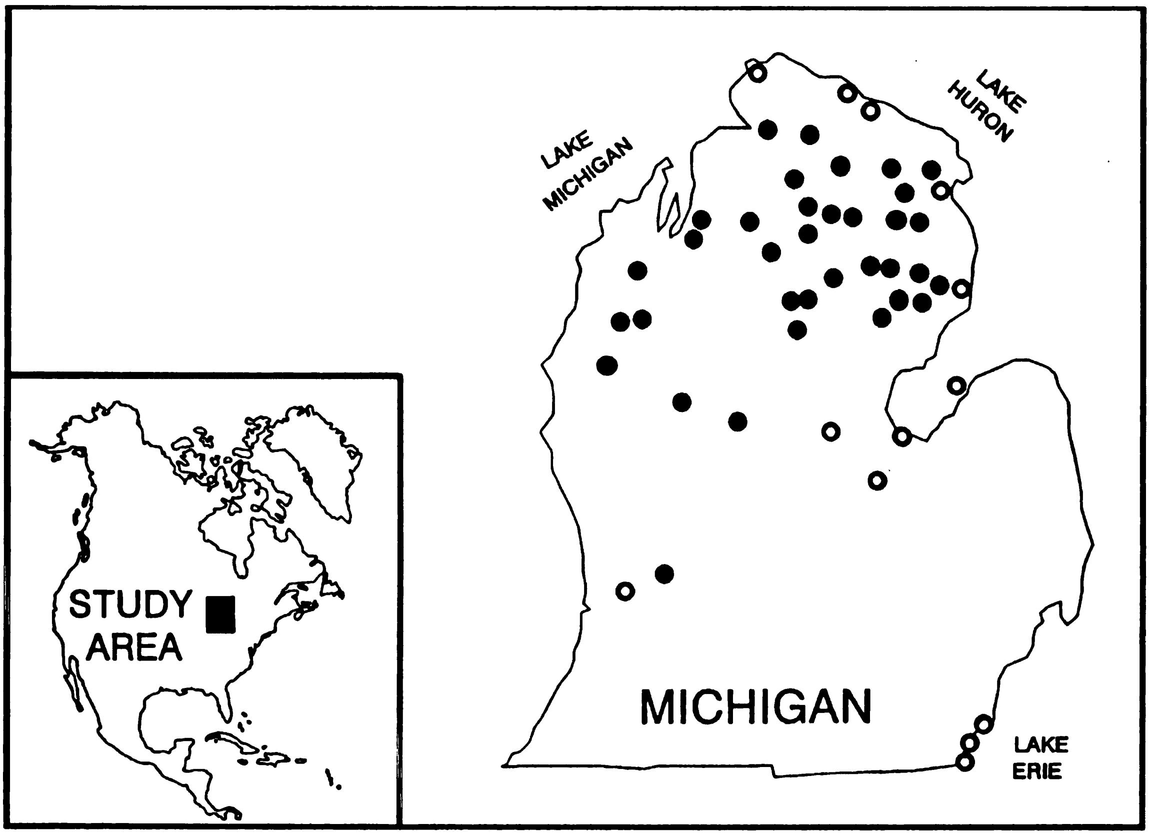
The bald eagle (*Haliaeetus leucocephalus*) is found only in North America within the United States, Canada, and Mexico. The bald eagle has been proposed as an ecosystem monitor species of Great Lakes water quality by the International Joint Commission[7]. Specifically, the eagle's sensitivity to organochlorine pesticides, primarily p,p'-DDE, and PCBs, makes it a good potential indicator of reproductive effects and immune suppression. In order to evaluate this, however, it is necessary to determine if secondary indicators of stress to pollutants could be measured. Since it is both safe and easy to obtain blood samples from nestling eagles during banding of the young, and blood concentrations reflect the contamination of the prey base from the area surrounding the nest site[3], we collected blood samples from nestling eagles in the Lower Peninsula of Michigan during 1993. The objective of this study was to determine and report hematologic and plasma chemistry values for nestling bald eagles. A second, ongoing objective of this study, will be to compare these data with organochlorine pesticide and PCB concentrations to determine if any of the hematologic or plasma chemistry parameters can be used as indicators of stress induced by exposure to these organochlorine compounds.

MATERIALS AND METHODS

Blood samples were collected from 55 nestling bald eagles in the lower peninsula of Michigan during May-June 1992. Nineteen nestlings were from 13 breeding areas within 8.0 km of the Great Lakes or along rivers accessible to Great Lakes fish runs (i.e., Great Lakes breeding areas), and 36 nestlings were from 36 breeding areas from more interior areas (i.e., interior breeding areas, Figure 32). Age and sex were determined using morphometric measurements[2]. Nestlings included 39 females, 15 males, and 1 unknown sex. Evidence of recent feeding was determined by examination of the crop where 28 had partial to full crops, 22 had empty crops, and no determination was made in 5 cases. Samples were collected from manually restrained nestlings by venipuncture of the brachialis vein using a 22-ga intradermal needle and 10 cc syringe, both of which were pretreated with sodium heparin to prevent sample coagulation. Five hundred μl of whole blood were transferred to a collection tube containing ethylenediaminetetraacetic acid (EDTA). One to 1.5 ml of whole blood was transferred to a collection tube containing no additive. Blood slides of whole blood for hematologic evaluations were prepared in the field[4] and in the laboratory using whole blood stored in EDTA tubes. Hematologic evaluations were performed on whole blood, and after centrifugation, serum chemistries were determined. Hematologic evaluations and serum chemistry evaluations were performed within 12 hr of sample collection for 70% of all samples collected. A number (30%) of serum samples were prepared by centrifugation within 12 h of collection and frozen for up to 21 days before evaluation.

Hematologic evaluations were performed on whole blood anticoagulated with EDTA. Blood slides were prepared from non anticoagulated blood using a cover glass method described previously.[4] Slides were protected in cardboard 'mailers' and maintained at room temperature until stained with an automatic Wright's stainer (Wescor, Inc., Logan, UT 84321 USA). Anticoagulated blood samples were stored chilled until

Figure 32. Locations of breeding areas where nestling bald eagles were sampled for hematology and serum chemistries in 1993. Solid circles indicate interior breeding areas, open circles indicate Great Lakes breeding areas.


LAKE MICHIGAN
LAKE HURON
LAKE ERIE
MICHIGAN
STUDY AREA

assayed.

Packed cell volume was determined with a microhematocrit centrifuge technique (Damon/IEC Division, Needham Hts., MA 02194 USA). Total plasma protein was determined with a temperature corrected refractometer (Cambridge Instruments, Buffalo, NY 14240 USA). Erythrocytes were enumerated with an automatic impedance counter (Model ZBI, Coulter Corp., Miami, FL 33116 USA) appropriately adjusted for cell size. Hemoglobin measurement was by the cyanmethemoglobin method (Coulter Corp., Miami, FL 33116 USA) with centrifugation to remove erythroid nuclei prior to measurement. The leukocyte count was performed manually using the eosinophil Unopette (Becton-Dickinson, Rutherford, New Jersey 07070, USA) technique described previously for avian species.[4]

Biochemical data was obtained from serum samples on an Abbott Spectrum automated analyzer (Abbott, Diagnostics Division, Abbott Park, IL 60064-3500). Sodium, potassium, and chloride were determined by use of ion selective electrodes. Anion gap, sodium/potassium ratio, globulin, albumin/globulin ratio, and osmolarity were calculated values. Abbott reagents (Abbott Diagnostics Division, Abbott Park, IL 60064-3500) were used to determine calcium, phosphorus, glucose, uric acid, cholesterol, aspartate aminotransferase (AST), alanine aminotransferase (ALT), amylase, creatine kinase (CK), bicarbonate, total protein, albumin, blood urea nitrogen (BUN), and serum iron levels.

Cholesterol, total bilirubin, alkaline phosphatase, and magnesium were assayed with reagents from MAS (Medical Analytical Systems, Camarillo, CA 93012). Total

CO_2 was measured with reagents from DMA (DMA, Arlington, TX 76011) and the sorbitol dehydrogenase (SDH) assay used reagents from Sigma Chemical Co. (St. Louis, MO 63103). All of the biochemical constituents could be measured on either serum or heparinized plasma except for calcium, phosphorus, amylase, CK, SDH, and serum iron. It is unknown if the small volume of heparin used to rinse the syringe prior to obtaining the sample would be sufficient to interfere with the assay procedure for these biochemical constituents.

When differences in white cell counts between field prepared and laboratory prepared blood slides were observed, a simple experiment to test these differences was developed. Four captive bald eagles were bled and blood slides were prepared immediately after venipuncture with blood from the collection syringe, and with EDTA preserved blood at 1 h, 24 h, 48 h, and 72 h post-venipuncture.

Statistical analyses were completed using SAS NPAR1WAY[9] procedure for the Wilcoxon rank-sum or Kruskal-Wallis one-way analysis of variance, a chi-square approximation test. The independent classification variables analyzed using the Wilcoxon test included nestling age in days (<50 d vs. ≥ 50 d), sex, presence of recent feeding as evidenced by a full or empty crop, or subpopulation (i.e., Great Lakes or interior breeding area) for all hematologic and serum chemistry values, or between field and laboratory prepared blood slides of the same eagle for white cell differentials. White cell differential counts were analyzed using the Kruskal-Wallis test for data derived from blood samples collected from the 4 captive eagles. The Kruskal-Wallis simultaneous rank procedure was then applied to differentiate among ranks.[9] Differences were considered to be significant if $P \leq 0.05$ and values were outside of normal clinical variation for each analytical method.

RESULTS

Hematologic data are presented in Table 27. Values were within normal ranges for avians for all but eosinophils which were greater than normal[5,10]. Normal values for plasma total solids were not available for avian species. Serum chemistries are presented in Table 28. Values were within normal ranges for avians for all but six measures, uric acid, cholesterol, alkaline phosphatase, total protein, globulin, and urea nitrogen, which were greater than normal and glucose which was lesser[1,7]. Normal values for amylase, ALT, CK, magnesium, Total CO_2, anion gap, sorbitol dehydrogenase, osmolarity, and serum iron were not available for avian species.

Significant differences in leukocyte differential counts were observed between field (i.e., non-EDTA preserved blood) and laboratory (i.e., EDTA preserved blood) prepared slides (Table 27). Differences were statistically significant for percent lymphocytes, monocytes, or eosinophils by treatment (with or without EDTA) but not by length of storage in EDTA treated blood for 4 captive bald eagles (Table 29). Differences were clinically significant (i.e., outside of 95% C.I. for percent cell count method) only for lymphocytes. Differences were statistically different for percent heterophils, lymphocytes, or eosinophils, and for number of lymphocytes for 12 paired comparisons between field and laboratory prepared slides (Table 30). Differences were clinically significant only for lymphocytes.

Table 27. Hematologic data for 55 nestling bald eagles (*Haliaeetus leucocephalus*).

Blood Measure	n	Mean	SD	Range
Hemoglobin (g/dl)	52	11.83	1.85	9.10-16.30
Packed cell volume (%)	52	32	4	25-41
Mean cell hemoglobin concentration (g/dl)	50	37.4	5.4	27.70-53.70
Plasma total solids (g/dl)	52	4.5	0.4	3.8-5.2
Field Prepared Slides				
Leukocytes (WBC)($10^3/\mu l$)	21	17.21	7.96	4.62-32.47
Heterophils ($10^3/\mu l$)	21	7.59	3.82	1.29-16.56
% of WBC		44	11	19-61
Lymphocytes ($10^3/\mu l$)	21	6.75	3.86	1.74-14.43
% of WBC		38	10	23-60
Monocytes ($10^3/\mu l$)	21	0.67	0.43	0.00-1.62
% of WBC		4	2	0-8
Eosinophils ($10^3/\mu l$)	21	2.19	1.60	0.38-6.95
% of WBC		13	6	4-26
Laboratory Prepared Slides				
Leukocytes (WBC)($10^3/\mu l$)	37	16.69	16.24	3.23-100.96
Heterophils ($10^3/\mu l$)	37	9.60	6.14	1.94-28.62
% of WBC		66	14	2-84
Lymphocytes ($10^3/\mu l$)	37	0.72	0.98	0.00-5.66
% of WBC		5	6	0-33
Monocytes ($10^3/\mu l$)	37	1.46	3.42	0.09-21.20
% of WBC		6	4	1-21
Eosinophils ($10^3/\mu l$)	37	3.11	1.91	0.52-9.09
% of WBC		21	8	5-41

Table 28. Serum chemistry values for 55 nestling bald eagles (*Haliaeetus leucocephalus*). (AST, aspartate aminotransferase; ALT, alanine aminotransferase; CK, creatine kinase).

Plasma measure	n	Mean	SD	Range
Calcium (mg/dl)	46	10.8	0.55	9.3-11.8
Phosphorus (mg/dl)	51	6.0	0.7	4.2-7.7
Glucose (mg/dl)	51	280	32.2	96-337
Uric Acid (mg/dl)	47	16.8	4.3	4.4-25.6
Cholesterol (mg/dl)	50	211.8	32.6	130-306
Sodium (mEq/L)	51	148.0	2.3	143.2-153.3
Potassium (mEq/L)	51	3.5	0.63	2.5-5.5
Chloride (mEq/L)	51	117.0	2.5	111.7-121.8
AST(IU/L)	51	198	62	139-542
Total Bilirubin (mg/dl)	47	0.23	0.17	0.05-0.70
Alkaline Phosphatase (U/L)	46	449	91.7	295-654
ALT (IU/L)	47	15.5	6.7	2-34
Amylase (U/L)	48	684.7	248.7	324-1357
CK (IU/L)	48	2157	603	1017-3490
Magnesium (meq/L)	47	1.59	0.11	1.29-1.80
TotalCO_2 (mmol/L)	51	20.7	5.3	11.2-31.0
Anion Gap (mmol/L)	51	14	5	3-27
Sorbitol Dehydrogenase (U/L)	50	5.6	2.0	2.4-13.1
Total Protein (g/dl)	51	3.4	0.5	2.5-5.5
Albumin (g/dl)	46	1.4	0.2	1.0-1.8
Globulin (g/dl)	46	2.0	0.3	1.4-2.9
Osmolarity (mOS/Kg)	51	313	5	304-324
Urea Nitrogen (mg/dl)	51	4.6	1.6	1.5-8.0
Serum Iron (μg/dl)	51	149	41	33-223

Table 29. Mean, SD, range, and determination of clinical differences[1] for field[2] and EDTA[3] prepared blood slides of 4 captive bald eagles.

Cell type/ Slide Type	n	Mean (%)	SD (%)	Range (%)	P	Clinical Difference
Lymphocytes					0.0039	Yes
Field	4	38	8	25-44		
EDTA-1h	4	10	4	8-16		
EDTA-24 h	4	8	2	5-9		
EDTA-48 h	4	10	2	7-12		
EDTA-72 h	4	4	2	2-5		
Monocytes					0.0305	No
Field	4	4	1	2-5		
EDTA-1h	4	9	6	4-15		
EDTA-24 h	4	14	3	10-12		
EDTA-48 h	4	8	1	7-9		
EDTA-72 h	4	11	3	8-15		
Lymphocytes					0.0074	Yes
Field	4	37	8	25-44		
All EDTA	12	8	3	2-16		
Monocytes					0.0079	No
Field	4	4	1	2-5		
All EDTA	12	10	4	4-18		
Eosinophils					0.0383	No
Field	4	10	3	6-13		
All EDTA	12	18	7	6-33		

[1]Clinical differences are those outside of 95% C.I. for percent cell counts.
[2]Field slides were prepared from blood in the syringe.
[3]EDTA slides were prepared from blood treated with EDTA.

Table 30. Mean, SD, range, and determination of clinical differences[1] between paired field[2] and laboratory[3] prepared blood slides for 12 bald eagles sampled in 1993.

Cell type/ Slide type	n	Mean	SD	Range	P	Clinical Difference
Heterophils (%)					0.0045	No
Field	12	43	11	19-55		
Laboratory	12	62	21	2-83		
Lymphocytes (%)					0.0006	Yes
Field	12	41	9	30-60		
Laboratory	12	6	9	0-33		
Eosinophils (%)					0.0280	No
Field	12	12	7	4-26		
Laboratory	12	21	10	9-41		
Lymphocytes (n)					0.0005	Yes
Field	12	8.60	3.41	1.98-14.43		
Laboratory	12	0.80	1.55	0.00-5.66		

[1]Clinical differences are those outside of 95% C.I. for percent cell counts.
[2]Field slides were prepared from blood in the syringe.
[3]EDTA slides were prepared from blood treated with EDTA.

In comparing between field and laboratory prepared slides, significant differences were found between age and breeding area locations for some white cell types. Significant statistical and clinical differences were found between the number of eosinophils and nestling age (Table 31). Significant statistical differences were found between percent heterophils or lymphocytes between Great Lakes and interior breeding areas, and for percent eosinophils and nestling age (Table 31). None of these differences, however, where clinically significant. Significant differences were also found between hemoglobin concentration and nestling age ($<$50d, 11.3 g/dl vs. $>$49d, 12.6 g/dl, P=0.0001).

DISCUSSION

The value of hematology and serum chemistries as potential indicators of stress induced by exposure to organochlorine compounds may only be relevant for lymphocytes counts and percentages. All other parameters were non-discriminatory between Great Lakes and interior breeding areas. A bias in our analysis, however, is the low sample size from both areas for comparison using field prepared slides. This needs further study to determine if lymphocyte numbers could be used as indicators of immune system compromise due to organochlorine exposure both by correlation to organochlorine concentrations in blood plasma and also by greater sample sizes.

