MI/DEQ/WRD-14/024

MICHIGAN WILDLIFE CONTAMINANT TREND MONITORING

Nestling Bald Eagle DDE and PCB Report

Spatial Trends
1999-2008
Temporal Trends
1987-2008

Prepared by:

Michael R. Wierda, Katherine F. Leith, and
Dr. William Bowerman

Department of Forestry and Natural Resources
Institute of Environmental Toxicology
Clemson University

Abstract

The bald eagle (*Haliaeetus leucocephalus*) is an extensively researched tertiary predator. Studies have delineated information about its life history and the influences of various stressors on its reproduction. Due to the bald eagle's position at the top of the food web, it is susceptible to biomagnification of xenobiotics. The Michigan Department of Environmental Quality implemented a program under the Clean Michigan Initiative in 1999 to monitor persistent and bioaccumulative chemicals, including PCBs and organochlorine pesticides, in bald eagles. The objectives of this monitoring program were to evaluate spatial and temporal trends of these contaminants in nestling bald eagles in Michigan. Spatially, our study found that concentrations of PCBs and pesticides were higher in Great Lakes areas compared to inland areas, with Lakes Michigan and Huron having the highest concentrations of pesticides and Lake Erie having the highest concentrations of PCBs. Temporally, our study found declines in PCB and *p*,*p*'-DDE concentrations with a few exceptions. Continued monitoring of bald eagle populations is important since PCB and *p*,*p*'-DDE concentrations for 37 and 40 percent, respectively, of the nestling eagles sampled were above the no observable adverse effect levels.

INTRODUCTION

The bald eagle (*Haliaeetus leucocephalus*) is one of the most studied birds of North America. Scientific studies have described its life history and have shown the influence of various stressors on reproduction.[1-3] The bald eagle population in Michigan has recovered since the population bottleneck of the 1960s and early 1970s.[4] In the 1960s, when Michigan's eagle population was first being monitored, less than 100 nests were occupied (i.e., 100 active breeding pairs existed).[5] In 2009, there were approximately 500 occupied nests with over 700 known breeding areas in the state.[6]

The bald eagle is a tertiary predator of the Great Lakes Basin aquatic food web generally preferring fish over a variety of avian, mammalian, and reptilian prey.[7] As a result, this species is susceptible to biomagnification of a wide array of contaminants such as polychlorinated biphenyls (PCB) and organochlorine pesticides (e.g., dichlorodiphenyltrichloroethane [DDT] and its metabolites).

Blood is commonly used to monitor environmental exposure of birds to contaminants.[8-11] The concentrations of PCBs and organochlorine pesticides in nestling eagles are directly related to food they receive from the attending adults who hunt within their breeding territory. Thus, blood from a nestling eagle is an appropriate sample to measure contamination of the habitat surrounding a nest site, providing further support for using the bald eagle as an appropriate bioindicator of ecosystem quality. This 'snapshot' of local contamination allows for comparison among different geographic regions and temporal periods. Contaminant levels in the blood of bald eagles has been measured in the Great Lakes region since 1987.[9-13]

The Michigan Department of Environmental Quality (MDEQ) implemented Michigan's bald eagle biosentinel program to monitor trends of a suite of organic pollutants under the Clean Michigan Initiative.[14] These compounds include PCBs and organochlorine pesticides. The state has been divided into major "watershed years" with 20 percent of Michigan's watersheds being sampled each year.[6] This sampling procedure allows for the entire state to be sampled and analyzed every five years. During annual banding activities, blood samples from nestling bald eagles were collected within these designated watersheds.

This research targeted 20 congeners of PCBs, DDT and its metabolites, and 10 other organochlorine pesticides.[6] Because of its pervasiveness and demonstrated ecological effects, the concentrations of the DDT metabolite, *p*,*p*'-dichlorodiphenyldichloroethylene (DDE), are reported here. It should also be noted that 94 percent of the total DDT in eaglet plasma was DDE. For PCBs, the 20 congeners were summed to determine "Total PCBs." This report presents the results of the spatial and temporal assessment of DDE and total PCB concentrations in the plasma of nestling bald eagles. The other 10 organochlorine pesticides measured in this study are not reported here because they failed to be detected in 50 percent of the samples analyzed.[14]

METHODS

Sample Collection and Analysis

Aerial surveys were conducted by Michigan Department of Natural Resource pilots and contracted observers to determine which nests were active. Field crews were directed to the nests at the appropriate time for sampling from observer notes and GPS coordinates. Nestling eagles were sampled at five to nine weeks of age, from early May to July each year. Blood was collected from the brachial vein and derivative plasma was used for analyses.

