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Environmental Contamination and Toxicology

Environmental Contaminants Associated with Reproductive Failure in Bald Eagle (*Haliaeetus leucocephalus*) Eggs in New Jersey

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Bald eagles (*Haliaeetus leucocephalus*) in New Jersey once numbered approximately 22 pairs, but declined to just one nesting pair by 1970. This decline mirrored the national trend, caused by the effects of the pesticide dichlorodiphenyltrichloroethane (DDT). With the ban on DDT, and state and federal eagle recovery programs, the eagle population has increased substantially. The bald eagle is currently listed as a threatened species by the United States government, and as endangered by the state of New Jersey. Since it is a relatively long-lived bird, the species remains sensitive to environmental toxins that bioaccumulate and affect reproduction (Bowerman 1993, Wiemeyer et al. 1993, Nisbet and Risebrough 1994).

The Endangered and Nongame Species Program (ENSP) in New Jersey's Division of Fish, Game and Wildlife has monitored levels of organochlorines in bald eagle nestlings since 1992 (USFWS and NJDFGW 1995), and in eggs as they became available. The ENSP monitors all active eagle nests for nest success and productivity. Most nests are located in the Delaware Bay drainage basin in southern New Jersey, which was the center of the historic population. Productivity has averaged 1.26 young per active nest in the period 1988-1997, above the 1.0 minimum required for maintaining the population (Wiemeyer et al. 1984). The population has grown steadily since 1989, and numbered 14 nesting pairs in 1997. However, some pairs nesting in the Delaware Bay drainage have experienced reproductive failure.

In this paper we present chlorinated pesticide and polychlorinated biphenyl (PCB) levels in five bald eagle eggs from two sites where reproductive failures have occurred. Four of the eggs were collected from the same nesting pair between 1993 and 1997. We discuss the relationship between contaminants and bald eagle reproduction in NJ.

MATERIALS AND METHODS

Bald eagle nests at Raccoon Creek, Stow Creek and Mannington Meadow (Fig. 1) were observed regularly during the breeding season to record nesting chronology

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and success. Behavior of adult eagles was recorded to determine the onset and duration of incubation, and approximate date of hatching. When available, eggs were collected after incubation ceased and adults abandoned the nest, or when incubation lasted more than 48 d (two weeks beyond the normal 35 d incubation period). In two cases eggs were collected during the incubation period, when we fostered a live eaglet to the nest, replacing natural reproduction. Each egg was weighed and measured before dissection, then contents were placed in a chemically clean glass jar with a teflon-lined cap. All samples were stored in a freezer (-20° C) and shipped to analytical laboratories on dry ice.

Chemical analyses of all eggs were conducted at Mississippi State Chemical Laboratory, Mississippi State, MS. Samples for total PCBs and chlorinated pesticides analysis were soxhlet extracted and the extracts were fractionated on a Florisil column. PCBs were further separated from other organochlorines in one fraction using a silicic acid column. Sample extracts for PCB congener analysis were fractionated on Florisil and silicic acid columns, and PCB congeners were separated using a carbon column. Analyses were performed by electron capture gas chromatography. All analytical and quality assurance procedures were approved under a contract with the U.S. Fish and Wildlife Service. Wet weight concentrations reported by the lab were converted to fresh weight to correct for moisture loss (Stickel et al. 1973). Eggs containing less than the detection limit of a chemical were assigned a value of one-half the detection limit for statistical analysis.

PCB congener data were used to calculate 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQs) using the original World Health Organization (WHO) toxic equivalency factors (TEFs) developed by the Ahlborg et al. (1994) and newer WHO TEFs proposed for birds (van Leeuwen 1997).

We measured eggshell thickness (shell and membrane) at 6-8 different locations near the equator of each egg and computed a mean. Eggshell thinning was calculated as the percent difference between mean thickness of each shell and mean thickness (0.6165 mm) of eastern bald eagle eggs prior to 1946 (Anderson and Hickey 1972). Statistical correlations (Pearson's) were performed using SigmaStat (Jandel Corp. 1995), and a significance level of $P<0.05$ was employed for all tests.