Statistical differences were only clinically significant for lymphocytes and hemoglobin. The significant differences between field and laboratory prepared slides for lymphocytes illustrates the importance of preparing field slides of all blood samples and ensuring that field personnel have been adequately trained to perform this method.

Table 31. Mean, SD, range, and determination of clinical differences[1] between field[2] or laboratory[3] prepared blood slides for bald eagles sampled in 1993.

Cell type/ Classification	n	Mean	SD	Range	P	Clinical Difference
Laboratory Slides						
Eosinophils (n)					0.0063	Yes
Age <50 d	18	4.14	2.18	0.87-9.09		
Age >49 d	19	2.15	0.90	0.52-3.68		
Field Slides						
Heterophils (%)					0.0378	No
Great Lakes	11	39	11	19-55		
Interior	10	50	10	33-61		
Lymphocytes (%)					0.0133	No
Great Lakes	11	44	8	32-60		
Interior	10	32	7	23-42		
Eosinophils (%)					0.0091	No
Age <50 d	16	15	5	4-26		
Age >49 d	5	7	3	4-12		

[1]Clinical differences are those outside of 95% C.I. for percent cell counts.
[2]Field slides were prepared from blood in the syringe.
[3]Laboratory slides were prepared with blood treated with EDTA.

Differences in hemoglobin concentrations between older and younger nestlings follows previously reported observations in other avian species where older nestlings have greater hemoglobin concentrations than younger nestlings.[6]

Samples of blood collected from wild bald eagles can be used for hematologic and serum chemistry determinations. We caution, however, based on our experience in the field, that if possible, prior arrangements for localized analysis of samples be done in advance. Some samples were lost due to long storage times or field centrifugation techniques. For Quality Assurance/Quality Control, baseline studies in hematology need to be done by a single pathologist. In addition, blood smears need to be produced both in the field immediately after blood collection and at the lab for comparison. Large discrepancies in leucocyte numbers were observed between field and lab slides, indicating that damage to leucocytes occurs with storage.

LITERATURE CITED

1. Altman, R.B. 1973. Avian clinical serum chemistries. Veterinary Clinics of North America, 13(2)(May 1973).

2. Bortolotti, G. R. 1984. Criteria for determining age and sex of nestling bald eagles. Journal of Field Ornithology 55(4):467-481.

3. Bowerman, W. W., IV. 1993. Regulation of Bald Eagle (*Haliaeetus leucocephalus*) Productivity in the Great Lakes Basin: An Ecological and Toxicological Approach. Ph.D. Dissertation, Mich. State Univ., E. Lansing, Michigan. Chapter 5.

4. Campbell, T. W. 1988. Avian Hematology and Cytology. Iowa State Univ. Press, Ames, Iowa.

5. Hawkey, C. M., and T. B. Dennett. 1989. Color Atlas of Comparative Veterinary Hematology. Iowa State Univ., Ames, Iowa.

6. Hodges, R. D. 1977. Normal Avian (Poultry) Haematology. pp. 483-517 in Comparative Clinical Haematology. R. K. Archer and L. B. Jeffcott (ed.). Blackwell Scientific Publications, Oxford.

7. International Joint Commission. 1989. Proceedings of the Expert Consultation Meeting on Bald Eagles. International Joint Commission, Windsor, Ontario.

8. Kaneko, J. J. 1989. Clinical Biochemistry of Domestic Animals. pp. 898-899.

9. Miller, R. G. 1981. Simultaneous Statistical Inference. Springer-Verlag, New York.

10. SAS Institute Inc. 1991. SAS/STAT Version 6.06. Carey, North Carolina.

11. Zinkl, J. G. 1986. Avian Hematology. pp. 256-273 in Schlam's Veterinary Hematology, 4th ed., N.C. Jain, (ed.). Lea and Febiger, Philadelphia.

CHAPTER 8:

OBSERVED ABNORMALITIES IN MANDIBLES OF NESTLING BALD EAGLES *HALIAEETUS LEUCOCEPHALUS*

INTRODUCTION

Abnormalities in avian bills have been observed in many fish-eating birds within the Great Lakes Basin including herring gulls (*Larus argentatus*), ring-billed gulls (*Larus delawarensis*), common terns (*Sterna hirundo*), Caspian terns (*Sterna caspia*), Forster's terns (*Sterna forsteri*), black-crowned night-herons (*Nycticorax nycticorax*), great blue herons (*Ardea herodias*), double-crested cormorants (*Phalacrocorax auritus*), and Virginia rails (*Rallus limicola*) (Ryder and Chamberlain 1972, Scharf and Buckingham 1974, Gilbertson et al. 1976, Hoffman et al. 1987, Kubiak et al. 1989, Fox et al. 1991a). A bald eagle (*Haliaeetus leucocephalus*) nestling with a crossed bill was observed previously in northwest Ontario (Grier 1968). We report here on five additional observations of bill deformities in nestling eagles in Michigan, Minnesota, and Wisconsin.

MATERIALS AND METHODS

Bill defects in nestling bald eagles were documented by contacting individuals who banded eagles throughout the Great Lakes Basin within the period 1966-1989 and from the author's field notes from this time period. Banding data were obtained from the U.S. Fish and Wildlife Service, Bird Banding Laboratory, Patuxent Wildlife Research Center, Laurel, Maryland. Numbers of nestlings banded during this time period were determined from these records and used for comparison of deformity rates using the method described by Fox et al. (1991b).

RESULTS AND DISCUSSION

On 29 June 1968, while banding nestling eagles, J Holt observed an 8-9 week old nestling with its upper mandible curved to the right. The upper mandible was crooked near the tip so most of the lower mandible was covered by the upper mandible. The nestling was observed in a nest located 10 km southeast of Crystal Falls, Iron County, in the western upper peninsula of Michigan. The nestling appeared healthy and was left in its nest (Figure 33).

A nestling with an abnormal bill was observed by J Holt on 18 June 1982 near Grass Lake Flooding, Benzie County, in the western lower peninsula of Michigan (Figure 33). The upper mandible was crooked to the right but also had a fibrous growth on the left side of the upper mandible near the cere. This nestling appeared healthy and was left in its nest.

On 11 June 1986, D Evans observed a 6-7 week old nestling with its lower mandible extending 7 mm to the left farther than the upper mandible at a nest 14 km east of Pembine, Marinette County, Wisconsin (Figure 33). The beak almost shut but had worn a groove on the side of the left upper mandible. The extending point was trimmed off and the beak closed better though not completely. This was the only nestling in the nest. This eagle was recovered injured and alive on 20 June 1989 near Turtle Lake, Ontario, Canada but was non-releasable.

On 9 June 1987, R Eckstein and C Sindelar observed a 7-8 week old nestling with its upper mandible curved to the right at a nest 2 km east of Laona, Forest County, Wisconsin (Figure 33). The upper mandible was crooked near the tip and

Figure 33. The geographical locations of bald eagle nestlings with bill defects in this study: (A) Iron County, Michigan, (B) Benzie County, Michigan, (C) Marinette County, Wisconsin, (D) Forrest County, Wisconsin, and (E) Voyageurs National Park, Minnesota.


LAKE SUPERIOR
ONTARIO
MINNESOTA
E
A
C
D
B
WISCONSIN
LAKE MICHIGAN
LAKE HURON
MICHIGAN
LAKE ONTARIO
NEW YORK
IOWA
LAKE ERIE
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA

approximately 1.27 cm shorter than the lower mandible. Because of the deformity, the bill did not close completely. The single nestling appeared healthy and its crop was approximately one-half full.

A nestling with a shortened upper mandible was observed on 26 June 1989 at Wolfpack Island, St. Louis County, within Voyageurs National Park, Minnesota by D Evans and K Kozie (Figure 33). This nestling also had avian pox and was not handled. A sibling female nestling from this nest was handled and blood was drawn for contaminant analysis. The concentrations of total polychlorinated biphenyls (PCBs) in plasma collected from this nestling were 1600 ppb and p,p'-DDE were 216 ppb. The PCB concentration was the single greatest concentration recorded in plasma collected from 141 nestling eagles from Michigan, Minnesota, Ohio, Ontario, and Wisconsin between 1987-1989 (W Bowerman, unpubl. data). The concentrations of both PCBs and DDE were far greater ($P<0.0001$, Kruskal-Wallis) than mean concentrations from nestlings from within 8.0 km of the Great Lakes shorelines (mean 183 ppb, PCBs; mean 61 ppb, DDE) and from more interior areas (mean 24 ppb, PCBs; mean 20 ppb, DDE) (Bowerman et al. 1990). Other geographically diverse nestling plasma samples (1984-1987) from the lower Columbia River, Oregon (Garrett et al. 1988) and subadult plasma samples (1977-1978) from Missouri and Colorado (Henny et al. 1981) have shown a wide range of contamination consistent with contamination of the general environment from which these samples were obtained. Table 32 provides comparative data sets on plasma values from these areas.

A comparison of bill deformity occurrences in relation to banding of nestling

Table 32. Plasma concentrations of PCBs in bald eagles from various regions of North America

Location	N	PCB Range (ug/kg, ppb)	Life Stage	Reference
Great Lakes Region				
Great Lakes	42	33.0 - 520.0	Nestling	Bowerman et al. 1990
Interior	79	5.0 - 217.0	Nestling	Bowerman et al. 1990
Washington/Oregon				
Lower Columbia	14	14.0 - 351.0	Nestling	Garrett et al. 1988
Oregon[1]	74	<100.0 - 580.0	Nestling	Weimeyer et al. 1989
Western United States				
Missouri	11	<100.0 - 680.0	Subadult	Henny et al. 1981
Colorado	10	<100.0 - 360.0	Subadult	Henny et al. 1981
Montana[1]	11	<200.0	Nestling	Weimeyer et al. 1989

[1]Plasma concentrations estimated as 2x whole blood value.

eagles in the Great Lakes region was performed using banding records from the USDI-Fish and Wildlife Service Bird Banding Laboratory (Table 33). The prevalence of bill deformities in eagles is comparable to the prevalence of bill deformities observed in double-crested cormorants in the Great Lakes Basin (Table 33) (Fox et al. 1991b). Congenital malformations in birds are uncommon (Dow and Hess 1965). Bill defects are an example of developmental asymmetry and are an indication of developmental instability in local populations (Fox et al. 1991b). At present, the most likely causative agent of bill defects in fish-eating birds from the Great Lakes are polyhalogenated aromatic hydrocarbons, specifically certain non-orthosubstituted coplanar PCB congeners which induce aryl hydrocarbon hydroxylase (AHH) (Hoffman et al. 1987, Kubiak et al. 1989, Smith et al. 1990, Fox et al. 1991a, Gilbertson et al. 1991). Although similar bill defects are observable in birds exposed to high concentrations of selenium (Ohlendorf et al. 1986, Hoffman et al. 1988), feather concentrations from nestling bald eagles from the Great Lakes Basin are low (mean 1.8 ppm, Bowerman 1991). Selenium is therefore an unlikely causative agent in this case.

Congenital defects in bald eagles are a rare occurrence. The present observed incidence rate may not reflect the actual rate of defects since only productive nests are visited, nests are only visited once a year, and few nests are located along the shores of the Great Lakes and other areas associated with high PCB concentrations. Congenital defects including deformed toes and bill defects have been observed in white-tailed eagle (*Haliaeetus albicilla*) nestlings in Sweden and have been linked to

Table 33. Geographical variation in bill deformity observations in nestling bald eagles in the Great Lakes Basin, 1966-1989.

Geographical Region	Years banded	Nests banded (a)	Chicks banded (b)	Chicks with defects (c)	Incidence (c/a) Prevalence (c x 10000/b)
Bald Eagles					
Michigan	24	1189	1594	2	0.2% 12.5
Minnesota[1]	24	521	1006	1	0.2% 9.9
Voyageurs NP[2]	1	9	10	1	11.1% 1000.0
Other Areas[2]	24	512	996	0	0.0% 0.0
Ohio	21	24	90	0	0.0% 0.0
Ontario[1]	24	541	1098	1	0.2% 9.1
Southern[2]	15	53	83	0	0.0% 0.0
Northwest[2]	24	468	1015	1	0.2% 9.9
Wisconsin	24	1727	3552	2	0.1% 5.6
Green Bay[3]	9	N/A	11520	60	0.5% 52.1
Prairie[3]	9	N/A	16778	1	0.0% 0.6

[1]State or Provincial Data
[2]Regional Data within a State or Province
[3]Fox et al. (1991b)

PCB contamination in the Baltic Sea (Helander 1983). PCB concentrations from sea eagle eggs collected during this time period from the Baltic ranged from 18.7-159.0 ppm fresh weight where bill deformities were noted in 2 of 115 nestlings examined in comparison to Lapland concentrations of 8.8-11.1 ppm where no deformities were noted in 60 nestlings examined (Helander et al. 1982, Helander 1983). These types of anomalies have been shown to occur in domestic chicken embryos in PCB contaminated eggs (MacLaughlin 1963, Bush et al. 1974, Lillie et al. 1975, Brunstrom and Andersson 1988, Brunstrom 1990). A causal relationship between bald eagle bill defects and high PCB concentrations also appears likely in the Great Lakes Basin, since high PCB concentrations are known to have been present temporally and within the yearly geographic range of the eagles. Concentrations of PCBs in addled eggs of bald eagles in the Great Lakes Region ranged from 19.0-98.0 ppm fresh weight from 1976-1978 (Weimeyer et al. 1984) and from 3.4-119.0 ppm fresh weight from 1985-1990 (Kubiak and Best 1991, D Best unpubl. data). Schwartz et al. (1993) have recently published congener specific PCB data on an addled bald eagle egg salvaged from Lake Huron in 1986. PCB 126 (3,3',4,4',5-pentachlorobiphenyl), a highly embryotoxic and teratogenic PCB congener, was quantified at a wet weight concentration of 71 ng/g. Normalization to a fresh weight concentration because of field dehydration yielded a concentration of approximately 42 ng/g (T Kubiak and D Best unpubl. data). The LD_{50} for PCB 126 injected into American kestrel (*Falco sparverius*) eggs is 70-100 ng/g (Hoffman in prep.). The dead eagle embryo in the addled egg analyzed by Schwartz et al. (1993) was reported to have a "beak skewed to the right". No other reports of bill defects in bald eagles have been reported outside of the Great Lakes Region.

REFERENCES

Bowerman WW, DA Best, ED Evans, S Postupalsky, MS Martell, KD Kozie, RL Welch, RH Scheel, KF Durling, JC Rogers, TJ Kubiak, DE Tillitt, TR Schwartz, PD Jones, and JP Giesy (1990) PCB concentrations in plasma of nestling bald eagles from the Great Lakes Basin, North America. Vol. IV, pp. 212-216 in Proc. 10th Int. Conf. on Organohalogen Compounds (H Fiedler and O Huttzinger, eds.) , Ecoinforma Press, Bayreuth, Germany

Bowerman WW (1991) Factors influencing breeding success of bald eagles in upper Michigan. unpubl. MA thesis, N. Michigan Univ., Marquette, 113 p

Brunstrom B (1990) Mono-ortho-chlorinated chlorobiphenyls: toxicity and induction of 7-ethoxyresorufin o-deethylase (EROD) activity in chicken embryos. Arch. Toxicol. 64:188-192

Brunstrom B and L Andersson (1988) Toxicity and 7-ethoxyresorufin-o-deethylase-inducing potency of coplanar polychlorinated biphenyls in chick embryos. Arch. Toxicol. 62:263-266

Bush B, CF Tumasonis, and FD Baker (1974) Toxicity and persistence of PCB homologs and isomers in the avian system. Arch. Environ. Contam. Toxicol. 2:195-212

Dow DD and W Hesse (1965) House sparrow with a bill abnormality. Wils. Bull. 77:86-88

Fox GA, B Collins, E Hayakawa, DV Weseloh, JP Ludwig, TJ Kubiak, and TC Erdman (1991b) Reproductive outcomes in colonial fish-eating birds: A biomarker for developmental toxicants in Great Lakes food chains: II. Spatial variation in the occurrence and prevalence of bill defects in young double-crested cormorants in the Great Lakes, 1979-1987. J. Great Lakes Res. 17(2):158-167

Fox GA, DV Weseloh, TJ Kubiak, and TC Erdman (1991a) Reproductive outcomes in colonial fish-eating birds: A biomarker for developmental toxicants in Great Lakes food chains: I. Historical and ecotoxicological perspectives. J. Great Lakes Res. 17(2):153-157

Garrett M, RG Anthony, JW Anthony, and K McGarigal (1988) Ecology of bald eagles on the lower Columbia River. Final report to U.S. Army Corps of Engineers, Contract No. DACW57-84-C-0071, Oregon Coop. Wildl. Res. Unit, Oregon State Univ., Corvallis

Gilbertson M, TJ Kubiak, JP Ludwig, and GA Fox (1991) Great Lakes embryo mortality, edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: Similarity to chick-edema disease. J. Tox. Env. Health. 33(4):455-520

Gilbertson M, RD Morris, and RA Hunter (1976) Abnormal chicks and PCB residue levels in eggs of colonial birds on the lower Great Lakes (1971-1973). Auk 93:434-442