Concentrations of DDE and total PCBs in eaglet plasma were quantified using gas chromatography as previously described.[14] Half the detection limit was used for non-detect values when calculating geometric means and conducting statistical analysis. All concentrations in this report are presented on a wet weight basis.

Statistical Methods

Distributions of contaminant concentrations were tested for normality using the Kolmogorov-Smirnov test and found to be non-normal for the raw data. While log-transformed concentrations successfully normalized distributions for some scales of analysis, it did not perform well for all. Analyses for differences between multiple groups were therefore conducted using the nonparametric Kruskal-Wallis equivalent, rank-converted ANOVA (Kruskal-Wallis) test. Post-hoc analyses were conducted using Wilcoxon rank-sum test, which is equivalent to the Fisher's least significant difference test. It should be noted that critical values for the post-hoc analyses are set to control only pair-wise error rate and not experiment-wise error rate. This approach increases the likelihood of detecting a difference at the cost of an increased Type I error rate. With monitoring as the research's primary function, this was considered to be the preferable compromise, because it increases the ability to detect trends of concern.

Distributions of concentrations were both left-censored and positively skewed in a manner similar to log-normal distributions commonly seen in other contaminant research.[15] For this reason, geometric means were estimated using nonparametric Kaplan-Meier analyses. Medians, which provide an additional indicator of central tendency and data ranges, are included in our tables to facilitate a better understanding of the data presented. All analyses were performed using SAS 9.2.[16]

Spatial Analyses

Organochlorine concentrations in the plasma of nestling eagles were compared at three spatial scales: Category; Subpopulation; and Great Lakes Watershed.[14] Breeding areas, which include all nests used by a territorial pair of eagles, were the sampling unit used for all analyses. The breeding area was assigned to a single grouping at each spatial scale for comparison.

The Category spatial scale compared Inland (IN) and Great Lakes (GL) breeding areas. Great Lakes breeding areas are defined as being within 8.0 kilometers (km) of Great Lakes shorelines and/or along tributaries open to anadromous Great Lakes fish. Inland breeding areas are defined as being more than 8.0 km from the Great Lakes shorelines and not along tributaries open to anadromous Great Lakes fish.[14]

The Subpopulation spatial scale subdivided the Category spatial scale into four GL and two IN groups. The GL subpopulations consisted of Lake Superior (LS), Lake Michigan (LM), Lake Huron (LH), and Lake Erie (LE). The IN subpopulations consisted of Upper Peninsula (INUP), and Lower Peninsula (INLP).

At the Great Lakes Watershed spatial scale all breeding areas were sorted into eight groupings (four GL and four IN) based on Great Lakes Basin drainages. The GL groups were Lake Superior Great Lakes (LSGL), Lake Michigan Great Lakes (LMGL), Lake Huron Great Lakes (LHGL), and Lake Erie Great Lakes (LEGL). The IN groups were Lake Huron

Inland (LHIN), Lake Michigan Inland Upper Peninsula (LMINUP), Lake Michigan Inland Lower Peninsula (LMINLP), and Lake Superior Inland (LSIN).

We do not report the T1 spatial results here, which were previously published.[17,18] However, we include the T1 data in the temporal analyses and as a point of reference in tables, figures, and discussions with the exception of the Great Lakes Watershed analyses.

Temporal Analyses

Temporal analyses among the two current sampling periods (1999-2003 [T2] and 2004-2008 [T3]) and the previous sampling period (1987-1992 [T1]) were conducted at the state, Category and Subpopulation spatial scales.[17,14] For the Great Lakes Watershed spatial scales, analyses between only T2 and T3 were conducted because previously collected data could not be reliably converted to the Great Lakes Watershed spatial scale.

RESULTS AND DISCUSSION

From 1999-2008, 921 nestling eagle plasma samples were analyzed for DDE and PCBs. These 921 samples represented 386 breeding areas. Concentrations of DDE were detected in 841 samples and total PCBs were detected in 718 samples. Concentrations of DDE ranged from non-detect (ND) to 257 micrograms per kilogram (μg/kg) and concentrations of total PCBs ranged from ND to 544 μg/kg (Tables 1 and 2, respectively). Regionally, the analyzed samples were taken from the INUP (n = 228), INLP (n = 254), LS (n = 134), LM (n = 136), LH (n = 155), and LE (n = 13) breeding areas.

