

The Influence of Environmental Contaminants on Bald Eagle *Haliaeetus* *leucocephalus* Populations in the Laurentian Great Lakes, North America

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ABSTRACT

Concentrations of PCBs and *p,p'*-DDE in blood plasma of nestling Bald Eagles, *Haliaeetus leucocephalus*, were higher in areas near the Great Lakes, where productivity was depressed, than in interior areas where productivity was higher. Residues in addled eggs were highest in samples from Lakes Michigan and Huron; although productivities were lowest in these areas, they were higher than those that would be predicted from previous studies that have related DDE levels to productivity. The productivity estimates may, however, be biased if the breeding sites were experiencing a high rate of turn-over of adult eagles. Fresh, wet-weight concentrations of PCBs, *p,p'*-DDE, and dieldrin in addled eggs were significantly and inversely correlated with productivity, but the three residues were highly correlated among themselves, precluding any assessment of their relative contributions to depressed productivities.

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.* this volume). 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.* this volume). 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 brachial 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.* (1988a) 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-Wallis² 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* 0.0001; Kruskal-Wallis ² 28.6, PCBs; 21.8 *p,p'*-DDE; Table 1).

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 2). 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* 0.0001).

Table 1. Arithmetic mean concentrations and ranges of *p,p'*-DDE and total PCBs in plasma of nestling Bald Eagles, Great Lakes Basin.

Region	n	<i>p,p'</i> -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 ²: PCBs, 28.6; *p,p'*-DDE, 21.8; *P* 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 regions (Table 2). In a much larger sample Best *et al.* (this volume) 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

Table 2. Productivity within the Great Lakes Basin and Alaska (Kubiak & 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 Penin.	4	2.2 (1.0-5.7)	6.2 (1.9-14)	0.09 (0.06-0.25)	1.14
Michigan Upper Penin.	9	1.7 (0.5-16)	5.0 (1.8-29)	0.13 (0.02-0.91)	0.93
Interior Ohio	3	1.8 (1.3-3.1)	9.0 (5.7-20)	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)	0.19 (0.08-0.51)	0.84
Lake Erie	7	2.8 (1.9-10)	20 (8.6-44)	0.45 (0.25-0.69)	0.75
Lake Michigan	2	17 (10-30)	38 (27-55)	1.1 (0.60-2.0)	0.68
Lake Huron	3	16 (8.5-41)	73 (50-110)	0.88 (0.39-2.3)	0.59

¹ Fresh wet weight, ppm.

² Total number of fledged young divided by the total number of occupied breeding areas (Postupalsky 1974).

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 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; Bowerman *et al.* in prep.). 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.

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