Grier JW (1968) Immature bald eagle with an abnormal beak. Bird Banding 39:58-59

Helander B (1983) Sea eagle--experimental studies: Artificial incubation of white-tailed sea eagle eggs 1978-1980 and the rearing and introduction to the wild of an eaglet. Nat. Swedish Environ. Protection Board Report snv pm 1386

Helander B, M Olsson, and L Reutergardh (1982) Residue levels of organochlorine and mercury compounds in unhatched eggs and the relationships to breeding success in white-tailed sea eagles *Haliaeetus albicilla* in Sweden. Holarct. Ecol. 5:349-366

Henny CJ, CR Griffin, DW Stahlecker, AR Harmata, and E Cromartie (1981) Low DDT residues in plasma of bald eagles (*Haliaeetus leucocephalus*) wintering in Colorado and Missouri. Can. Field Nat. 95:249-252

Hoffman DJ (in prep.) Developmental toxicity of PCB congeners in American kestrels (*Falco sparverius*). J. Toxicol. Environ. Health

Hoffman DJ, HM Ohlendorf, and TW Aldrich (1988) Selenium teratogenicity in natural populations of aquatic birds in central California. Arch. Environ. Contam. Toxicol. 17:519-525

Hoffman DJ, BA Rattner, L Sileo, D Docherty, and TJ Kubiak (1987) Embryotoxicity, teratogenicity and aryl hydrocarbon hydroxylase activity in Forster's terns on Green Bay, Lake Michigan. Environ. Res. 42:176-184

Kubiak TJ and DA Best (1991) Wildlife risks associated with passage of contaminated, anadromous fish at Federal Energy Regulatory Commission licensed dams in Michigan. U.S. Fish and Wildl. Serv., E. Lansing, Michigan 55 p

Kubiak TJ, HJ Harris, LM Smith, TR Schwartz, DL Stalling, JA Trick, L Sileo, D Docharty, and TC Erdman (1989) Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan-1983. Arch. Environ. Contam. Toxicol. 18:706-727

Lillie RJ, HC Cecil, J Bitman, and GF Fries (1975) Toxicity of certain polychlorinated and polybrominated biphenyls on reproductive efficiency of caged chickens. Poult. Sci. 54:1550-1555

MacLaughlin J Jr, JP Marliac, MJ Verrett, MK Mutchler, and OG Fitzhugh (1963) The injection of chemicals into the yolk sac of fertile eggs prior to incubation as a toxicity test. Toxicol. Appl. Pharmacol. 5:760-771

Ohlendorf HM, DJ Hoffman, MK Saiki, and TW Aldrich (1986) Embryonic mortality and abnormalities of aquatic birds: Apparent impacts of selenium from irrigation drainwater. Sci. Total. Environ. 52:49-63

Ryder JP and DJ Chamberlain (1972) Congenital foot abnormality in the ring-billed gull. Wilson Bull. 84:342-344

Scharf WC and B Buckingham (1974) Congenital foot abnormality in a herring gull. Inland Bird Banding 46:30-32

Schwartz TR, DE Tillitt, KP Feltz, and PH Peterman (1993) Determination of mono- and non-o,o'-chlorine substituted polychlorinated biphenyls in aroclors and environmental samples. Chemosphere 26(8):1443-1460

Smith LM, TR Schwartz, K Feltz, and TJ Kubiak (1990) Determination and occurrence of AHH-active polychlorinated biphenyls, 2,3,7,8-tetrachloro-p-dioxin and 2,3,7,8-tetrachlorodibenzofuran in Lake Michigan sediment and biota. The question of their relative toxicological significance. Chemosphere 21(9):1063-1085

Weimeyer SN, RW Frenzel, RG Anthony, BR McClelland, and RL Knight (1989) Environmental contaminants in blood of western bald eagles. J. Raptor Res. 23(4):140-146

Weimeyer SN, TG Lamont, CM Bunch, CR Sindelar, FJ Gramlich, JD Fraser, and MA Byrd (1984) Organochlorine pesticide, polychlorinated biphenyl, and mercury residues in bald eagle eggs--1969-79--and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549

ADDENDUM

In 1993, an additional three nestling bald eagles with crossed-bills were found in the lower peninsula of Michigan. Two nestlings were from Monroe County, along Lake Erie, one on the Woodtick Peninsula north of Toledo, the other from along the Raisin River in Monroe. A third nestling was found in Montmorency County near the Tomahawk Flooding. A sibling with a normal bill was also found within the Raisin River nest. The addition of these three nestlings increases the prevalence rate in Michigan from 12.5 per 10,000 (1966-1989) to 22.9 per 10,000 (1966-1993). For the period 1990-1993, the prevalence rate was 50.4 per 10,000. These rates reflect only nestling eagles at the time of banding and do not include the embryo with a crossed-bill reported in Schwartz et al. (1993).

SECTION III:

PRODUCTIVITY

CHAPTER 9:

DIFFERENTIAL PRODUCTIVITY OF BALD EAGLES IN THE MIDWEST: EFFECTS ON POPULATION RECOVERY

Populations of the bald eagle (*Haliaeetus leucocephalus*) in North America have increased since the ban of DDT in North America and the subsequent lessening of egg-shell thinning effects of its metabolite, p,p'-DDE (Grier 1980; Postupalsky 1985; Colborn 1991). However, the recovery has not been uniform and several regions where populations are not reproducing at a level considered to be healthy continue to exist (Colborn 1991). One of these areas is along the shores of the Great Lakes, where concentrations of organochlorine compounds, such as p,p'-DDE and PCBs have been linked to poor reproductive success (Kozie and Anderson 1991; Bowerman 1991; Best et al. 1993). With recent proposals to alter the status of the eagle under the Federal Endangered Species Act (Federal Register 1990) focusing primarily on the increased numbers of breeding pairs in the contiguous United States, it is important to understand the dynamics of the population recovery as part of this decision.

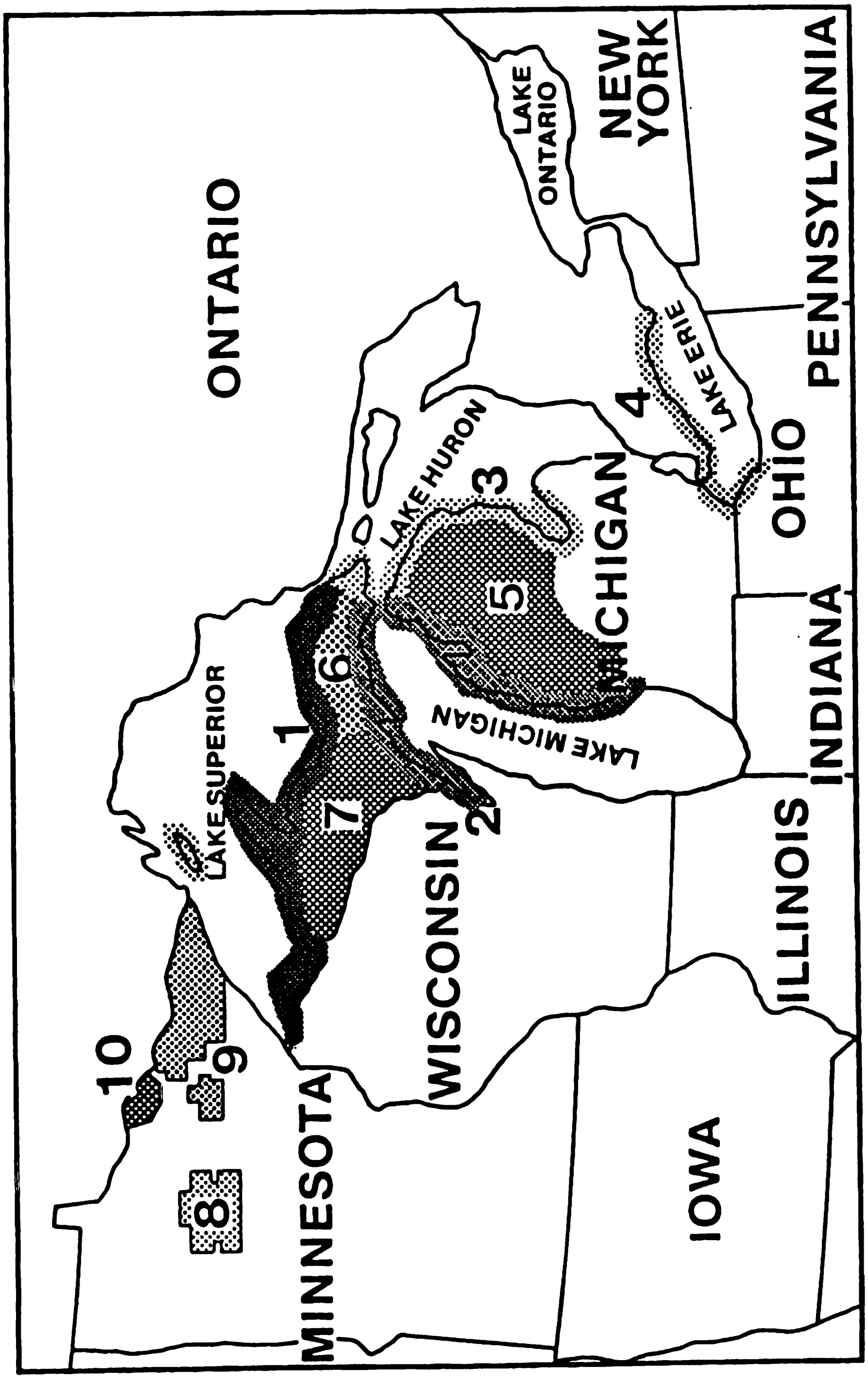
To understand the current population dynamics of bald eagles, we examined data from ten continuously monitored subpopulations within and adjacent to the Great Lakes Basin for the years 1977 through 1993. The eagle population within the upper midwest, including our study area, constitutes the largest single population within the contiguous United States (USFWS 1991). We determined the number of breeding areas, rate of nesting occupancy, breeding rates of new pairs, numbers of fledged young, reproductive productivity and success rates, and differences in the size of populations among regions.

STUDY AREA

Our study area consisted of ten subpopulations (Figure 34). These were defined as: the area within 8.0 km of the United States' (U.S.) and Canadian shorelines of the Great Lakes and anadromous fish accessible areas along 1) Lake Superior (LS), 2) Lake Michigan (LM), 3) Lake Huron (LH), and 4) Lake Erie (LE); areas in Michigan greater than 8.0 km from the shorelines of the Great Lakes and not along anadromous fish accessible areas in 5) the lower peninsula (LP), 6) the eastern upper peninsula (EUP) east of U.S. Highway 41, and 7) the western upper peninsula (WUP) west of U.S. Highway 41; and 8) the Chippewa National Forest (CNF), 9) the Superior National Forest (SNF), and 10) Voyageurs National Park (VNP) in Minnesota (Figure 34).

The relative composition of the vegetative cover types varies greatly across the Great Lakes Basin. A northern spruce-fir forest occurs along the north shore of Lake Superior where dominant trees include aspen (*Populus grandidentata, P. tremuloides*), spruce (*Picea mariana, P. glauca*), and balsam fir (*Abies balsamea*). The central lakes area comprising the south shore of Lake Superior, and northern shores of Lakes Michigan and Huron consists of mixed northern hardwood-pine forest of maple (*Acer rubrum, A. saccharum*), oak (*Quercus rubra, Q. alba*), and pine (*Pinus strobus, P. banksiana, P. resinosa*), southern Lakes Michigan and Huron, and Lake Erie are primarily oak forests (Great Lakes Basin Commission 1975). Vegetative types within the Chippewa and Superior National Forests and Voyageurs National Park include boreal forests of black spruce, eastern tamarack (*Larix laricina*), and eastern arborvitae (*Thuja occidentalis*), and mixed northern hardwood-pine forests of quaking aspen, red, white,

Figure 34. Ten subpopulations used for comparison of PCB and p,p'-DDE concentrations in plasma of nestling bald eagles in the midwest. Subpopulations were: within 8.0 km of Lakes 1) Superior, 2) Michigan, 3) Huron, and 4) Erie; interior areas within 5) the northern lower, 6) eastern upper, and 7) western upper peninsulas of Michigan; and 8) the Chippewa and 9) Superior National Forests, and 10) Voyageurs National Park, Minnesota.


ONTARIO
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and jack pine, balsam fir, maple, and paper birch (*Betula papyrifera*) (Fraser et al. 1985).

METHODS

Productivity Analysis

We analyzed bald eagle productivity data for all breeding areas within Michigan, the CNF, SNF, VNP, and Great Lakes shorelines of Ohio and southern Ontario, 1977-1993. Populations were analyzed three ways: within Michigan; by region; and by subpopulation. In Michigan, breeding areas were assigned three categories: Great Lakes, those breeding areas within 8.0 km of a Great Lake shoreline; interior, those breeding areas 8.0 km or further from a Great Lakes shoreline; and anadromous, those inland breeding areas accessible to runs of anadromous Great Lakes fish. After initial analysis of differences between Great Lakes and anadromous categories, these two were combined for all further analyses. Breeding areas were assigned three regional categories: interior Michigan; Minnesota; and Great Lakes. Breeding areas were then further delineated to ten subpopulations (Figure 34).

We calculated reproductive productivity (i.e., total number of fledged young per occupied nest) and success rate (percent of nests producing at least one fledged young) for bald eagles for all breeding areas 1) within Michigan, 2) by region, and 3) by subpopulations, 1977-1993 using the method of Postupalsky (1974). Breeding areas were analyzed two ways: by mean of yearly productivity or success rate; and by overall productivity or success rate for the entire time period. Information on the productivity of eagles also exists for central Wisconsin, inland Ohio, and the northern shores of Lakes Huron and Superior in Ontario. These data, however, were not used since they included a classification of "some degree of activity" (Wisconsin) which caused an overestimate of productivity from these areas; were based on information from a geographically isolated subpopulation <5 breeding areas (Ohio); or on information from nests producing fledged young but without information on nest failures (Ontario). Productivity within each area was determined by dividing the total number of young by the number of occupied breeding areas for each year (Postupalsky 1974). Success was determined by dividing the number of nests producing fledged young by the number of occupied breeding areas for each year (Postupalsky 1974). Annual productivities or success rates as well as the overall productivity or success rate by subpopulation for the period 1977-1993 were correlated with geometric mean concentrations of PCBs and p,p'-DDE.

Time-Series Analysis

Productivity as a function of occupancy over time was determined by comparing breeding attempts for each breeding area sequentially from year of initiation of breeding attempts (Year one) through Year seven of breeding. Productivity was calculated for all new or re-established breeding areas 1979-90. We selected 1979 since first year breeders at their first reproductive year (age five) would be the first nestlings not exposed to point sources of DDT after the 1973 ban in the U.S. Breeding areas were considered only if they were occupied in at least four of six years from initiation. When breeding areas were unoccupied for four or more years, we considered the next occupancy as a new breeding pair within the breeding area and used that year as the year of initiation in our analyses. Mean productivity rates were calculated by region and subpopulation.

Statistical Analysis

Differences among regions or subpopulations were assessed with either the Kruskal-Wallis one-way analysis of variance, a chi-square approximation test, or the Wilcoxin rank sums test (NPAR1WAY procedure, SAS/STAT 6.03, SAS Institute Inc. 1991). Differences among individual locations or ages were determined using the Kruskal-Wallis multiple range test (Miller 1981).

Relationships between geometric mean concentrations of PCBs or p,p'-DDE in plasma of nesting eagles and means of annual productivities or success rates or overall productivity or success rate for the 10 subpopulations were determined using general linear models for regression analysis (PROC GLM, SAS/STAT 6.03, SAS Institute Inc. 1991). Analyses for PCBs were run without the Lake Erie subpopulation due to a preponderance of nestlings sampled that were greater than eight weeks of age which were significantly greater in concentrations of PCBs in blood plasma than younger nestlings, a ratio of PCBs:p,p'-DDE which was over two times greater than any other subpopulation, and observations of adult replacement within breeding areas every five years.

RESULTS

Productivity Analysis

The bald eagle population has continued to grow from 1977 to 1993 (Figure 35). Within regions, breeding pairs along the Great Lakes and anadromous streams increased from 26 to 134 (515%), interior Michigan, 73 to 160 (219%), and Minnesota, 99 to 262 (237%) (Table 34). The percentage of breeding areas along the Great Lakes increased from 13% to 25% of the total population (Table 34).

However, during this period the productivity has varied among breeding areas in Michigan, with interior breeding areas having significantly greater productivity (χ^2=22.367, df=2, P>0.0001) than Great Lakes or anadromous breeding areas (Table 35). No statistically significant differences in productivity were found between Great Lakes and anadromous breeding areas so anadromous areas were included within Great Lakes regions and subpopulations for further analyses. No differences in productivity among years were found between 1977 and 1993 (P = 0.8106).

Productivity varied among regions with Minnesota and interior Michigan breeding areas having significantly greater productivity (χ^2=22.446, df=2, P>0.0001) than Great Lakes breeding areas (Table 36). Productivity among subpopulations varied with SNF, CNF, LP, EUP, and WUP (χ^2=87.8, df=9, P>0.0001) having significantly greater productivity than VNP, LS, and LE, and LM and LH (Table 36).

All productivity measurements were significantly, and inversely correlated with geometric mean concentrations of PCBs and p,p'-DDE in plasma of nestling eagles. Overall productivity within subpopulations was significantly and inversely correlated with

Figure 35. Number of breeding areas and fledged young for bald eagles breeding in the upper midwest, 1977-1993.