Temporal Trends

There was a significant decrease in concentrations of DDE and total PCBs from T1 to T2 for all subpopulations, except there were no statistically significant decreases in the concentrations of DDE within LM or LH breeding areas during this time period (Kruskal-Wallis, $P < 0.0001$).[30] Declines in DDE and total PCB for bald eagle plasma and eggs consistent with our findings have been reported for the Great Lakes, Lake Superior near the Apostle Islands, and in Wisconsin.[13,19] Other studies have also reported significant temporal declines in DDE and total PCBs in other species.[20,21]

Concentrations of DDE and total PCBs declined statewide from T2 toT3 (Wilcoxon, $P \leq 0.05$; Tables 1 and 2). At the Category spatial scale, both DDE and total PCB concentrations declined within GL breeding areas and DDE concentrations declined within IN breeding areas between T2 and T3 (Wilcoxon, $P \leq 0.05$; Tables 3 and 4). At the Subpopulation spatial scale, both DDE and total PCB concentrations declined within INUP, LM, and LS breeding areas; DDE concentrations declined within LH breeding areas, and total PCB concentrations declined within LE breeding areas between T2 and T3 (Wilcoxon, $P \leq 0.05$; Tables S1 and S2). At the Great Lakes Watershed spatial scale, both DDE and total PCB concentrations declined within LHGL (Kruskal-Wallis, $P < 0.0001$ and $P = 0.0042$, respectively), LMGL (Kruskal-Wallis, $P < 0.0001$), LMINUP (Kruskal-Wallis, $P < 0.0001$ and $P = 0.0066$, respectively), and LSGL (Kruskal-Wallis, $P < 0.0001$ and $P = 0.0028$, respectively) breeding areas and total PCB concentrations declined within LEGL breeding areas between T2 and T3 (Kruskal-Wallis, $P = 0.0348$; Tables S3 and S4).

While the declines between T2 and T3 were not as extreme as the declines from T1 to T2 there were many statistically significant declines and a general trend of decline continues. Previous research[18] reported ND thresholds of 5 μg/kg for DDE and 10 μg/kg for PCBs, while the ND thresholds for this study were approximately 2 μg/kg for both DDE and PCBs.[6] The low rates of censorship in T1 data (15 percent for DDE and 6 percent for PCBs) make it unlikely that differences in detection limit would cause problems for analyses.

Spatial Trends

DDE and total PCB concentrations in blood samples from nestling eagles varied at the Category spatial scale (Kruskal-Wallis, $P < 0.0001$). GL geometric mean DDE and total PCB concentrations ranked higher than IN concentrations (Tables 5 and 6).

DDE and total PCB concentrations also varied at the Subpopulation spatial scale (Kruskal-Wallis, $P < 0.0001$). Post-hoc analyses showed that DDE concentrations from LM were greater than all other breeding areas except LH (Wilcoxon, $P \leq 0.05$). Post-hoc analyses also showed that DDE concentrations from LH, LE, and LS were greater than INLP and INUP (Wilcoxon, $P \leq 0.05$). Geometric mean DDE concentrations ranked in order from highest to lowest were: LM, LH, LE, LS, INLP, and INUP (Table 5). Post-hoc analyses showed that total PCB concentrations from LE were greater than all other breeding areas except LH (Wilcoxon, $P \leq 0.05$). Post-hoc analyses also showed that total PCBs from INLP and INUP were less than all other breeding areas (Wilcoxon, $P \leq 0.05$). Geometric mean total PCB concentrations ranked in order from highest to lowest were: LE, LH, LM, LS, INLP, and INUP (Table 6).

DDE and total PCB concentrations varied at the Great Lakes Watershed spatial scale (Kruskal-Wallis, $P < 0.0001$). Post-hoc analyses showed that DDE concentrations from LMGL were greater than all other breeding areas except LHGL (Wilcoxon, $P \leq 0.05$). Post-hoc analyses also showed that DDE concentrations from LSIN were less than all other breeding areas except LMINUP (Wilcoxon, $P \leq 0.05$). Geometric mean DDE concentrations ranked in order from highest to lowest were: LMGL, LHGL, LEGL, LSGL, LMINLP, LHIN, LMINUP, and LSIN (Table 5). Post-hoc analyses showed that total PCBs from LEGL were greater than all other breeding areas except LHGL (Wilcoxon, $P \leq 0.05$). Post-hoc analyses also showed that total PCBs from LSIN were less than all other breeding areas (Wilcoxon, $P \leq 0.05$). Geometric mean total PCB concentrations ranked in order from highest to lowest were: LEGL, LHGL, LMGL, LSGL, LMINLP, LHIN, LMINUP, and LSIN (Table 6).