RESULTS AND DISCUSSION

The Raccoon Creek eagles were in their second year of nesting (and about 7 yr old) when they failed in 1992, and continued to fail through 1997 (Table 1). One egg was collected for chemical analysis from the nest in 1993, 1994, 1995 and 1997. The Stow Creek eagles were very productive in their first 7 yr of nesting (mean= 2.28 young/yr), and failed in 1997 for the first time, at approximately 13 yr old. A single egg was collected from the nest in 1997. Reproductive failure was also documented at another nest in the same vicinity (Mannington Meadow, Fig.1),

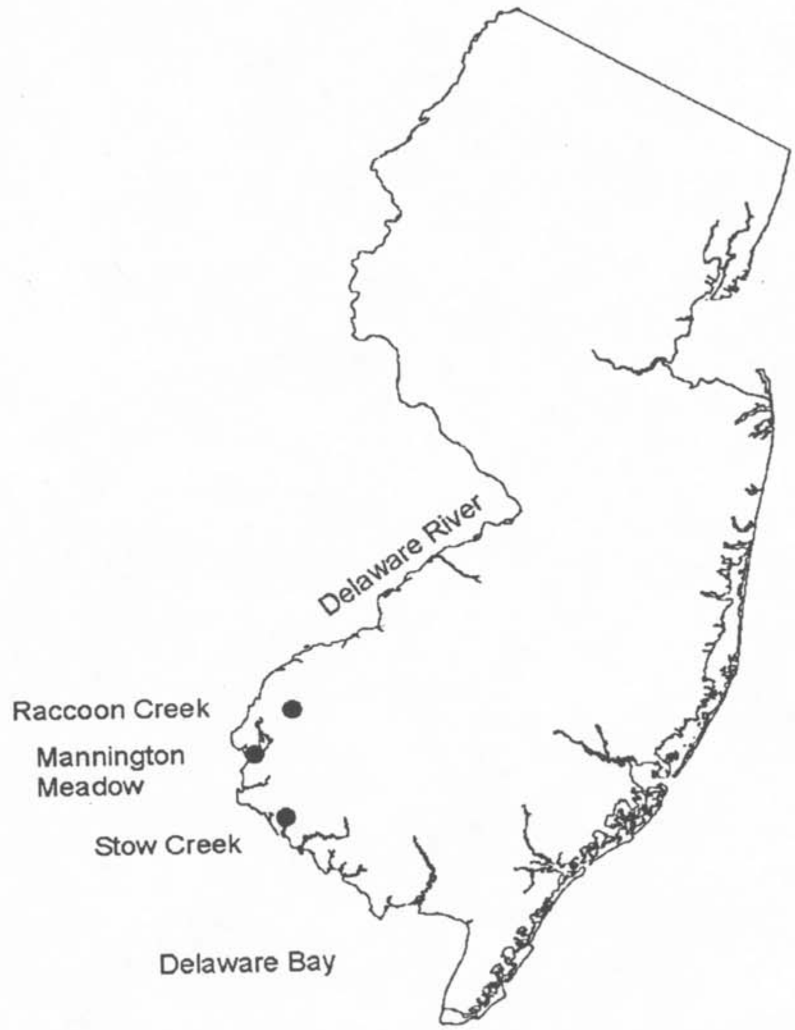

Figure 1. Locations of three bald eagle nests in New Jersey that have shown reproductive impairment.

although no eggs were collected for chemical analysis. The Mannington Meadow eagles never succeeded in hatching eggs. They failed from 1988-1997, even though a new (young) female was active since 1994. Examination of the limited number of samples from the failed nests suggests that some embryos died at advanced stages of development.

High levels of DDE and DDD were found in all eggs analyzed, especially those from Raccoon Creek (Table 2). DDE concentrations ranged from 12 to 18 μg/g in Raccoon Creek eggs (mean=15), while the concentration in the single Stow Creek egg was 6.3 μg/g. DDE concentrations in the Stow Creek and Raccoon Creek eggs are associated with productivity decreases of 50% and 75%, respectively, based on the predictive equations of Wiemeyer et al. (1993). DDE residues in

Table 1. Nest histories of New Jersey bald eagle nests that have failed, in comparison to statewide figures for all active nests, 1988-1997.