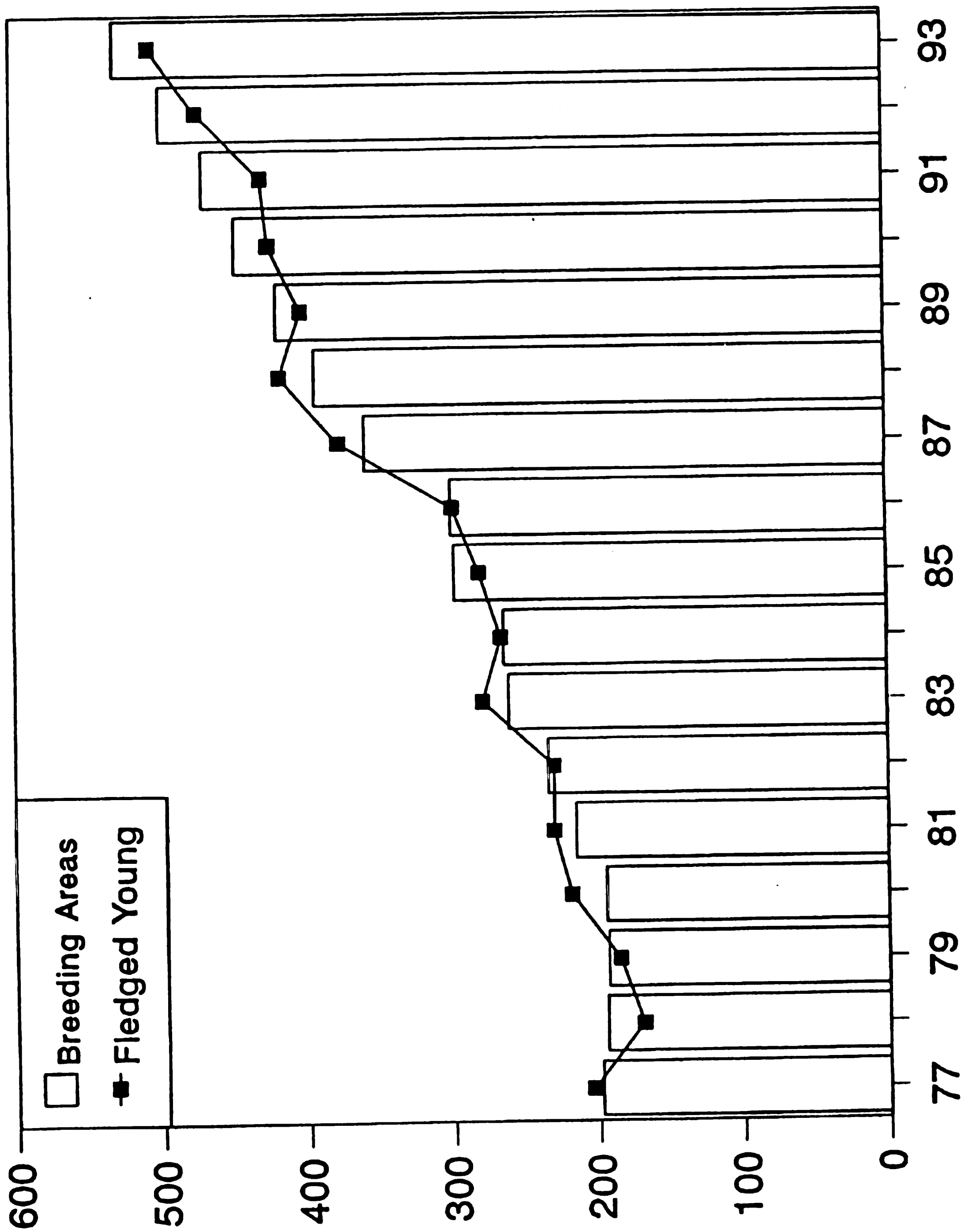

Breeding Areas
Fledged Young
600
500
400
300
200
100
0
77
79
81
83
85
87
89
91
93

Table 34. Numbers of occupied breeding areas, fledged young, and productivity (young/occupied nest) for 3 bald eagle populations in the upper Midwest, 1977-1993.

	Great Lakes			Minnesota
Year	Breeding Areas	Fledged Young	Productivity	Breeding Areas
1977	26	6	0.23	99
1978	26	7	0.27	92
1979	22	11	0.50	96
1980	29	18	0.62	94
1981	32	18	0.56	97
1982	34	22	0.65	115
1983	41	25	0.61	128
1984	43	29	0.67	129
1985	47	25	0.53	154
1986	56	38	0.68	152
1987	68	57	0.84	190
1988	77	66	0.86	198
1989	89	59	0.66	201
1990	96	70	0.73	225
1991	105	80	0.76	228
1992	121	103	0.85	238
1993	134	117	0.87	262
Total/Mean	1046	751	0.72	2698

Table 34 (Cont'd).

Minnesota			Interior Michigan	
Fledged Young	Productivity	Breeding Areas	Fledged Young	Productivity
110	1.11	73	89	1.22
101	1.10	76	63	0.83
103	1.07	75	71	0.95
134	1.43	71	66	0.93
117	1.21	86	96	1.12
129	1.12	85	81	0.95
165	1.29	92	92	1.00
145	1.12	92	92	1.00
154	1.00	97	102	1.05
176	1.16	93	85	0.91
207	1.09	101	112	1.11
222	1.12	119	130	1.09
215	1.07	129	128	0.99
236	1.05	127	118	0.93
219	0.96	137	132	0.96
208	0.87	139	164	1.18
266	1.02	160	152	0.95
2907	1.08	1752	1773	1.01

Table 35. Numbers of occupied breeding areas, fledged young, and productivity (young/occupied nest) for 3 bald eagle subpopulations in Michigan, 1977-1993.

	Anadromous			Great Lakes
Year	Breeding Areas	Fledged Young	Productivity	Breeding Areas
1977	4	0	0.00	8
1978	4	1	0.25	8
1979	4	2	0.50	9
1980	4	5	1.25	9
1981	5	3	0.60	12
1982	4	0	0.00	12
1983	5	1	0.20	16
1984	5	3	0.60	16
1985	3	0	0.00	24
1986	3	3	1.00	27
1987	2	2	1.00	34
1988	3	0	0.00	39
1989	10	11	1.10	37
1990	11	10	0.91	41
1991	12	11	0.92	48
1992	17	14	0.82	60
1993	20	16	0.80	66
Total/Mean	116	82	0.71	466

Table 35 (cont'd).

Great Lakes Fledged Young	Productivity	Breeding Areas	Interior Michigan Fledged Young	Productivity
4	0.50	73	89	1.22
2	0.25	76	63	0.83
5	0.56	75	71	0.95
6	0.67	71	66	0.93
8	0.67	86	96	1.12
9	0.75	85	81	0.95
11	0.69	92	92	1.00
10	0.63	92	92	1.00
13	0.54	97	102	1.05
15	0.56	93	85	0.91
30	0.88	101	112	1.11
28	0.72	119	130	1.09
15	0.41	129	128	0.99
30	0.73	127	118	0.93
38	0.79	137	132	0.96
40	0.67	139	164	1.18
54	0.82	160	152	0.95
318	0.68	1752	1773	1.01

Table 36. Numbers of occupied breeding areas, fledged young, and productivity (young/occupied nest) for 10 bald eagle subpopulations in the upper Midwest, 1977-1993.

	Lake Superior			Lake Michigan
Year	Breeding Areas	Fledged Young	Productivity	Breeding Areas
1977	13	5	0.38	2
1978	12	5	0.42	2
1979	14	7	0.50	2
1980	13	12	0.92	3
1981	17	8	0.47	4
1982	17	9	0.53	4
1983	21	13	0.62	6
1984	22	18	0.82	6
1985	24	13	0.54	7
1986	28	23	0.82	9
1987	33	28	0.85	9
1988	38	35	0.92	12
1989	44	33	0.75	13
1990	4	30	0.68	14
1991	48	49	1.02	14
1992	51	37	0.73	20
1993	48	41	0.85	28
Totals	487	366	0.75	155

Table 36 (cont'd).

Lake Michigan Fledged Young	Productivity	Breeding Areas	Lake Huron Fledged Young	Productivity
0	0.00	1	0	0.00
0	0.00	2	0	0.00
1	0.50	1	0	0.00
1	0.33	2	1	0.50
2	0.50	2	2	1.00
1	0.25	3	0	0.00
1	0.17	3	2	0.67
0	0.00	4	2	0.50
2	0.29	4	2	0.50
2	0.22	5	2	0.40
8	0.89	7	6	0.86
4	0.33	8	6	0.75
8	0.62	12	4	0.33
10	0.71	15	10	0.67
6	0.43	18	11	0.61
16	0.80	25	15	0.60
13	0.46	29	30	1.03
75	0.48	141	93	0.66

Table 36 (cont'd).

	Lake Erie			Lower Peninsula of Michigan
Breeding Areas	Fledged Young	Productivity	Breeding Areas	Fledged Young
10	1	0.10	24	25
10	2	0.20	22	16
5	3	0.60	24	19
11	4	0.36	23	18
9	6	0.67	31	27
10	12	1.20	32	32
11	9	0.82	30	36
11	9	0.82	34	33
12	8	0.67	32	39
14	11	0.79	32	40
19	15	0.79	42	53
19	21	1.11	48	51
20	14	0.70	52	54
23	20	0.87	52	59
25	14	0.56	54	60
25	35	1.40	57	80
29	33	1.14	69	70
263	217	0.83	658	712

Table 36 (cont'd).

Lower Peninsula of Michigan		E. Upper Peninsula of Michigan		W. Upper Peninsula of Michigan
Productivity	Breeding Areas	Fledged Young	Productivity	Breeding Areas
1.04	5	6	1.20	44
0.73	5	2	0.40	49
0.79	6	4	0.67	45
0.78	5	3	0.60	43
0.87	9	11	1.22	46
1.00	10	9	0.90	43
1.20	12	10	0.83	50
0.97	11	13	1.18	47
1.22	11	10	0.91	54
1.25	12	11	0.92	49
1.26	12	10	0.83	47
1.06	13	15	1.15	58
1.04	12	13	1.08	65
1.13	11	6	0.55	64
1.11	14	14	1.00	69
1.40	12	19	1.58	70
1.01	14	12	0.86	77
1.08	174	168	0.97	920

Table 36 (cont'd).

W. Upper Peninsula of Michigan Fledged Young	Productivity	Breeding Areas	Chippewa National Forest Fledged Young	Productivity
58	1.32	77	86	1.12
45	0.92	80	92	1.15
48	1.07	77	91	1.18
45	1.05	76	113	1.49
58	1.26	74	101	1.36
40	0.93	90	108	1.20
46	0.92	100	130	1.30
46	0.98	94	110	1.17
53	0.98	111	118	1.06
34	0.69	117	134	1.15
49	1.04	136	151	1.11
64	1.10	141	146	1.04
61	0.94	145	161	1.11
53	0.83	158	165	1.05
58	0.84	159	141	0.89
65	0.93	172	140	0.81
70	0.91	185	169	0.91
893	0.97	1992	2157	1.08

Table 36 (cont'd).

	Superior National Forest			Voyageurs National Park
Breeding Areas	Fledged Young	Productivity	Breeding Areas	Fledged Young
12	18	1.50	10	6
7	8	1.14	5	1
10	12	1.20	9	0
9	15	1.67	9	6
14	13	0.93	9	3
14	16	1.14	11	5
15	19	1.27	13	16
18	26	1.44	17	9
24	18	0.75	19	18
22	29	1.32	13	13
31	41	1.32	23	15
36	58	1.61	21	18
34	41	1.21	22	13
40	48	1.20	27	23
45	56	1.24	24	22
38	43	1.13	28	25
44	51	1.16	33	47
413	512	1.24	293	240

Table 36 (cont'd).

Voyageurs National Park	TOTALS		
Productivity	Breeding Areas	Fledged Young	Productivity
0.60	198	205	1.04
0.20	194	171	0.88
0.00	193	185	0.96
0.67	194	218	1.12
0.33	215	231	1.07
0.45	234	232	0.99
1.23	261	282	1.08
0.53	264	266	1.01
0.95	298	281	0.94
1.00	301	299	0.99
0.65	359	378	1.05
0.86	394	418	1.06
0.59	419	402	0.96
0.85	448	424	0.95
0.92	470	431	0.92
0.89	498	475	0.95
1.42	556	536	0.96
0.82	5496	5434	0.99

geometric mean concentrations of PCBs ($P=0.0003$, $R^2=0.869$, Figure 36) and p,p'-DDE ($P=0.0001$, $R^2=0.945$, Figure 37). Mean annual productivity within subpopulations were significantly and inversely correlated with geometric mean concentrations of PCBs ($P=0.0005$, $R^2=0.839$, Figure 38) and p,p'-DDE ($P=0.0001$, $R^2=0.950$, Figure 39).

Overall success rates within subpopulations was significantly and inversely correlated with geometric mean concentrations of PCBs ($P=0.0005$, $R^2=0.840$, Figure 40) and p,p'-DDE ($P=0.0001$, $R^2=0.923$, Figure 41). Mean annual success rates within subpopulations were significantly and inversely correlated with geometric mean concentrations of PCBs ($P=0.0009$, $R^2=0.812$, Figure 42) and p,p'-DDE ($P=0.0001$, $R^2=0.927$, Figure 43).

Occupancy Analysis

Productivity varied over time of breeding area occupancy by region with Minnesota and interior Michigan breeding areas have significantly greater productivity ($\chi^2=13.615$, df=2, $P=0.0011$) than Great Lakes breeding areas (Figure 44). Productivity among subpopulations varied with SNF, CNF, LP, EUP, WUP, and LE ($\chi^2=33.254$, df=9, $P>0.0001$) having significantly greater productivity than VNP, LS, LM, and LH (Figures 45 and 46). No differences in productivity by year were found between 1977 and 1993 ($F_{2,6} = 0.62$, $P = 0.8970$).

Productivity increased over time of breeding area occupancy by region for Great Lakes and interior Michigan breeding areas, but did not vary in Minnesota. Productivity

Figure 36. Relationship between overall productivity, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of Total PCBs in plasma of nestling bald eagles within ten subpopulations in the upper midwest.

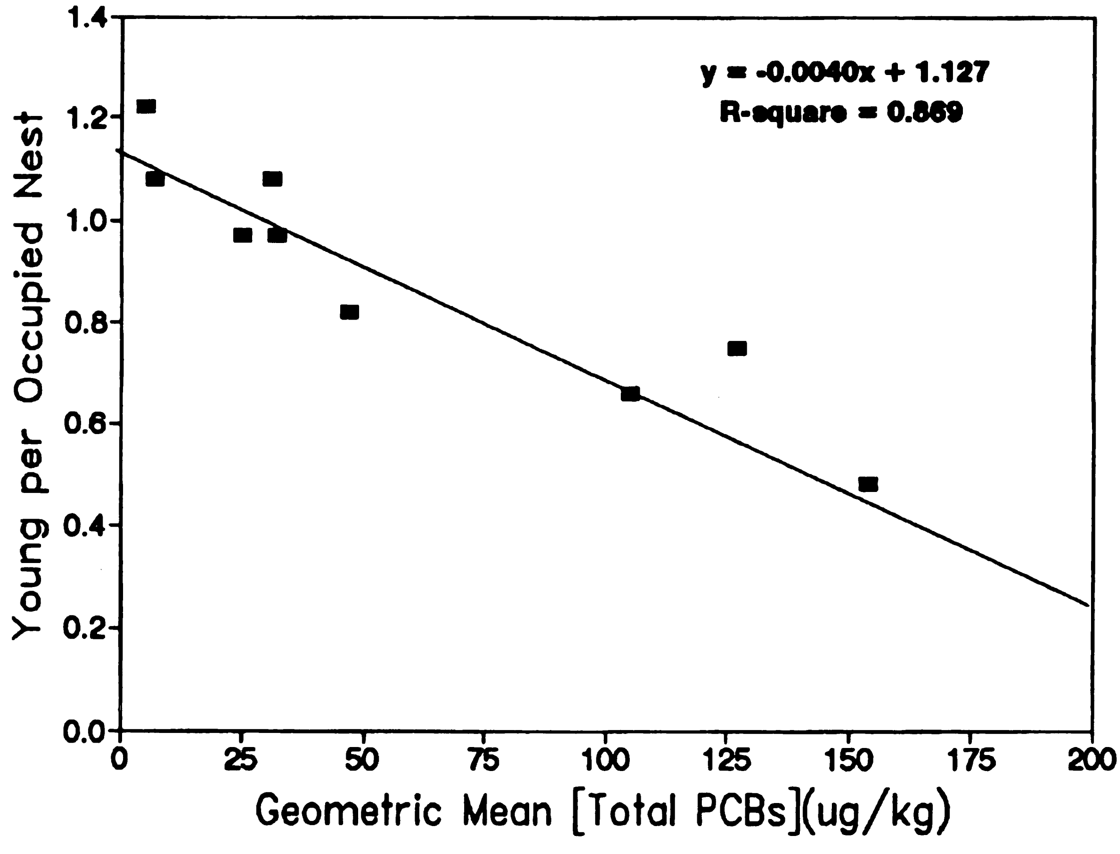

y = -0.0040x + 1.127
R-square = 0.869
Young per Occupied Nest
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
25
50
75
100
125
150
175
200
Geometric Mean [Total PCBs](ug/kg)

Figure 37. Relationship between overall productivity, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of p,p'-DDE in plasma of nestling bald eagles within ten subpopulations in the upper midwest.