For both DDE and total PCB a general trend was clear, Great Lakes concentrations were higher than inland areas. This is possibly a result of several factors including location of toxicant production; patterns of urban, industrial, and agricultural usage; storage practices; and aerial deposition. Most industrial production was located near water sources and these water sources are often used for cooling of equipment and pre-regulatory flushing of equipment. With urban growth there was an increased need for PCB-filled industrial transformers and capacitors. Transformers and capacitors can develop leaks through the breakdown of seals and housings, lightning strikes, and fires. DDT was used extensively in agricultural and urban areas. Michigan's "fruit belt," a highly active agriculture area, is located near Great Lakes shorelines, mostly along Lake Michigan.

High DDE concentrations in western and northern portions of Michigan's Lower Peninsula are likely related to past agricultural, tourism, and fruit producing industries. Concentrations of persistent DDT metabolites in the Niagara River are associated with widespread use of DDT in orchards and vineyards.[20] At the Subpopulation and Great Lakes Watershed spatial scales DDE concentrations in LM and LMGL were consistently among the highest. LH and LHGL were also high in contaminants. Michigan's western coast, northeastern portions of the Lower Peninsula, and the "thumb" (i.e., the peninsula east of Saginaw Bay) areas of Michigan have been fruit producers since the decline of the lumber industry. Some of the earliest evidence of the fruit belt in Michigan dates back to 1891.[22] Thus, with the advance of effective pesticides it is logical to assume they were applied to orchards and farms. Local residents of Michigan spoke of the days in the 1970s when sprayer trucks would come through neighborhoods spraying DDT (personal observations of senior author). In addition to agriculturally productive areas, these practices would likely have occurred in populated urban areas and popular tourist destinations, also common in western Michigan.

In contrast, total PCB concentrations were highest in LE and LEGL areas. While these results are consistent with previous studies, they are based on a small number of nestling blood samples (n = 13) collected from only seven breeding areas.[9,10] Because the bald eagle monitoring results in this report only provide data for the portion of Lake Erie bordering the state of Michigan, the samples represent a limited portion of the entire Lake Erie ecosystem. In a Canadian study, plasma concentrations of PCBs in bald eagles from Lake Erie (n = 30) were greater than samples collected from Lake Nipigon in the province of Ontario (n = 7).[19]

Spatial trends of total PCBs and DDTs in nestling eagles are similar to trends in whole fish analyzed by the MDEQ, Water Resources Division. A superficial examination of their data comparing total PCB and DDT concentrations of Great Lakes fish supports our findings. Average total DDT concentrations in whole fish reported by the MDEQ from highest to lowest were: LM (0.57 µg/kg), LH (0.41 µg/kg), LE (0.23 µg/kg) and LS (0.13 µg/kg). Average total PCB concentrations in whole fish reported by the MDEQ from highest to lowest were: LE (2.23 µg/kg), LM (1.75 µg/kg), LH (1.59 µg/kg), and LS (0.026 µg/kg; unpublished data). In our study, total PCB in nestling eagles from LH and LM did not differ.

Concentrations of DDE and PCBs have been negatively correlated with reproductive outcomes for bald eagles.[23,9] DDE has been correlated with egg shell thinning directly through laboratory work and indirectly through biomonitoring work.[23-27] PCBs have been suggested as a causative agent for observed declines in productivity of fish eating birds.[28] Concentrations of total PCBs in the eggs of bald eagles have also been correlated with reduced productivity.[28,29] While DDE concentrations have declined, they were likely the greatest causative agent of the population declines of the 1960s; however, PCBs are likely the greatest causative agent of reproductive issues in Michigan's eagles today.[17]

The no observable adverse effect limit (NOAEL) for total PCBs and DDE in the blood of nestling bald eagles was determined to be 33 µg/kg and 11 µg/kg, respectively.[9] Of the 921 nestling blood samples analyzed for total PCBs and DDE, 259 (28 percent) and 332 (36 percent), respectively, exceeded the NOAEL. It is therefore possible that once these nestlings reach breeding age, they may not be able to reproduce at a level necessary to support a healthy population due to elevated DDE and PCB concentrations. The presence of DDE and PCBs above their respective NOAELs supports the importance of long-term monitoring. Also, the consistently high concentrations of DDE in Lake Michigan and Lake Huron breeding areas and total PCBs in Lake Erie breeding areas suggest that a more intensive sampling strategy should be applied in these locations.