Nest	No. of Nest Attempts	Productivity	Total Number of Eggs Collected (Year Collected)
Raccoon Creek	9	0.14	4 (1993, 1994, 1995, 1997)
Stow Creek	8	2.00	1 (1997)
Mannington Meadow	9	0.00	None
Statewide Population	70	1.26	

Raccoon Creek eggs were similar to those in eggs from Great Lakes lakeshore nest areas in 1986-1990 (Bowerman 1993). Great Lakes residues averaged 16 and 17 µg/g from Lake Huron and Lake Michigan, respectively, where productivity has been reduced, at <0.70.

Eggshell thinning was evident in eggs from Raccoon Creek, but not in the egg from Stow Creek (Table 2). However, eggshell thinning did not reach the threshold associated with population decline (>15-18%; Blus 1996). Eggshell thickness did not correlate with DDE or total DDT-related compounds, in contrast to other studies that have shown a relationship (e.g., Blus et al. 1972, Wiemeyer et al. 1993). However, this may be an artifact of the small sample size and the clumped distribution of the data. The absence of biologically significant eggshell thinning suggests that other factors may have contributed to reproductive failures.

In addition to DDE, the eggs also contained high levels of PCBs (Table 2). As in other studies, there was a strong correlation between DDE and PCB concentrations (Pearson coefficient=0.91, $P<0.05$), making it difficult to attribute effects to a particular contaminant (Wiemeyer, 1993, Bowerman et al. 1994). Nonetheless, the PCB concentrations measured in the present study were similar to concentrations associated with reproductive impairment in other eagle populations. PCB concentrations in Raccoon Creek eggs were within the range reported for bald eagle eggs from Lakes Michigan and Huron, which had the highest PCB residues (41.0-76.7 µg/g) and lowest reproductive rates (0.59-0.68) in the Great Lakes region (Kubiak and Best 1991). Good productivity (1.0) is associated with total PCB concentrations of 5-10 µg/g in the eggs of bald eagles (Kubiak and Best 1991) and white-tailed sea eagles (*H. albicilla*, Healander 1983 as cited in Hoffman et al. 1996). These findings are in agreement with those of Nisbet and Risebrough (1994), who reported reduced nesting success at PCB levels above 12 µg/g. Total PCB levels in Stow Creek and Raccoon Creek eggs are approximately

Table 2. Eggshell thickness, selected contaminant concentrations and TCDD-EQs in five bald eagle eggs from New Jersey. All concentrations are reported on a fresh weight basis. Chlorinated pesticide and PCB concentrations are reported to two significant figures. "RC" samples are from Raccoon Creek and "SC" sample is from Stow Creek

	RC-93[1]	RC-94	RC-95	RC-97	SC-97
Eggshell Thinning[2]	14.1%	12.8%	13.5%	11.0%	0.0%
<u>DDT-related Compounds and Total PCBs (μg/g)</u>					
p,p'-DDD	2.3	2.8	2.6	2.1	0.62
p,p'-DDE	12	14	18	18	6.3
p,p'-DDT	0.030	<0.010	<0.010	<0.010	<0.010
Total PCBs (μg/g)[3]	24	48	54	54	20
<u>Non-ortho-substituted PCB Congeners (ng/g)</u>					
PCB 77	ND[4]	1.5	2.1	1.4	1.0
PCB 81	ND	ND	0.76	0.73	0.23
PCB 126	ND	3.5	4.3	3.8	1.8
PCB 169	ND	0.34	0.86	0.78	0.59
Σ TCDD-EQs[5] (pg/g)	ND	354	440	388	186
	ND	***425***	***612***	***524***	***254***
<u>Mono-ortho-substituted PCB Congeners (ng/g)</u>					
PCB 105	ND	810	1000	980	320
PCB 114	ND	58	45	40	70
PCB 118	ND	2100	2300	2200	460
PCB 123	ND	ND	260	230	600
PCB 156	ND	390	420	500	250
PCB 157	ND	74	230	230	18
PCB 167	ND	190	190	180	77
PCB 189	ND	35	46	43	19
Σ TCDD-EQs (pg/g)	ND	589	751	771	327
	ND	***156***	***197***	***202***	***77***
Total TCDD-EQs (pg/g)	ND	943	1191	1159	513
	ND	***581***	***809***	***726***	***331***

[1] Data provided by U.S. Fish and Wildlife Service (USFWS and NJ DFGW 1995)

[2] Relative to pre-1946 thickness in E. bald eagles (0.6165 mm; Anderson and Hickey 1972)

[3] Sum of Aroclors 1242, 1248, 1254 and 1260

[4] Not Determined

[5] Calculated using WHO TEFs from Ahlborg et al. (1994). TCDD-EQs were not calculated for PCB 81 since no TEF was reported for this congener. TCDD-EQs in boldface italics were calculated using new WHO TEFs for birds (van Leeuwen 1997) and include TCDD-EQs contributed by PCB 81.