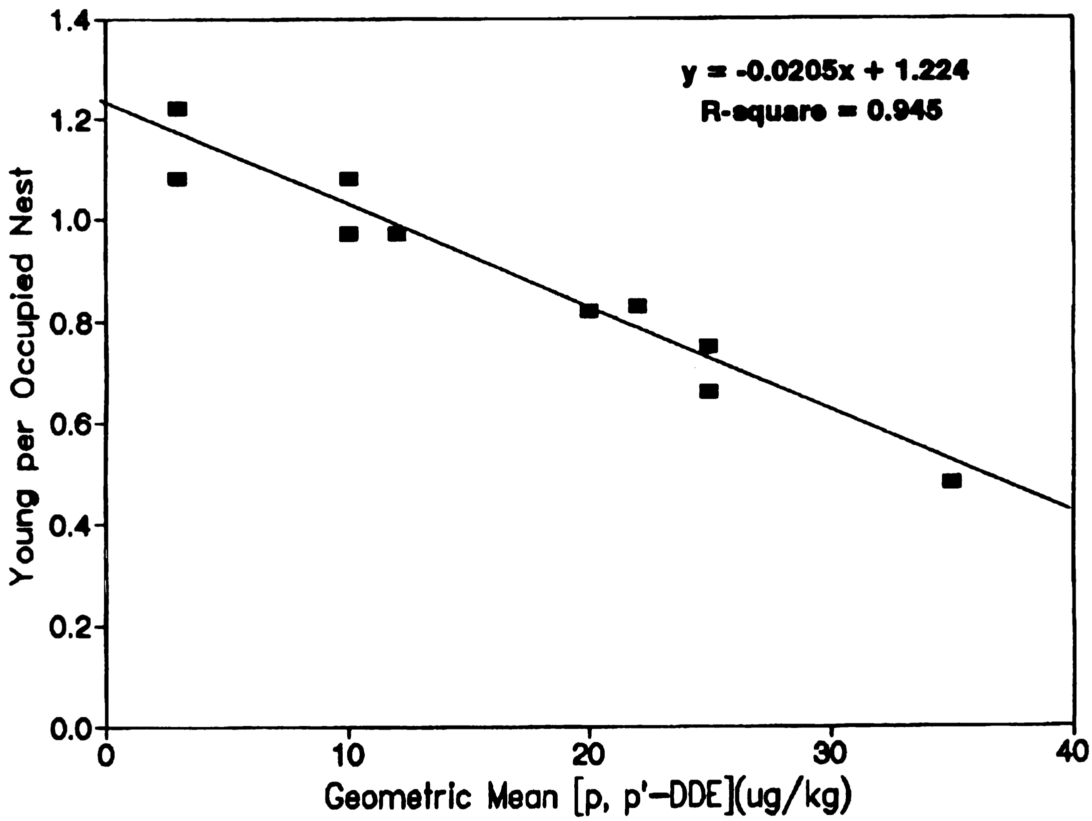
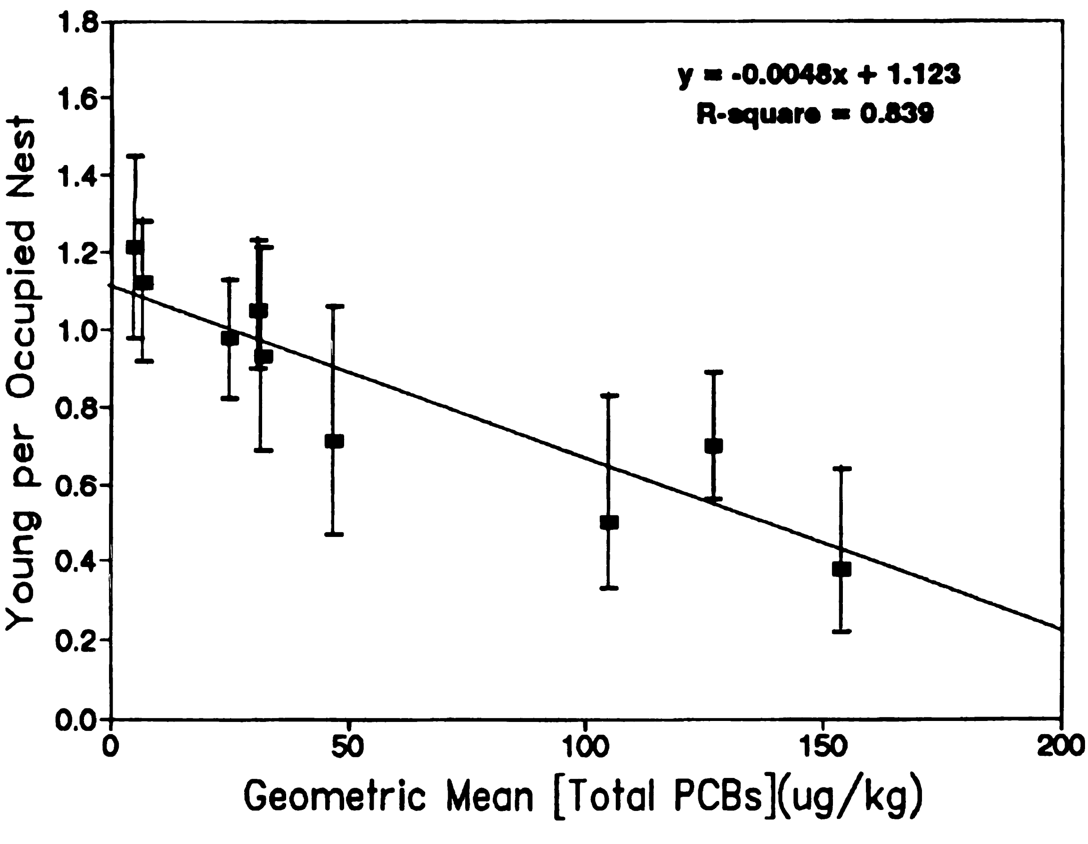

y = -0.0205x + 1.224
R-square = 0.945
Young per Occupied Nest
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
Geometric Mean [p, p'–DDE](ug/kg)

Figure 38. Relationship between mean annual productivity, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of Total PCBs in plasma of nestling bald eagles within nine subpopulations in the upper midwest. Error bars are one standard deviation from the mean.



y = -0.0048x + 1.123
R-square = 0.839
Young per Occupied Nest
Geometric Mean [Total PCBs](ug/kg)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
50
100
150
200

Figure 39. Relationship between mean annual productivity, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of p,p'-DDE in plasma of nestling bald eagles within ten subpopulations in the upper midwest. Error bars are one standard deviation from the mean.

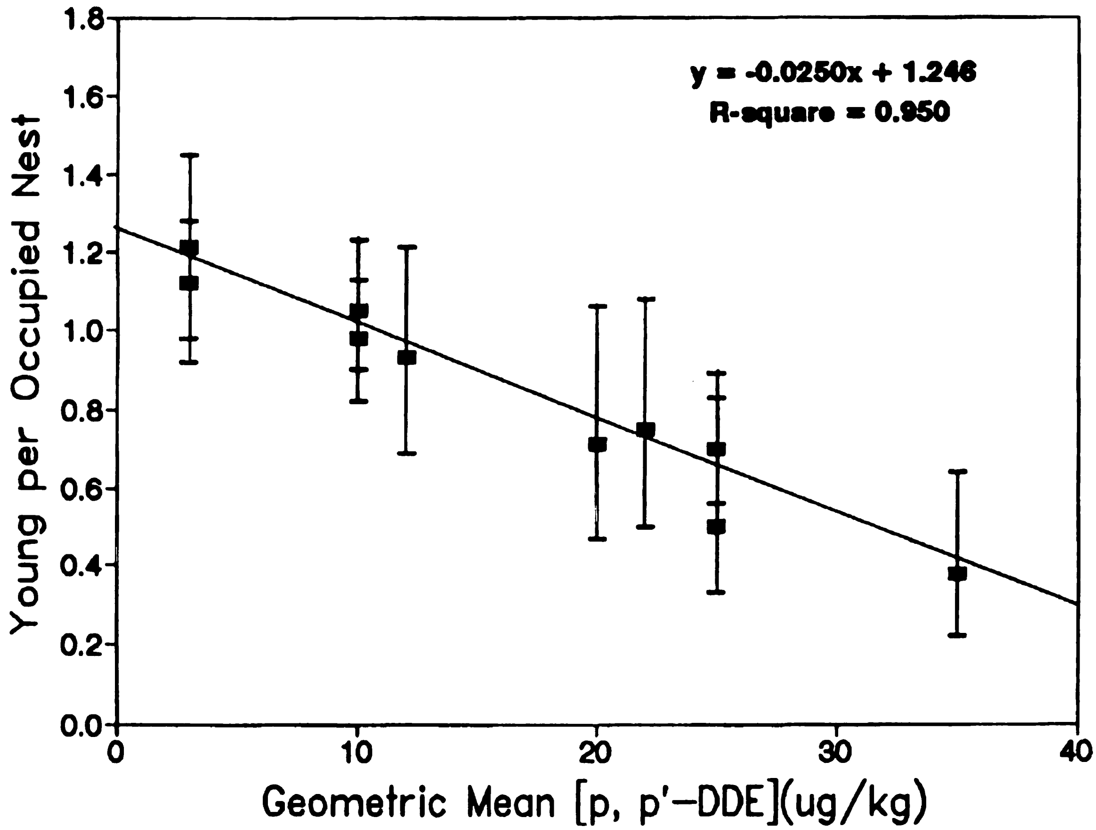
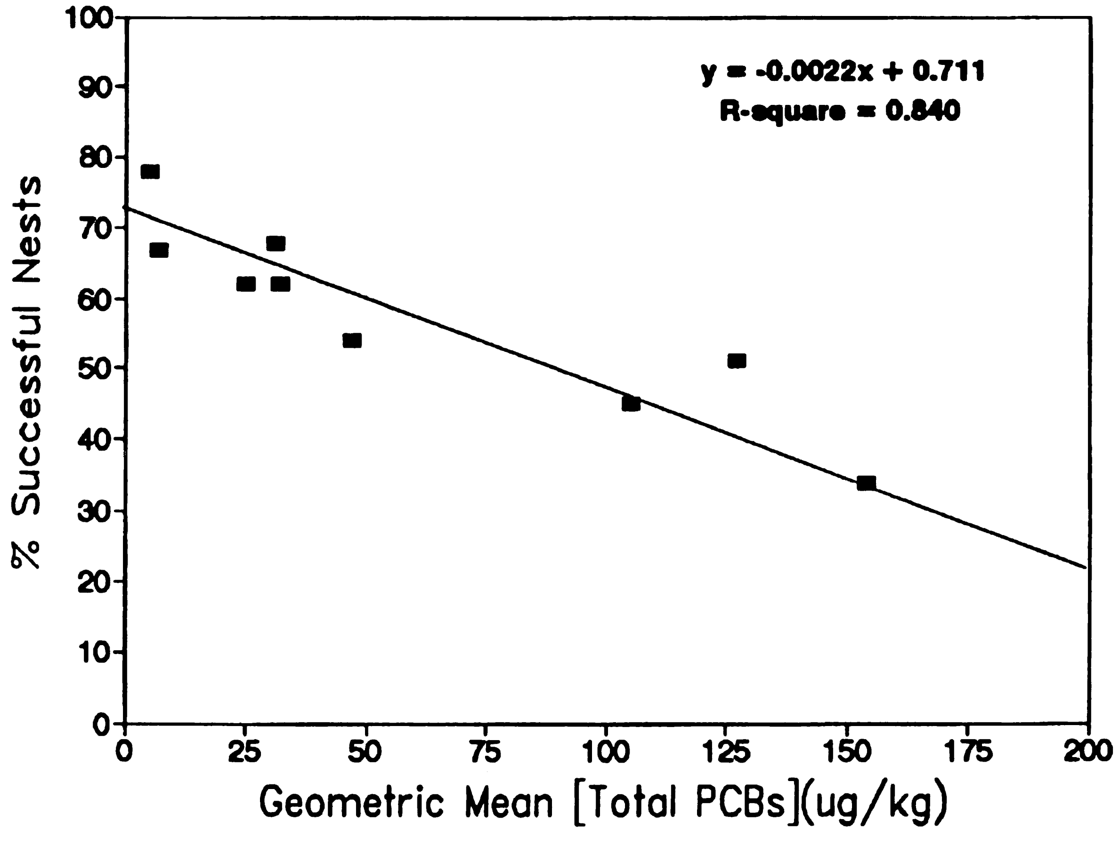

y = -0.0250x + 1.246
R-square = 0.950
Young per Occupied Nest
Geometric Mean [p, p'-DDE](ug/kg)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40

Figure 40. Relationship between overall success rate, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of Total PCBs in plasma of nestling bald eagles within nine subpopulations in the upper midwest.



y = -0.0022x + 0.711
R-square = 0.840
% Successful Nests
0
10
20
30
40
50
60
70
80
90
100
0
25
50
75
100
125
150
175
200
Geometric Mean [Total PCBs](ug/kg)

Figure 42. Relationship between overall success rate, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of p,p'-DDE in plasma of nestling bald eagles within ten subpopulations in the upper midwest.

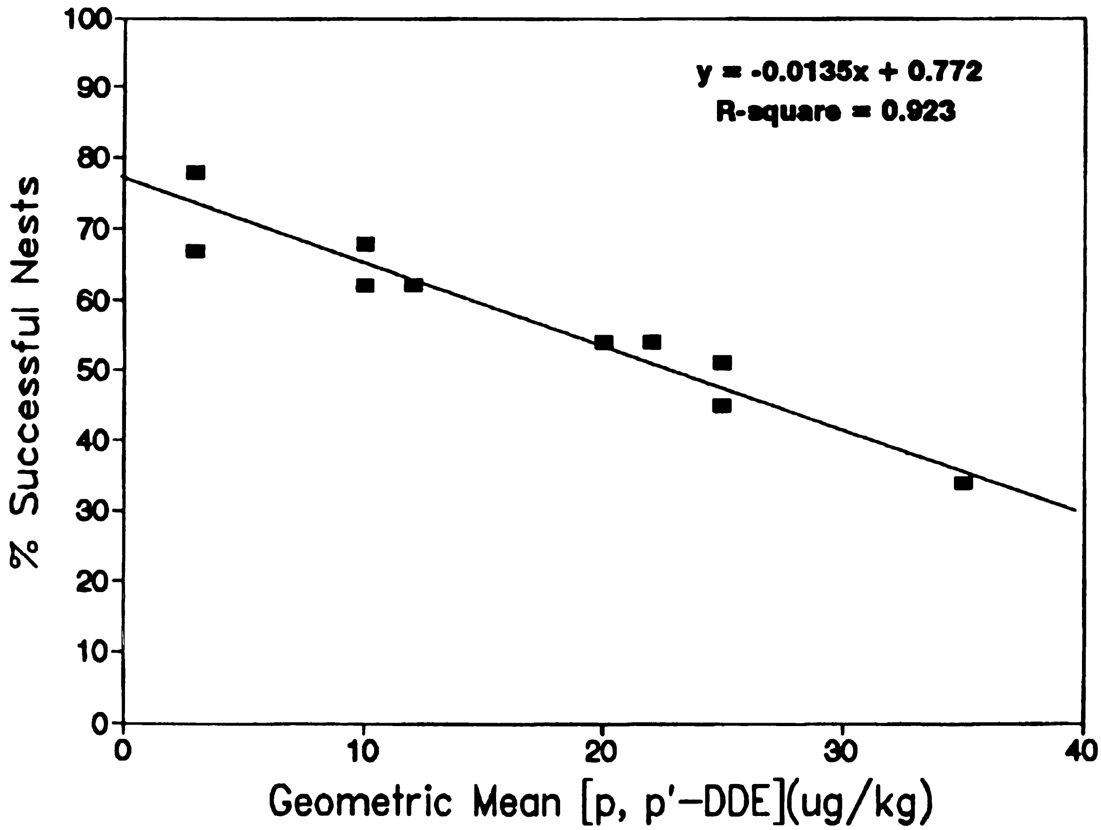

y = -0.0135x + 0.772
R-square = 0.923
% Successful Nests
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
Geometric Mean [p, p'-DDE](ug/kg)

Figure 42. Relationship between mean annual success rate, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of Total PCBs in plasma of nestling bald eagles within nine subpopulations in the upper midwest. Error bars are one standard deviation from the mean.