LITERATURE CITED

1. Wiemeyer, S.N.; Lamont, T.G.; Bunck, C.M.; Sindelar, C.R.; Gramlich, F.J.; Fraser, J.D.; 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 (5), 529-49.

2. Bowerman, D.W.; Roe, A.S.; Gilbertons, M.J.; Best, D.A.; Sikarskie; J.G.; Mitchell, R.S.; Summer, C.L. 2002. Using Bald Eagles to Indicate the Health of the Great Lakes' Environment. Lakes and Reservoirs: Research and Management, 7, 183-187.

3. Cesh, L.S.; Williams, T.D.; Garcelon, D.K.; Elliott, J.E. 2008. Patterns and Trends of Chlorinated Hydrocarbons in Nestling Bald Eagle (*Haliaeetus leucocephalus*) Plasma in British Columbia and Southern California. Archives of Environmental Contamination and Toxicology, 55(3), 496-502.

4. Nadeau, A.J. 2012. A Genetic Analysis of Bald Eagles in the Pacific Northwest: Retained Genetic Diversity Following a Large Scale Population Bottleneck. MS. Boise State University.

5. Postupalsky, S. 1967. Reproductive Success and Population Trends in the Bald Eagle in Michigan. *(The link provided was broken and has been removed)*

6. Wierda, M.R. 2009. Using Bald Eagles to Track Spatial and Temporal Trends of Contaminants in Michigan's Aquatic Systems. Ph.D Dissertation, Clemson University, Clemson, SC.

7. Buehler, D.A. 2000. Bald Eagle. The Birds of North America. 506.

8. Olsson, A.; Ceder K.; Bergman, A.; Helander B. 2000. Nestling Blood of the White-tailed Sea Eagle (*Haliaeetus albicilla*) as an Indicator of Territorial Exposure to Organohalogen Compounds - An Evaluation. Environmental Science and Technology, 34 (13), 2733-2740.

9. Bowerman W.W.; Best, D.A; Giesy, J.P; Shieldcastle, M.C.; Meyer, M.W.; Postupalsky, S.; Sikarskie, J.G. 2003. Associations Between Regional Differences in Polychlorinated Biphenyls and Dichlorodiphenyldichloroethylene in Blood of Nestling Bald Eagles and Reproductive Productivity. Environmental Toxicology and Chemistry, 22 (2), 371-376.

10. Dykstra, C.R.; Meyer, M.W.; Rasmussen, P.W.; Warnke, D.K. 2005. Contaminant Concentrations and Reproductive Rate of Lake Superior Bald Eagles, 1989-2001. Journal of Great Lakes Research, 31 (2), 227-235.

11. Bowerman, W.W.; Best, D.A.; Grubb, T.G.; Zimmerman, G.M.; Giesy, J.P. 1998. Trends of Contaminants and Effects in Bald Eagles of the Great Lakes Basin. Environmental Monitoring and Assessment, 53 (1), 197-212.

12. Dykstra, C.R.; Meyer, M.W.; Stromborg, K.L.; Warnke, D.K.; Bowerman, W.W.; Best, D.A. 2001. Association of Low Reproductive Rates and High Contaminant Levels in Bald Eagles on Green Bay, Lake Michigan. Journal of Great Lakes Research, 27 (2), 239-251.

13. Dykstra, C.R.; Route, W.T.; Meyer, M.W.; Rasmussen, P.W. 2010. Contaminant Concentrations in Bald Eagles Nesting on Lake Superior, the Upper Mississippi River, and the St. Croix River. Journal of Great Lakes Research, 36 (3), 561-569.

14. Roe, A.S. 2001. The Development of an Avian Biosentinel Program for Michigan using the Bald Eagle, MS Thesis, Clemson University, Clemson, South Carolina.

15. Leith, K.F.; Bowerman, W.W.; Wierda, M.R.; Best, D.A.; Grubb, T.G.; Sikarskie, J.G. 2010. A Comparison of Techniques for Assessing Central Tendency in Left-Censored Data using PCB and *p*,*p*′-DDE Contaminant Concentrations from Michigan's Bald Eagle Biosentinel Program, Chemosphere 80 (1), 7-12.