2-4 times higher than the highest concentration associated with healthy productivity in those studies. Bowerman et al. (1995) derived a no observable adverse effect concentration (NOAEC) of 4 μg/g fresh weight based on regression analysis of data collected throughout the U.S. (Wiemeyer et al 1984, 1993). Total PCBs in the Stow Creek and Raccoon Creek eggs was 5- to 14-fold higher than the NOAEC.

PCB 126 and combined non-ortho substituted PCBs accounted for 33-37% and 34-38%, respectively, of the total TCDD-EQs in the eagle eggs, based on the WHO TEFs of Ahlborg et al. (1994; Table 2). Based on the newer WHO TEFs for birds (van Leeuwen 1997), PCB 126 and combined non-ortho substituted PCBs accounted for 52-60% and 72-77%, respectively, of the total TCDD-EQs. Under the latter TEF scheme, greater weight is given to the toxicity of non-ortho congeners, while less weight is given to mono-ortho congeners. TCDD-EQs calculated with the new WHO TEFs are more consistent with the findings reported for birds in the Great Lakes, where most of the dioxin-like toxicity to is attributed to PCB 126 (Kubiak et al. 1989, Kubiak and Best 1991, Yamashita et al. 1991). It should also be noted that although the eggs were not analyzed for dioxins and furans, these compounds may also contribute significantly to total TCDD-EQs.

Bald eagles in this study reside year round in the vicinity of their nests, and forage in the open waters of the Delaware River and its tributaries. High concentrations of PCBs have been found in fish from the Delaware River and Bay (Hauge 1993). In New Jersey, contaminant levels in fish were highest in 1) northeastern NJ, and 2) the lower Delaware River. In the Camden area, about 20 km north of Raccoon Creek, PCB concentrations in brown bullhead (*Ictalurus nebulosus*), white perch (*Morone americana*), and carp (*Cyprinus carpio*) were 0.62 and 0.85 and 1.73 μg/g, respectively. Two bullheads sampled in Raccoon Creek itself had an average 1.95 μg/g PCBs. DDT compounds were also elevated, with bullhead and carp from Camden at 0.14 and 0.37 μg/g, respectively, and Raccoon Creek bullhead averaged 0.56 μg/g total DDT. Another study documented high levels of PCBs (1.0 μg/g) and DDTs (0.34 μg/g) in striped bass (*Morone saxatilis*) in the Delaware River within 20 km of Raccoon Creek (Delaware Dept. of Natural Resources and Environmental Control 1994). The region of elevated contaminants in fish was generally associated with the area of reduced eagle productivity. Assuming a bioconcentration factor of 32 for PCBs from forage to eagle eggs (Kubiak and Best 1991), a concentration of 1.25 μg/g in forage would account for the mean PCB concentration in eggs (40 μg/g). Although the exact composition of the eagles' diet is unknown, the available data on PCB residues in fish from the area are consistent with the high concentrations found in the eagle eggs. Bowerman et al. (1995) concluded that although DDE may still affect bald eagle productivity in the Great Lakes region, the negative correlation between PCBs in bald eagle eggs and productivity has become stronger and more statistically significant than the correlation between DDE and productivity. Our data indicate that PCBs may also be important in limiting bald eagle productivity in parts of the Delaware Bay drainage. Of particular interest is the observation that reproductive failure in bald eagles at Raccoon Creek and Stow Creek occurred after several years of successful nesting. One possible explanation is that reproductive failure occurs after contaminants bioaccumulate and exceed an effect threshold. Total PCBs in the egg collected at Raccoon Creek in 1993 were lower than levels measured in subsequent years, but no conclusions regarding trends in PCB levels can be reached due to the limited amount of data. We concur with the observation made by Best et al. (1994) that additional research is needed to determine whether productivity decreases over the lifetime of highly contaminated individuals.

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