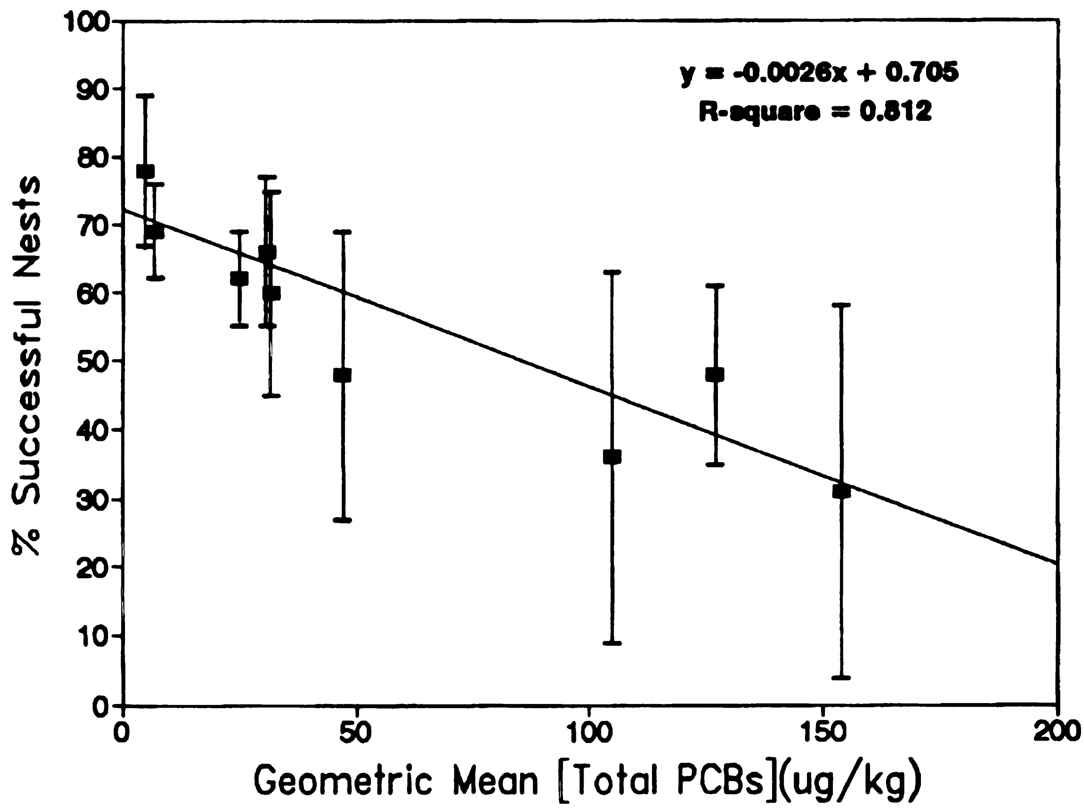

y = -0.0026x + 0.705
R-square = 0.812
100
90
80
70
60
50
40
30
20
10
0
% Successful Nests
0
50
100
150
200
Geometric Mean [Total PCBs](ug/kg)

Figure 43. Relationship between mean annual success rate, 1977-1993, and geometric mean concentrations (ug/kg wet wt) of p,p'-DDE in plasma of nestling bald eagles within ten subpopulations in the upper midwest. Error bars are one standard deviation from the mean.

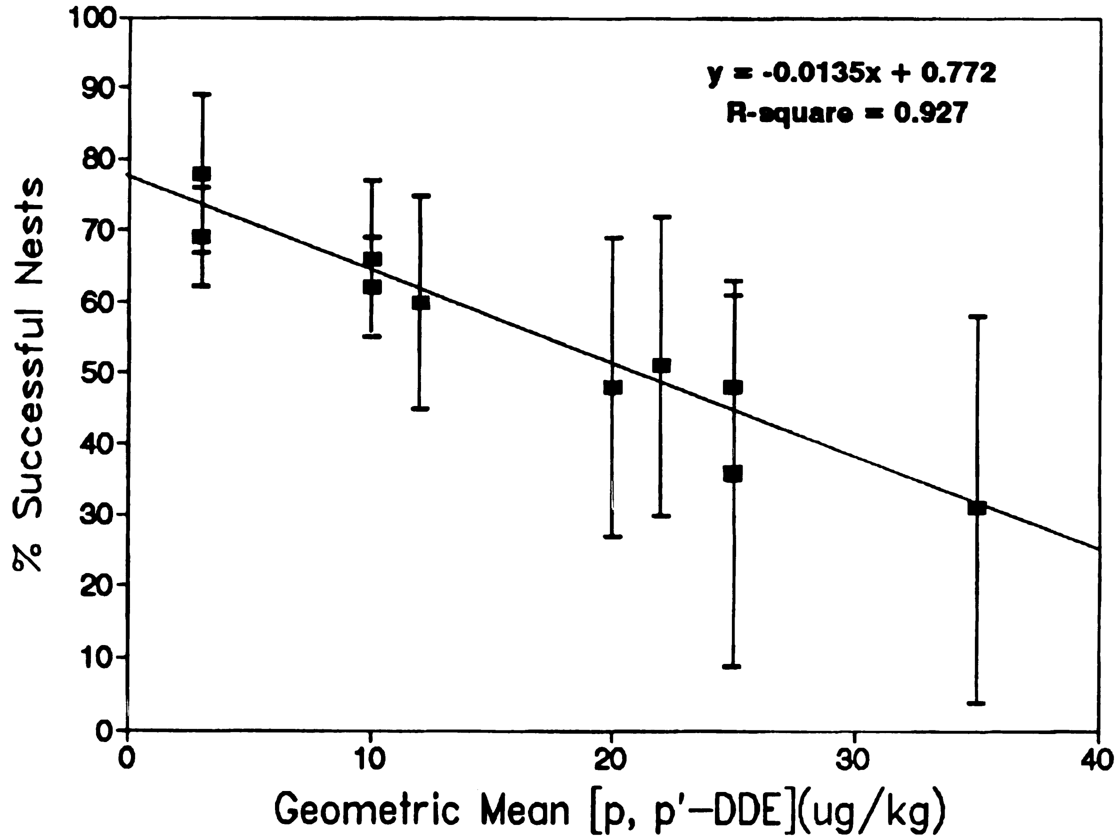
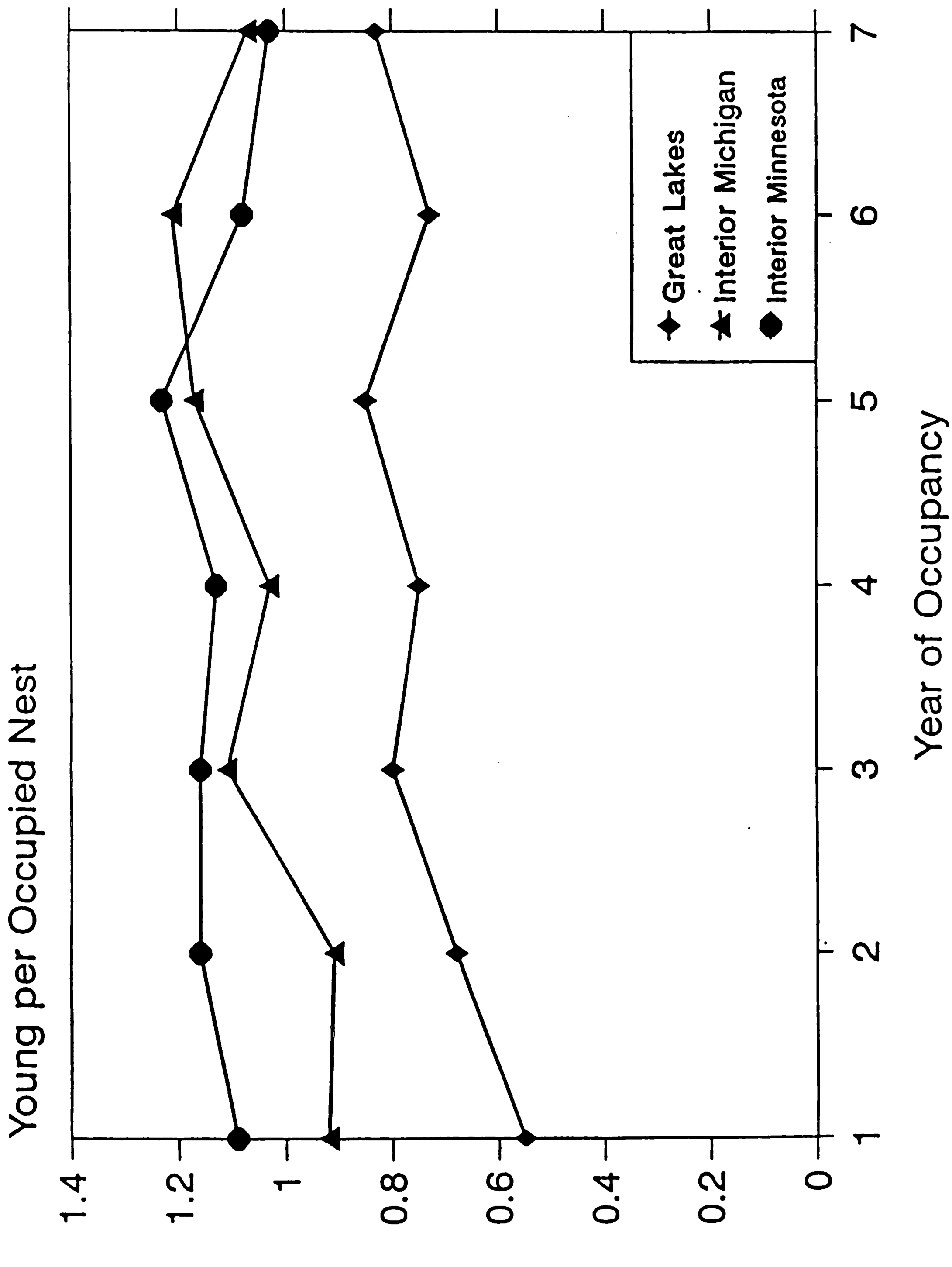
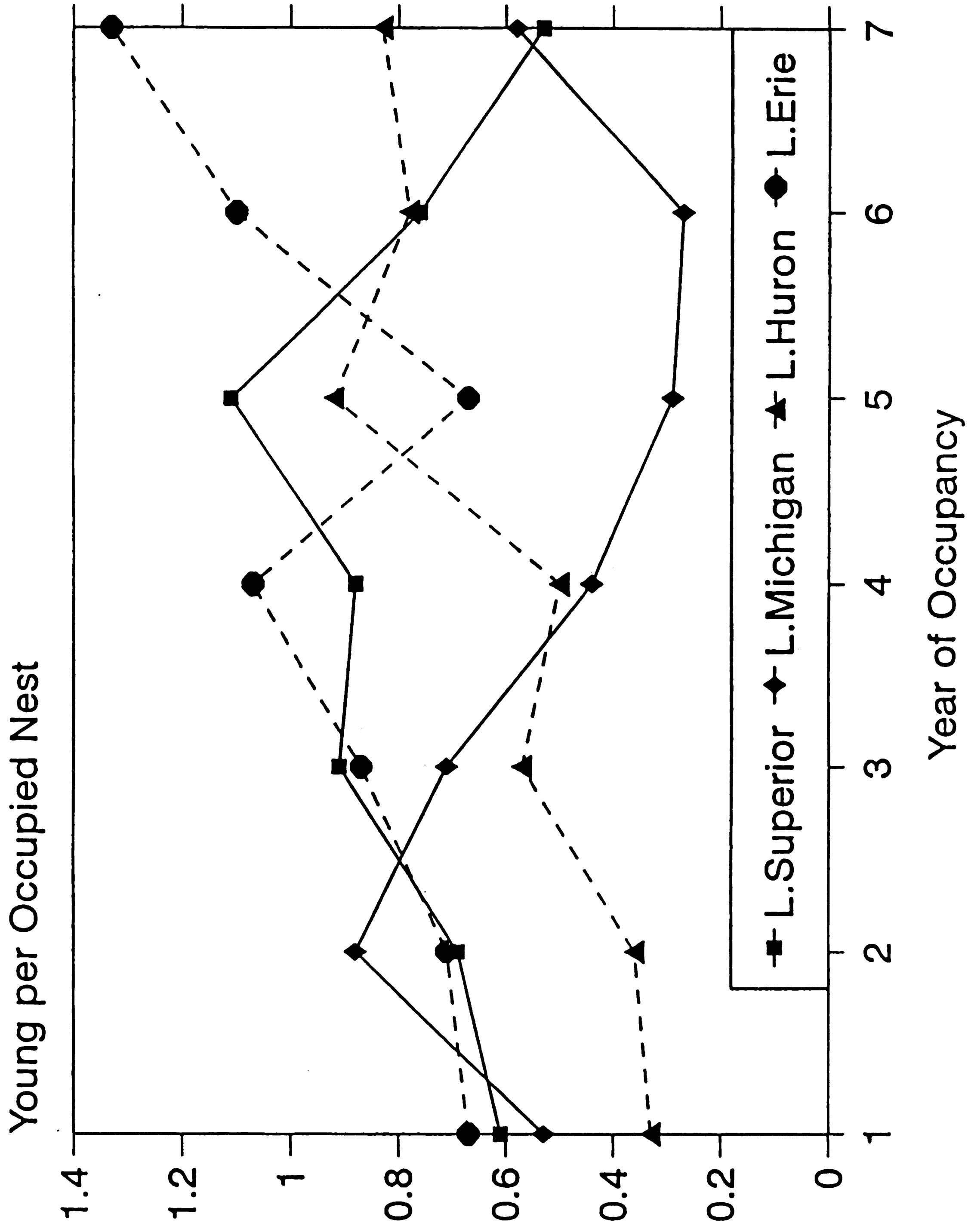

y = -0.0135x + 0.772
R-square = 0.927
% Successful Nests
Geometric Mean [p, p'–DDE](ug/kg)
0
10
20
30
40
50
60
70
80
90
100

Figure 44. Number of young per occupied nest over time of occupancy for three regions within the upper midwest. Breeding areas are those newly established since 1978.



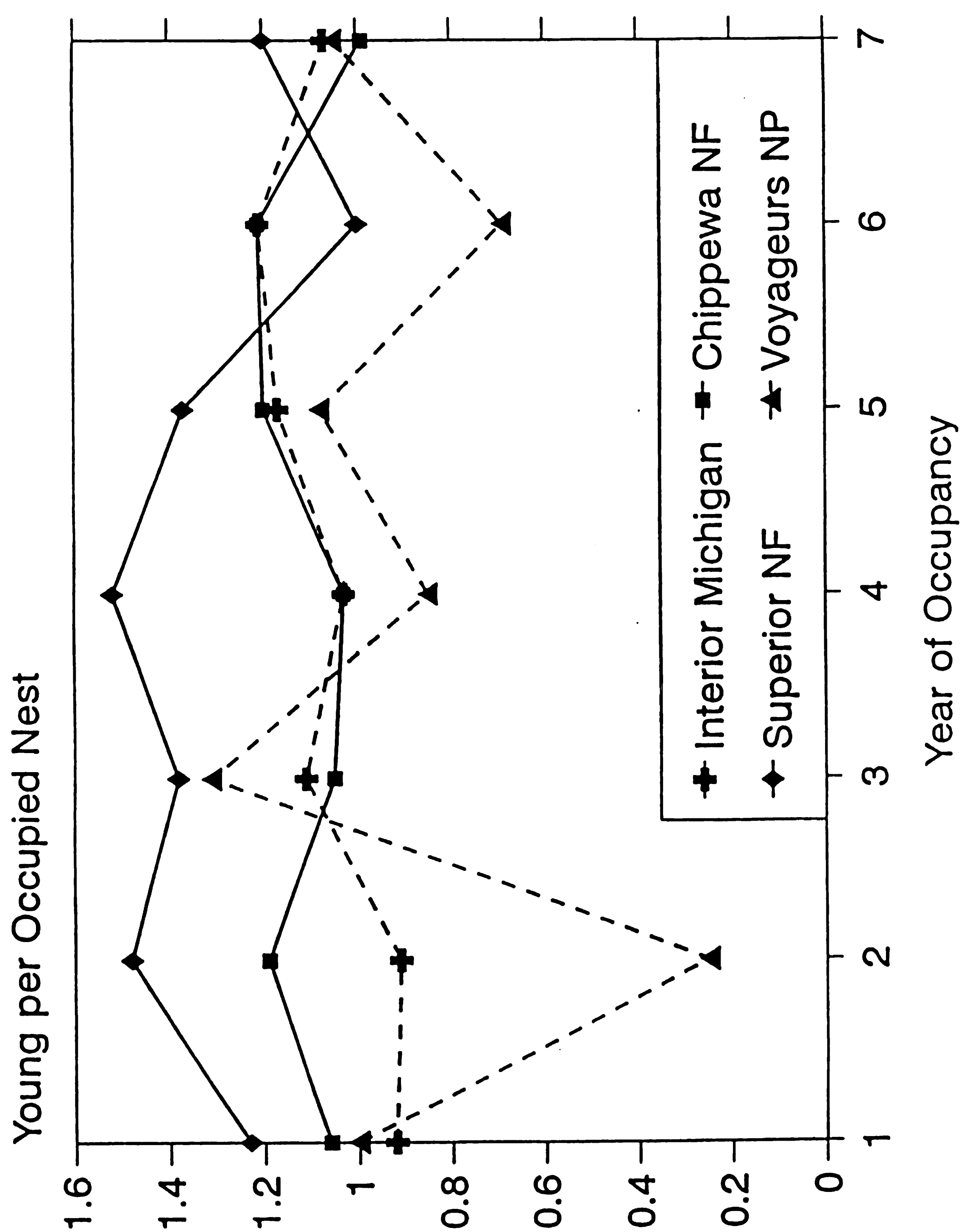
Young per Occupied Nest
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
Year of Occupancy
Great Lakes
Interior Michigan
Interior Minnesota

Figure 45. Number of young per occupied nest over time of occupancy for four Great Lakes subpopulations within the upper midwest. Breeding areas are those newly established since 1978.



Young per Occupied Nest
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
Year of Occupancy
L.Superior
L.Michigan
L.Huron
L.Erie

Figure 46. Number of young per occupied nest over time of occupancy for four interior subpopulations within the upper midwest. Breeding areas are those newly established since 1978.