16. SAS. 2007. SAS 9.2. Cary, NC, USA, SAS Institute, Inc.

17. Bowerman, W.W.; Giesy, J.P.; Best, D.A.; Kramer, V.J. 1995. A Review of Factors Affecting Productivity of Bald Eagles in the Great Lakes Region: Implications for Recovery. Environmental Health Perspectives, 103, 51-59.

18. Bowerman, W.W. 1993. Regulation of the Bald Eagle (*Haliaeetus leucocephalus*) Productivity in the Great Lakes Basin: An Ecological and Toxicological Approach. PhD thesis. Michigan State University, East Lansing, Michigan.

19. Donaldson, G.M.; Shutt, J.L.; Hunter, P. 1999. Organochlorine Contamination in Bald Eagle Eggs and Nestlings from the Canadian Great Lakes. Archives of Environmental Contamination and Toxicology, 36 (1), 70-80.

20. Suns, K.R.; Hitchin, G.G.; Toner, D. 1993. Spatial and Temporal Trends of Organochlorine Contaminants in Spottail Shiners from Selected Sites in the Great Lakes (1975-1990). Journal of Great Lakes Research, 19(4), 703-714.

21. Bishop, C.A.; Ng, P.; Norstrom, R.J.; Brooks, R.J.; Pettit, K.E. 1996. Temporal and Geographic Variation of Organochlorine Residues in Eggs of the Common Snapping Turtle (*Chelydra serpentina serpentina*) (1981-1991) and Comparisons to Trends in the Herring Gull (*Larus argentatus*) in the Great Lakes Basin in Ontario, Canada. Archives of Environmental Contamination and Toxicology, 31(4), 512-524.

22. Garrett, B. 2009. A Fruitful Industry. *(The link provided was broken and has been removed)*

23. Helander, B.; Olsson, M.; Reutergardh, L. 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. Holarctic Ecology, 5 (4), 349-366.

24. Wiemeyer, S.N. and Porter R.D. 1970. DDE Thins Eggshells of Captive American Kestrels. Nature, 227, 737-738.

25. Heath, R.G.; Spann, J.W.; Kreitzer, J.F.; Vance, C. 1972. Marked DDT Impairment of Mallard Reproduction in Controlled Studies. Nature, 224, 47-48.

26. McClain, M. and Hall, L.C. 1972. DDE Thins Screech Owl Eggshells. Bulletin of Environmental Contamination and Toxicology, 8, 65-68.

27. Giesy, J.P.; Ludwig, J.P.; Tillitt, D.E. 1994. Dioxins, Dibenzofurans, PCBs and Similar Chlorinated, Diaromatic Hydrocarbons and their Effects on Birds: Wildlife Biomonitoring for Hazards of Complex Environmental Mixtures in the Laurentian Great Lakes. In: Dioxins and Health. A. Schecter, Gasiewicz, T.A. Eds.; Plenum Press: New York.

28. Postupalsky, S. 1971. Toxic Chemicals and Declining Bald Eagle and Cormorants in Ontario. Manuscript Report 20. Ottawa, Canadian Wildlife Service.

29. Kozie, K.D. and Anderson R.K. 1991. Productivity, Diet, and Environmental Contaminants in Bald Eagles Nesting near the Wisconsin Shoreline of Lake Superior. Archives of Environmental Contamination and Toxicology, 20 (1), 41- 48.

30. Roe, A.; Parmentier, K.; Leith, W.; Bowerman, W., Sikarskie, J.; and Best, D. 2008. Concentrations of Organochlorine Pesticides and PCBs in Nestling Bald Eagle Plasma from Michigan, 1999-2003, and Relations to Productivity at Multiple Geographic Scales. MI/DEQ/WRD-12/013.

Table 1. Sample sizes and medians, ranges, and geometric means (μg/kg) of DDE in plasma samples of nestling bald eagles for the state of Michigan. For each analysis significant differences are indicated by different letters.					
Whole State	**N**	**median**	**Range**	**g-mean**	
1987-1992	234	17	ND-429	18	a
1999-2003	483	8	ND-257	9	b
2004-2008	438	5	ND-186	6	c

Table 2. Sample sizes and medians, ranges, and geometric means (μg/kg) of PCB in plasma samples of nestling bald eagles for the state of Michigan. For each analysis significant differences are indicated by different letters.					
Whole State	**N**	**median**	**Range**	**g-mean**	
1987-1992	234	76	ND-1325	70	a
1999-2003	483	15	ND-368	13	b
2004-2008	438	7	ND-544	9	c