Young per Occupied Nest
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
Year of Occupancy
Interior Michigan
Chippewa NF
Superior NF
Voyageurs NP

was above the population recovery goal of 1.0 young per occupied nest (Grier et al. 1983) in all years for Minnesota, after year 2 in interior Michigan, but never in Great Lakes breeding areas (Figure 44). Productivity generally increased over time by subpopulation along Lakes Huron and Erie, but varied along Lakes Superior and Michigan. Productivity was above the population recovery goal only in years 4, 6, and 7 for Lake Erie and year 5 for Lake Superior (Figure 45). Productivity increased over time for interior Michigan, declined for Superior National Forest, did not change for Chippewa National Forest, and was variable for Voyageurs National Park. Productivity was greater than the recovery plan goal for all years for Chippewa and Superior National Forests, after year 2 for Michigan, and on alternate years for Voyageurs National Park (Figure 46).

DISCUSSION

The mean productivities of 0.71 of pairs within the Great Lakes (LS, LM, LH, LE) (N = 1046) and Voyageurs National Park subpopulations (N = 293) during the period of 1977-1993 are considered just sufficient to maintain a population, let alone to permit an increase (Sprunt *et al.* 1973). The number of breeding pairs along the Great Lakes has increased from 26 in 1977 to 134 in 1993, and at Voyageurs from 10 to 33 (Table 36). We attribute this growth to the relatively great productivity of the interior Michigan and Minnesota nesting birds of >1.0 (N = 4468 fledged young, 1977-1993), which has provided not only enough young to produce an increase in numbers of breeding pairs in the interior areas from 162 in 1977 to 418 in 1993, but to repopulate historic and other available habitat along the Great Lakes shorelines.

Increases in productivity over time of occupancy of pairs in new breeding areas was less for the breeding areas from contaminated areas, i.e., Great Lakes and Voyageurs National Park subpopulations. Over time, however, trends in productivity both increase and decline for these subpopulations. The explanation for this may be due at least in part to replacement of breeding adults by younger, relatively uncontaminated, birds in the breeding population (Kozie and Anderson 1991; Bowerman 1991; P.Hunter and M. Shieldcastle, unpubl. data). Whether productivity decreases over the life-time of more contaminated individuals will be determined only by continuing research. Whether the shore-nesting birds experience greater mortalities as a result of feeding on Great Lakes fish, as has been suggested (Kozie 1986; Bowerman 1991), is also the subject of continuing investigations.

Bald eagles nesting along the Great Lakes shorelines and interior areas accessible to runs of Great Lakes anadromous fish and those from Voyageurs National Park contain greater concentrations of chlorinated hydrocarbons such as pesticides and PCBs in blood plasma and addled eggs than those eagles from more interior sites (Kubiak and Best 1991; Chapter 5). Thus, there is a negative correlation between productivity and concentrations of PCBs and p,p'-DDE within the regional population.

The lesser productivity of bald eagles nesting near the Great Lakes or anadromous accessible rivers is believed to be due to the effects of PCBs and p,p'-DDE. Bald eagle productivity has previously been demonstrated to be inversely correlated with concentrations of PCBs and p,p'-DDE in addled eggs (Wiemeyer et al. 1984). Greater mortality of adult bald eagles has been observed along shores of Lakes Superior, Michigan, and Erie (Kozie 1986; Bowerman 1991; pers. comm., P. Hunter and M. Shieldcastle). Concentrations of PCBs in blood plasma from nestling bald eagles from Great Lakes nests were greater than from those nestlings in Oregon and Washington (Chapter 8). Low reproductive success coupled with high egg and plasma concentrations of p,p'-DDE and PCBs has been noted on the Lower Columbia River (Garrett et al. 1988).

Meteorological events have recently been suggested as a potential factor in determining reproductive success of bald eagles in the Apostle Islands, Lake Superior (Meyer 1993). However, productivity did not vary among years for regions or subpopulations. Weather may cause localized nesting failure, but its effects seem to be localized and no trends among years within a location were observed. Weather may be a cofactor due to the fact that during periods of lesser temperatures, the mobilization of xenobiotics from fat reserves may increase.

The greater rate of increase in the numbers of occupied breeding areas along the Great Lakes shoreline will probably continue. A considerable amount of unoccupied nesting habitat exists along the shores of the Great Lakes (Chapter 4). The lesser productivity of this subpopulation, however, should be a concern for recovery of the species. Previous modeling of eagle population dynamics found that increased adult mortality lead to population declines over time (Grier 1980). Increased adult mortality and lesser fecundity in combination could greatly affect population structure and function. The lesser productivity on the Chippewa National Forest may be related to density dependant factors as unoccupied breeding areas in the interior become less due to the expanding interior population (Mathisen 1993). This may in the future decrease the number of available replacement adults due to decreased interior productivity, which could result in even lower regional productivity. The population dynamics of this regional population and the impact of increased density dependant factors in interior areas and contaminant effects of the Great Lakes shoreline breeding areas needs to be discerned prior to abandonment of yearly bald eagle surveys.

MANAGEMENT IMPLICATIONS

The increases in the bald eagle population of the upper midwest are undisputed. The primary reason for this recovery has been the banning of DDT (Grier 1980; Postupalsky 1985; Colborn 1991). There are, however, subpopulations which have greater adult mortality and impaired reproductive productivity that have the potential for population level effects on continued recovery of the species. The loss of annual surveys for this k-selected species could hinder the analysis of future population trends. It is important to maintain annual surveys in at least a portion of the eagles range in order to maintain comparable data in view of the impaired productivity of >25% of the current monitored population in our study area. In view of the only analysis of eagle population dynamics (Grier 1980) and the long period of time (>15 years) necessary to observe population effects in a population of this size, it is imperative that continuous surveys of eagles continue in large geographical areas until after the population comes to equilibrium.

LITERATURE CITED

Best, D.A., W.W. Bowerman, T.J. Kubiak, S.R. Winterstein, S. Postupalsky, M.C. Shieldcastle, and J.P. Giesy. 1993. Reproductive impairment of bald eagles along the Great Lakes shorelines of Michigan and Ohio. Proc. IV World Conf. on Birds of Prey and Owls, Berlin, Germany. In Press.

Bowerman, W.W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. unpubl. M.A. thesis, Northern Michigan University, Marquette, 113pp.

Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. J. Toxicol. Environ. Health 33:395-453.

Federal Register. 1990. 50 CFR Part 17, Endangered and Threatened Wildlife and Plants; Advance Notice of a Proposal to Reclassify or Delist the Bald Eagle (*Haliaeetus leucocephalus*). 55(38):4209-4212.

Fraser, J.D., L.D. Frenzel, and J.E. Mathisen. 1985. The impact of human activities on breeding bald eagles in northcentral Minnesota. J. Wildl. Manage. 49:585-592.

Garrett, M., R.G. Anthony, J.W. Watson, and K. McGarigal. 1988. Ecology of bald eagles on the lower Columbia River. Final Report to U.S. Army Corps of Engineers, Contract No. DACW57-84-C-0071, Oregon Coop. Wildl. Res. Unit, Oregon State Univ., Corvallis.

Great Lakes Basin Commission. 1975. Report: Great Lakes Basin Framework Study. Public Information Office, Great Lakes Basin Commission, Ann Arbor, Michigan.

Grier, J.W., J.B. Elder, F.J. Gramlich, N.F. Green, J.B. Kussman, J.E. Mathisen, and J.P. Mattsson. 1983. Northern states bald eagle recovery plan. USDI-Fish and Wildl. Ser. , Washington, D.C. 105 pp.

Grier, J.W. 1980. Modeling approaches to bald eagle population dynamics. Wildl. Soc. Bull. 8(4):316-322.

Kozie, K.D. 1986. Breeding and feeding ecology of bald eagles in the Apostle Islands National Lakeshore. unpubl. M.S. thesis, Univ. Wis.-Stevens Point, Stevens Point.

Kozie, K.D., and R. K. Anderson. 1991. Productivity, diet, and environmental contaminants in bald eagles nesting near the Wisconsin Lake Superior shoreline. Arch. Environ. Contam. Toxicol. 20:41-48.

Kubiak, T.J, and D.A. Best. 1991. Wildlife risks associated with passage of contaminated, anadromous fish at Federal Energy Regulatory Commission licensed dams in Michigan. U.S. Fish & Wildl. Serv., E. Lansing, Michigan. 55p.

Mathisen, J.E. 1993. Annual bald eagle productivity report. unpubl. rep., Chippewa National Forest, Cass Lake, Minnesota.

Meyer, M.W. 1993. Factors controlling Great Lakes bald eagle productivity: 1992 annual progress report. unpubl. rep. to Great Lakes Protection Fund, Wisconsin DNR, Madison, Wisconsin.

Miller, R.G. 1981. Simultaneous Statistical Inference. Springer-Verlag, New York.

Postupalsky, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. pp. 21-31 in F.N. Hamerstrom, Jr., B.E. Harrell, and R.R. Ohlendorff (eds.), Management of Raptors. Proc. Conf. Raptor Conserv. Tech., Raptor Res. Report No. 2.

Postupalsky, S. 1985. The bald eagles return. Natural History 87:62-63.

SAS Institute Inc. 1991. SAS/STAT User's Guide, Release 6.03 Edition.

USFWS. 1991. Compilation of 1991 bald eagle nesting data for the 48 contiguous United States. unpubl. rep., U.S. Fish and Wildlife Service, Minneapolis, Minnesota.

Wiemeyer, S.N., T.J. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser, and M.A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs--1969-1979--and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

CHAPTER 10:

THE INFLUENCE OF ENVIRONMENTAL CONTAMINANTS ON BALD EAGLE POPULATIONS IN THE LAURENTIAN GREAT LAKES, NORTH AMERICA

INTRODUCTION

Bald Eagle populations in North America declined during the 1950s and early 1960s, primarily due to the effects of *p,p'*-DDE, a degradation product of DDT (Wiemeyer *et al.* 1984). Bald Eagles nesting along the coasts and islands of the Laurentian Great Lakes were nearly extirpated by the mid 1960s. Since 1977, eagle populations have been increasing; in 1981-1990 the Great Lakes sub-population tripled, and a 50 % increase was recorded in inland areas in Michigan and Ohio (Best *et al.* 1993). Reproduction, however, is not uniform among locations; in areas where nesting eagles feed on the Great Lakes food chain, productivity is significantly lower (Best *et al.* 1993). We collected addled eggs and nestling blood plasma from throughout the Great Lakes Basin to relate measured concentrations of organochlorine pesticides and PCBs to adverse reproductive effects.

METHODS

Blood collection and analysis

Blood was collected from 46 nestling Bald Eagles in Michigan during 1987 and 1988, and from 121 nestlings in Michigan, Minnesota, Ohio, Ontario, and Wisconsin in 1989 (Bowerman *et al.* 1990). Blood was collected from the brachialus vein using sterile techniques with heparinized glass syringes fitted with 22- or 24-gauge needles. The syringes had previously been washed with hexane and acetone. Samples of whole blood were transferred to heparinized vacuum tubes, kept on ice in coolers, and centrifuged within 48 h of collection. Plasma was decanted and transferred to vacuum tubes and frozen (Morizot *et al.* 1985). Concentrations of PCBs and organochlorine pesticides were determined using gas chromatography and confirmed using GC/MS (Price *et al.* 1986; MDPH 1987). The reported limits of quantification were 5 ppb for *p,p'*-DDE and 10 ppb for total PCBs.

Addled egg collection and analysis

Forty-one addled or abandoned eggs were collected from 31 Bald Eagle breeding areas in Michigan and Ohio between 1986 and 1990. Five fresh eggs were collected from five breeding areas in Alaska in 1990 to determine background concentrations in eagle eggs from a control area. Eggs were archived using techniques developed by the Richter Museum of Natural History, University of Wisconsin-Green Bay (T. Erdmann, pers. corr.). Egg contents were stored in chemically-clean jars and frozen prior to shipment for chemical analyses. Eggs were measured, weighed, and eggshell thicknesses determined. Concentrations of PCBs and organochlorine pesticides were determined using gas chromatography and confirmed using GC/MS (Mississippi State University 1985). The reported limits of quantification, uncorrected for egg content moisture loss, were 0.10 ppm for *p,p'*-DDE and dieldrin, and 0.50 ppm for total PCBs. Fresh, wet-weight concentrations of organochlorine pesticides and PCBs were then determined using equations to adjust for moisture loss (Stickel *et al.* 1973).

Ambrose *et al.* (1988) have shown no differences in residue concentrations between addled eggs and eggs collected at random earlier in the season from the same clutch of Peregrine Falcons, *Falco peregrinus*. In this case therefore the addled eggs did not constitute a biased sample. Helander *et al.* (1982), however, demonstrated higher levels of DDE and PCBs in addled eggs than in other eggs; the addled eggs were not unbiased samples of the egg population, but represented rather a subset of the eagle population with higher contaminant levels. In this study we relate residue levels in addled eggs with productivity of the sampled sites; in this context therefore they are unbiased samples. See below, for a discussion of possible bias in the productivity estimates.

Productivity estimates

Reproduction was determined for eight geographic realms where eggs were collected for all breeding attempts between 1986-1990. Productivity of each realm was derived by dividing the total number of fledged young by the total number of occupied breeding areas (Postupalsky 1974).

Since the sample size of nests conforming to criteria previously used (i.e. Wiemeyer *et al.* 1984) was small, productivity of individual nests was estimated on a case-by-case basis. The population is rapidly expanding, and many nests where eggs were collected had fewer than 3 years of productivity data available between 1982-1990.

As in earlier studies, the site rather than the female was the sampling unit. Unlike this rapidly expanding population with a large number of non-territorial younger birds, populations in the 1960s and 70s were declining or stable, and can be expected to have had lower numbers of non-territorial birds. Productivity estimates may therefore be influenced by turnover rates.

Statistical analysis

Concentrations of *p,p'*-DDE, total PCBs, and dieldrin in blood plasma from nestling eagles were contrasted among geographic regions with the Kruskal-Wallis χ^2 approximation using SAS/STAT® NPAR1WAY (SAS Institute Inc. 1988). Differences among groups were determined using the Kruskal-Wallis simultaneous rank test (Miller 1981). Fresh, wet-weight concentrations of *p,p'*-DDE, total PCBs, and dieldrin in addled eggs from eight geographic realms were correlated with productivity using the Spearman's rank correlation test.

Definitions

Breeding areas were subdivided into two groups, Great Lakes and interior. Great Lakes breeding areas were those breeding areas located within 8.0 km of a Great Lakes shoreline or along a riverine reach with Great Lakes runs of anadromous fish. Interior breeding areas were those breeding areas located greater than 8.0 km from a Great Lakes shoreline and were not on an anadromous accessible riverine reach.

RESULTS

Mean concentrations of PCBs and *p,p'*-DDE in plasma from nestling eagles from Great Lakes breeding areas were significantly higher than those in plasma from interior areas ($P \leq 0.0001$; Kruskal-Wallis χ^2 28.6, PCBs; 21.8 *p,p'*-DDE; Table 37).

Eggs collected from Lake Michigan and Huron shorelines contained the highest mean concentrations of PCBs, *p,p'*-DDE, and dieldrin; these areas had the lowest productivity

Table 37. Arithmetic mean concentrations and ranges of p,p'-DDE and total PCBs in plasma of nestling Bald Eagles, Great Lakes Basin.

Region	n	p,p'-DDE	Total PCBs
Great Lakes	42	61 (13-306)	183 (33-520)
Interior	79	20 (2-193)	24 (5-200)

μg/l, wet weight. Kruskal-Wallis χ^2: PCBs, 28.6; p,p'-DDE, 21.8; $P \leq 0.0001$.

(Table 38). Eggs collected from Alaska contained the lowest concentrations of PCBs, *p,p'*-DDE, and dieldrin, and this area had the highest productivity. Productivity was significantly and inversely correlated with fresh, wet-weight mean concentrations of PCBs (r_s = -0.78), *p,p'*-DDE (r_s = -0.73), and dieldrin (r_s = -0.64) in addled eggs, but the residues were also significantly correlated with each other (Spearman's rank correlation test, N = 36; $P \leq 0.0001$).

DISCUSSION

Blood plasma of nestling bald eagles has been correlated with concentrations of organochlorine pesticides and PCBs representative of the eagles' prey base within roughly 8 km of the nest site for the first 6-9 weeks post-hatch (Bowerman *et al.* 1990). Nestlings are thereby appropriate biosentinels of the general contamination of their immediate environment. Concentrations of PCBs in plasma from nestlings from Great Lakes breeding areas were 6 times greater than those from interior breeding areas, while *p,p'*-DDE concentrations were 3 times greater.

Addled eagle eggs were used to determine concentrations of organochlorine pesticides and PCBs associated with reproductive impairment. Sprunt *et al.* (1973) recorded productivities of about 1.0 in two stable populations and about 0.7 in a third stable population in Florida. We follow Wiemeyer *et al.* (1984) in using a productivity of ≥ 1.0 as indicative of a healthy population unaffected by contaminants. In our sample (Table 2), mean productivities in the Great Lakes and in interior areas were 0.63 for Lakes Michigan and Huron, 0.78 for Lakes Erie and Superior, and 0.94 for the interior

Table 38. Productivity within the Great Lakes Basin and Alaska (Kubiak and Best 1991) and geometric mean concentrations, with the range, of p,p'-DDE, total PCBs, and dieldrin in addled Bald Eagle eggs.