Table 3. Sample sizes and medians, ranges, and geometric means (μg/kg) of DDE in plasma samples of nestling bald eagles for the Category designation. For each analysis significant differences are indicated by different letters.						
Category	**Sampling Period**	**N**	**median**	**range**	**g-mean**	
Great Lakes	1987-1992	121	27	ND-429	27	a
	1999-2003	221	17	ND-257	18	b
	2004-2008	217	10	ND-140	9	c
Inland	1987-1992	113	10	ND-245	12	a
	1999-2003	262	4	ND-192	5	b
	2004-2008	221	3	ND-186	4	c

Table 4: Sample sizes and medians, ranges and geometric means (μg/kg) of PCB in plasma samples of nestling bald eagles for the Category designation. For each analysis significant differences are indicated by different letters.						
Category	**Sampling Period**	**N**	**median**	**range**	**g-mean**	
Great Lakes	1987-1992	121	158	ND-1325	149	a
	1999-2003	221	40	ND-368	36	b
	2004-2008	217	23	ND-286	17	c
Inland	1987-1992	113	32	ND-200	31	a
	1999-2003	262	3	ND-189	6	b
	2004-2008	221	ND	ND-544	5	b

Table 5. Sample sizes and medians, ranges, and geometric means (µg/kg) of DDE in plasma samples of nestling bald eagles collected within Michigan, 1999-2008. Comparisons were made at three geographic scales; Category, Subpopulation, and Great Lakes Watersheds.

Comparison		**DDE**			
	N	**median**	**range**	**g-mean**	
Category					
Great Lakes	438	13	ND-257	13	a
Inland	483	17	ND-192	5	b
Subpopulation					
Lake Michigan	136	19	ND-212	15	a
Lake Huron	155	12	ND-105	12	a,b
Lake Erie	13	10	ND-19	10	b
Lake Superior	134	9	ND-257	9	b
Inland Lower Peninsula	254	5	ND-186	6	c
Inland Upper Peninsula	228	3	ND-192	4	d
Great Lakes Watershed					
Lake Michigan Great Lake	133	19	ND-212	15	a
Lake Huron Great Lake	158	13	ND-105	12	a,b
Lake Erie Great Lake	13	10	ND-19	10	b,c
Lake Superior Great Lake	134	8	ND-257	9	b,c
Lake Michigan Inland Lower Peninsula	90	6	ND-186	7	c,d
Lake Huron Inland	168	4	ND-98	5	d,e
Lake Michigan Inland Upper Peninsula	148	3	ND-192	5	e,f
Lake Superior Inland	69	2	ND-88	4	f

Great Lakes breeding areas are within 8.0 km of a Great Lake or along rivers open to Great Lakes fish runs. Inland breeding areas are greater than 8.0 km from a Great Lake and not along anadromous fish runs. For each analysis significant differences are indicated by different letters.

Table 6. Sample sizes and medians, ranges, and geometric means (µg/kg) of PCB in plasma samples of nestling bald eagles collected within Michigan, 1999-2008. Comparisons were made at three geographic scales; Category, Subpopulation, and Great Lakes Watersheds.					
Comparison		**PCB**			
	N	**median**	**range**	**g-mean**	
Category					
Great Lakes	438	30	ND-368	25	a
Inland	483	3	ND-544	5	b
Subpopulation					
Lake Erie	13	61	ND-213	58	a
Lake Huron	155	37	ND-268	32	a,b
Lake Michigan	136	41	ND-304	28	b
Lake Superior	134	16	ND-400	14	c
Inland Lower Peninsula	254	3	ND-544	6	d
Inland Upper Peninsula	228	1	ND-189	5	d
Great Lakes Watershed					
Lake Erie Great Lake	13	61	ND-213	58	a
Lake Huron Great Lake	158	37	ND-268	32	a,b
Lake Michigan Great Lake	133	41	ND-304	28	b
Lake Superior Great Lake	134	16	ND-400	14	c
Lake Michigan Inland Lower Peninsula	148	1	ND-189	7	d
Lake Huron Inland	168	3	ND-544	6	d
Lake Michigan Inland Upper Peninsula	90	4	ND-274	6	d
Lake Superior Inland	69	0	ND-73	4	e
Great Lakes breeding areas are within 8.0 km of a Great Lake or along rivers open to Great Lakes fish runs and inland breeding areas are greater than 8.0 km from a Great Lake and not along anadromous fish runs. For each analysis significant differences are indicated by different letters.					

Table S1. Sample sizes and medians, ranges, and geometric means (µg/kg) of DDE in plasma samples of nestling bald eagles for the state of Michigan.					
Whole State	**N**	**median**	**range**	**g-mean**	
1987-1992	234	17	ND-429	18	a
1999-2003	483	8	ND-257	9	b
2004-2008	438	5	ND-186	6	c
For each analysis significant differences are indicated by different letters.					
ND = non detect; DDE = p,p'-Dichlorodiphenyldichloroethylene					

Table S2. Sample sizes and medians, ranges, and geometric means (µg/kg) of PCB in plasma samples of nestling bald eagles for the state of Michigan. For each analysis significant differences are indicated by different letters.					
Whole State	**N**	**median**	**range**	**g-mean**	
1987-1992	234	76	ND-1325	70	a
1999-2003	483	15	ND-368	13	b
2004-2008	438	7	ND-544	9	c
For each analysis significant differences are indicated by different letters.					
ND = non detect; PCB = polychlorinated biphenlys					

Table S3. Sample sizes and medians, ranges, and geometric means (µg/kg) of DDE in plasma samples of nestling bald eagles for the Great Lakes Watershed designation.

Great Lakes Watershed	Sampling Period	N	median	range	g-mean	
Lake Erie Great Lakes	1999-2003	6	10	6-19	10	a
	2004-2008	7	10	ND-15	10	a
Lake Huron Great Lakes	1999-2003	75	16	ND-105	18	a
	2004-2008	83	9	ND-75	9	b
Lake Huron Inland	1999-2003	79	4	ND-89	5	a
	2004-2008	89	4	ND-98	6	a
Lake Michigan Great Lakes	1999-2003	61	35	6-212	35	a
	2004-2008	72	8	ND-45	7	b
Lake Michigan Inland Lower Peninsula	1999-2003	36	7	2-96	7	a
	2004-2008	54	6	ND-186	7	a
Lake Michigan Inland Upper Peninsula	1999-2003	102	4	ND-192	6	a
	2004-2008	46	ND	ND-40	3	b
Lake Superior Great Lakes	1999-2003	79	11	ND-257	12	a
	2004-2008	55	5	ND-136	6	b
Lake Superior Inland	1999-2003	40	ND	ND-43	3	a
	2004-2008	29	ND	ND-88	4	a

For each analysis significant differences are indicated by different letters.

Great Lakes breeding areas are within 8.0 km of a Great Lake or along rivers open to Great Lakes fish runs and inland breeding areas are greater than 8.0 km from a Great Lake and not along anadromous fish runs.

ND = non detect; DDE = p,p'-Dichlorodiphenyldichloroethylene

Table S4. Sample sizes and medians, ranges, and geometric means (µg/kg) of PCB in plasma samples of nestling bald eagles for the <u>Great Lakes Watershed</u> designation.						
Great Lakes Watershed	**Sampling Period**	**N**	**median**	**range**	**g-mean**	
Lake Erie Great Lakes	1999-2003	6	151	53-213	122	a
	2004-2008	7	29	ND-96	20	b
Lake Huron Great Lakes	1999-2003	75	42	ND-268	41	a
	2004-2008	83	27	ND-234	25	b
Lake Huron Inland	1999-2003	79	3	ND-82	5	a
	2004-2008	89	3	ND-544	7	a
Lake Michigan Great Lakes	1999-2003	61	63	6-304	63	a
	2004-2008	72	17	ND-178	15	b
Lake Michigan Inland Lower Peninsula	1999-2003	36	5	ND-123	6	a
	2004-2008	54	3	ND-274	6	a
Lake Michigan Inland Upper Peninsula	1999-2003	102	4	ND-189	8	a
	2004-2008	55	ND	ND-88	5	b
Lake Superior Great Lakes	1999-2003	79	21	ND-368	19	a
	2004-2008	55	5	ND-400	9	b
Lake Superior Inland	1999-2003	40	ND	ND-39	4	a
	2004-2008	29	ND	ND-73	4	a
For each analysis significant differences are indicated by different letters.						
Great Lakes breeding areas are within 8.0 km of a Great Lake or along rivers open to Great Lakes fish runs and inland breeding areas are greater than 8.0 km from a Great Lake and not along anadromous fish runs.						
ND = non detect; PCB = polychlorinated biphenlys						