Realm	n	p,p'-DDE[1]	Total PCBs[1]	Dieldrin[1]	Productivity[2]
Alaska	5	0.5 (0.3-0.7)	1.3 (0.8-2.1)	0.01 (0.01-0.02)	1.29
Interior Breeding Areas					
Michigan Lower Peninsula	4	2.2 (1.0-5.7)	6.2 (1.9-14.0)	0.09 (0.06-0.25)	1.14
Michigan Upper Peninsula	9	1.7 (0.5-16.0)	5.0 (1.8-29.0)	0.13 (0.02-0.91)	0.93
Interior Ohio	3	1.8 (1.3-3.1)	9.0 (5.7-20.0)	0.13 (0.07-0.42)	0.71
Great Lakes Breeding Areas					
Lake Superior	3	3.2 (1.5-9.5)	8.5 (3.4-14.0)	0.19 (0.08-0.51)	0.84
Lake Erie	7	2.8 (1.9-10.0)	20.0 (8.6-44.0)	0.45 (0.25-0.69)	0.75
Lake Michigan	2	17.0 (10.0-30.0)	38.0 (27.0-55.0)	1.10 (0.60-2.00)	0.68
Lake Huron	3	16.0 (8.5-41.0)	73.0 (50.0-110.0)	0.88 (0.39-2.30)	0.59

[1] Fresh wet weight, ppm. [2] Total number of fledged young divided by the total number of occupied breeding areas.

regions (Table 38). In a much larger sample Best *et al.* (1993) determined a mean productivity of 0.68 for all Great Lakes sites in 1981-1990 and 1.00 for the interior.

In this data set, like those previously examined for the relationships between productivity and contaminant residues (Wiemeyer *et al.* 1984, 1993; Nisbet 1989) the high correlation between DDE and PCB residues precludes any attempt to sort out their relative contributions to the depressed productivity. The previous analyses, however, would predict almost zero productivity at the DDE residue levels we measured in the eggs from Lakes Michigan and Huron. A possible bias in the productivity estimates, discussed above, might explain at least in part this apparent inconsistency between our data and those previously published.

DDE has been associated with the thin eggshell syndrome of Bald Eagles (Wiemeyer *et al.* 1984). Approximately 25 percent of the eggs represented in this paper have shells that are $\geq 15\%$ thin (Best, unpublished). A DDE effect on reproduction is therefore indicated.

We have no evidence that links the observed levels of dieldrin with reproductive failures.

PCBs produce teratogenic effects, such as bill defects (Gilbertson *et al.* 1991). Bill defects in six nestling eagles have been observed from areas in the Great Lakes region (Ontario, Michigan, Wisconsin, and Minnesota) between 1968 and 1989 (Grier 1968; Chapter 8). In Sweden, nestling White-tailed Eagles, *Haliaeetus albicilla*, with bill defects were believed to be related to PCBs (Helander 1983). In an examination of chicken feeding studies, Aroclor and dioxin-like PCB congener concentrations in hen's feed explained toxic, egg-intrinsic reproductive effects (Kubiak *et al.* 1989). PCB concentrations in Bald Eagle eggs are far greater than known effect levels in poultry experiments, as measured by either total PCB or by certain individual, dioxin-like, PCB congener concentrations (Kubiak 1988; Britton & Huston 1973; Brunström & Andersson 1988).

An assessment of the role of the PCB congeners producing dioxin-type effects in Bald Eagles of the Great Lakes region is nearing completion. This analysis should refine our understanding of the relative contributions of the dioxin-like effects of these congeners, of other effects of PCBs, and of DDE-induced eggshell deficiencies to the present reproductive failures of Bald Eagles in the Laurentian Great Lakes.

LITERATURE CITED

Ambrose, R.E., C.J. Henny, R.E. Hunter, and J.A. Crawford. 1988. Organochlorines in Alaskan peregrine falcon eggs and their current impact on productivity. In T.J. Cade, J.H. Enderson, C.G. Thelander, and C.M. White, eds., Peregrine Falcon Populations: Their management and recovery. The Peregrine Fund, Boise, Idaho, pp. 377-384.

Best, D. A., W. W. Bowerman, T. J. Kubiak, S. R. Winterstein, S. Postupalsky, M. C. Shieldcastle, J. P. Giesy. 1993. Reproductive impairment of bald eagles along the Great Lakes shorelines of Michigan and Ohio. Proceedings of the IV World Conf. on Birds of Prey and Owls, Berlin, Germany.

Bowerman, W. W., D. A. Best, E. D. Evans, S. Postupalsky, M. S.Martell, K. D. Kozie, R. L. Welch, R. H. Scheel, K. F. Durling, J. C. Rogers, T. J. Kubiak, D. E. Tillit, T. R. Schwartz, P. D. Jones, and J. P. Giesy. 1990. PCB concentrations in plasma of nestling bald eagles from the Great Lakes Basin, North America. In H. Fiedler and O. Huttzinger, eds., 10th Intl. Conf. on Organohalogen Compounds, Bayreuth, Germany, Vol. IV, pp. 212-216.

Britton, W.M., and T.M. Huston. 1973. Influence of polychlorinated biphenyls in the laying hen. Poultry Sci. 52:1620-1624.

Brunstrom, B., and L. Andersson. 1988. Toxicity and 7-ethoxyresorufin-o-deethylase-inducing potency of coplanar polychlorinated biphenyls in chick embryos. Arch. Toxicol. 62:263-266.

Gilbertson, M., T. J. Kubiak, J. P. Ludwig, and G. A. Fox. 1991. Great Lakes embryo mortality, edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: Similarity to chick-edema disease. J. Tox. Env. Health. 33(4):455-520.

Grier, J.W. 1968. Immature bald eagle with an abnormal beak. Bird Banding 39:58-59

Helander B., M. Olsson, and L. Reutergardh. 1982. Residue levels of organochlorine and mercury compounds in unhatched eggs and the relationships to breeding success in white-tailed sea eagles *Haliaeetus albicilla* in Sweden. Holarct. Ecol. 5:349-366.

Helander, B. 1983. Sea Eagle--Experimental studies: Artificial incubation of White-tailed Sea Eagle eggs 1978-1980 and the rearing and introduction to the wild of an eaglet. Nat. Swedish Environ. Protection Board Report snv pm 1386.

Kubiak, T.J. 1988. Diffuse toxic pollutants in the Great Lakes ecosystem. Hearing before the Subcommittee on Investigations and Oversight of the Committee on Public Works and Transportation. U.S. House of Representatives, Washington.

Kubiak, T. J., H. J. Harris, L. M. Smith, T. R. Schwartz, D. L. Stalling, J. A. Trick, L. Sileo, D. Docharty, and T. C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forster's Tern on Green Bay, Lake Michigan-1983. Arch. Environ. Contam. Toxicol. 18:706-727.

Kubiak, T.J., and D.A. Best. 1991. Wildlife risks associated with passage of contaminated, anadromous fish at Federal Energy Regulatory Commission licensed dams in Michigan. U.S. Fish and Wildl. Serv., E. Lansing, Michigan 55 p

Michigan Department of Public Health. 1987. Analytical method No. 7. Center of Environ. Hlth. Sci., Epidemol. Studies Lab., Lansing, Mich.

Miller, R. G. 1981. Simultaneous Statistical Inference. Springer-Verlag Inc., New York.

Mississippi State University. 1985. Method 1: Analysis for chlorinated hydrocarbon pesticides and related compounds. Mississippi State Chemical Laboratory, Mississippi State, Mississippi.

Morizot, D. C., R. G. Anthony, T. G. Grubb, S. W. Hoffman, M. E. Schmidt, and R. E. Ferrell. 1985. Clinal genetic variation at enzyme loci in bald eagles (*Haliaeetus leucocephalus*) from the western United States. Biochem. Gen. 23(3/4): 337-345.

Nisbet, I.C.T. 1989. Organochlorines, reproductive impairment and declines in bald eagle *Haliaeetus leucocephalus* populations: Mechanisms and dose-response relationships. In B.-U. Meyburg and R.D. Chancellor, eds., Raptors in the Modern World, World Working Group on Birds of Prey, Berlin.

Postupalsky, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. pp. 21-31 In F. N. Hamerstrom, B. E. Harrell, and R. R. Ohlendorff (eds.), Management of Raptors. Proc. Conf. Raptor Conserv. Techniques, Raptor Res. Report No. 2.

Price, H. A., R. L. Welch, R. H. Scheel, and L. A. Warren. 1986. Modified multiresidue method for chlordane, toxaphene, and polychlorinated biphenyls in fish. Bull. Environ. Contam. Toxicol. 37:1-9.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. Cary, North Carolina.

Sprunt, A., IV, W. B. Robertson, Jr., S. Postupalsky, R. J. Hensel, C. E. Knoder, and F. J. Ligas. 1973. Comparative productivity of six bald eagle populations. Trans. N. Am. Wildl. Nat. Resour. Conf., 38:96-106.

Stickel, L. F., S. N. Wiemeyer, and L. G. Blus. 1973. Pesticide residues in eggs of wild birds: adjustment for loss of moisture and lipid. Bull. Environ. Contam. Toxicol. 9(4):193-196.

Wiemeyer, S. N., T. J. Lamont, C. M. Bunck, C. R. Sindelar, F. J. Gramlich, J. D. Fraser, and M. A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs--1969-1979--and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

Wiemeyer, S.N., C.M. Bunck, and C.J. Stafford. 1993. Environmental contaminants in bald eagle eggs--1980-84--and further interpretations of relationships to productivity and shell thickness. Arch. Environ. Contam. Toxicol. 24:213-227.

SUMMARY

There are three primary factors which affect reproduction of bald eagles: environmental contaminants; habitat; and human disturbance. Research on which I have reported here addressed the first two factors, environmental contaminants and habitat. The third component, while not a primary focus of my doctoral research, was addressed by our research team and the results are reported in Grubb et al. (1993).

By far, the controlling factor to bald eagle reproduction along the shorelines of the Great Lakes, where eagles currently nest, is the influence of environmental contaminants. We have shown that p,p'-DDE and PCBs are correlated with impaired reproductive potential of eagles along the shorelines of Lakes Superior, Michigan, Huron, and Erie, as well as at Voyageurs National Park. Furthermore, current concentrations of PCBs and p,p'-DDE in eggs of bald eagles are sufficiently great, based on controlled laboratory studies, to cause adverse effects. While egg shell thinning due to p,p'-DDE may still be influencing eagle reproduction, we have further shown that PCBs are inversely correlated with reproduction. The occurrence of teratogenic effects in nestlings, which are similar to those that are known to be caused by dioxin-like coplanar compounds including PCBs, polychlorinated dibenzo-furans and polychlorinated dibenzo-dioxins, indicates that these compounds are the most likely causative agent. These effects have also been observed to occur with relatively great concentrations of

dioxin equivalents (TCDD-EQ) in controlled laboratory studies (Giesy et al. 1993). We have shown further that concentrations of mercury are not correlated with bald eagle reproductive productivity. We have further shown that the use of tissues, both blood and feathers, of nestling eagles, can be an effective way of monitoring the concentrations of organochlorine pesticides, PCBs, and heavy metals in bald eagles.

Availability of physical habitat does not seem to be limiting expansion of the bald eagle population along the upper Great Lakes shorelines. While bald eagles are restricted from some areas due to human disturbance or physical structure of the habitat, there are still areas, deemed to be suitable nesting habitat, which are currently unoccupied by bald eagles. This is especially true of the northern forested regions which are less populated by humans. Habitat along Lake Erie is scarce and may be a limiting factor in the near future. The aggressive management strategy of the Ohio Department of Natural Resources and the Ontario Ministry of Natural Resources to control human disturbance near nests along Lake Erie may be improving habitat that would otherwise be classified as marginal to good habitat. This is primarily due to control of the negative influence of human disturbance early in the nesting period.

We found that throughout the upper midwest, habitat use and feeding habits were similar. Bald eagles utilize large, open canopy trees that were either dominant or codominant in the stand for building nests, and perching in both summer and winter. In addition, eagles primarily foraged on fish. The same species of warm-water fish were utilized throughout the study area and were identical to species utilized throughout North America in regions away from the ocean coasts. These species are primarily of the

Families *Esocidae, Catostomidae, Ictaluridae, Amiidae,* and *Cyrprinidae.*

Bald eagle populations throughout the upper midwest have experienced a steady increase in breeding pairs throughout the period, 1977-1993. However, reproductive productivity has not been uniform throughout the study area. Bald eagles nesting in areas along the Great Lakes shoreline and at Voyageurs National Park were significantly less productive that those from interior areas of Michigan and the Chippewa and Superior National Forests in Minnesota. As these bald eagles continue to reoccupy areas where they were extirpated during the 1950s and 1960s, differential effects of productivity could become even more pronounced. Density-dependant factors will continue to cause eagles from the more interior areas, where more eagles are fledged than is necessary to maintain a stable age distribution, to reoccupy the Great Lakes shorelines. This is already occurring as the Great Lakes subpopulation has the greatest growth rate for numbers of new breeding areas. Additional investigation into the dynamics of these populations is needed to monitor the recovery of this species, and to compare areas of greater concentrations of organochlorine compounds with more pristine areas. Additionally, the effect of differential adult turnover along the Great Lakes shoreline needs to be understood before a population model of the region can be produced and verified. While the number of bald eagles in the Great Lakes Basin and adjacent areas has continued to increase as the effects of p,p'-DDE has subsided, it is uncertain what the carrying capacity of the region is.

LITERATURE CITED

Giesy, J.P., J.P. Ludwig, and D.E. Tillitt. 1993. Embryolethality and deformities in colonial, fish-eating waterbirds of the Great Lakes region: Assigning causality. Environ. Sci. Technol. In Press.

Grubb, T.G., W.W. Bowerman, J.P. Giesy, and G.A. Dawson. 1993. Responses of breeding bald eagles to human activity in northcentral Michigan. Canadian Field Naturalist. In Press.

MANAGEMENT RECOMMENDATIONS

The management recommendations given here are primarily adaptations of those found within the Northern States Bald Eagle Recovery Plan (Grier et al. 1983). The effects of p,p'-DDE and PCBs on reproduction along the Great Lakes shoreline have resulted in a net immigration of bald eagles from other areas, which are less contaminated and have greater reproductive productivities. Based on earlier studies of bald eagles (Sprunt et al. 1973), eagles breeding along the Great Lakes shorelines and Voyageurs National Park also reproduce at a rate barely able to sustain their population, let alone allow for the increase in breeding pairs observed in these areas during the period, 1977-1993. In order to compensate for the less than adequate production of bald eagles along the Great Lakes shoreline, it is necessary to protect the breeding potential of bald eagles in areas where these chlorinated hydrocarbons are not influencing reproductive productivity.

Our results suggest that exposure of eagles to Great Lakes fishes should be minimized. Thus, it would be premature to begin hacking programs to reestablish populations of eagles or improve their genetic diversity along the Great Lakes shoreline, especially Lakes Erie or Ontario. Furthermore, management practices that increase the potential exposure of eagles to chlorinated hydrocarbons in Great Lakes fishes, such as passage of fishes around dams on tributaries to Lakes Michigan, Huron, and Erie, could have adverse effects on productivity of bald eagles in regions which are currently sufficiently productive to act as a source of eagles to colonize other areas. Only by maintaining a vulnerable, relatively uncontaminated, food source for eagles during the breeding season can we continue to experience the population recovery of this species in the midwest.

The means of protecting bald eagle breeding areas from the effects of human disturbance, and to maintain nesting, perching, roosting, and foraging habitat within these breeding areas are given in the Recovery Plan. However, outside of the U.S. Forest Service, Ohio Department of Natural Resources, and along Lake Erie, the Ontario Ministry of Natural Resources, few of the state and federal agencies with jurisdiction over the bald eagle within the upper midwest have implemented these management guidelines. Furthermore, based on previous work on bald eagle foraging in the upper peninsula of Michigan (Bowerman 1991), there are no set guidelines for the protection of the bald eagles forage base within its breeding area.

To maintain a healthy bald eagle population across the upper midwest, it will be necessary to implement guidelines protecting bald eagle breeding habitat in areas outside of those areas that are still affected by chlorinated hydrocarbons. Only by continuing to produce a surplus of eagles in the interior areas can the detrimental effects of impaired productivity and increased adult mortality, be compensated for along the Great Lakes shoreline.

Those areas along the Great Lakes where potential bald eagle nesting habitat still exists needs to be managed as "Essential Habitat" under the Recovery Plan. This will maintain large areas of habitat for bald eagle occupation by requiring that human activities within these areas be planned to have little negative impact on the suitability of these areas for bald eagle nesting. This designation will allow for the reoccupancy of these habitats by bald eagles.

LITERATURE CITED

Bowerman, W.W. IV. 1991. Factors influencing breeding success of bald eagles in upper Michigan. unpubl. M.A. thesis, Northern Michigan University, Marquette, 113pp.

Grier, J.W., J.B. Elder, F.J. Gramlich, N.F. Green, J.V. Kussman, J.E. Mathisen, and J.P. Mattsson. 1983. Northern States Bald Eagle Recovery Plan. U.S. Fish and Wildlife Service, Washington, D.C.

Sprunt, A., IV, W.B. Robertson, Jr., S. Postupalsky, R.J. Hensel, C.E. Knoder, and F.J. Ligas. 1973. Comparative productivity of six bald eagle populations. Trans. N. Am. Wildl. Natural Resources Conf. 38:96-106.