CONTAMINANT LEVELS OF OSPREY EGGS AND PREY REFLECT REGIONAL DIFFERENCES IN REPRODUCTIVE SUCCESS

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Abstract: To determine if contaminants contributed to low hatching success of ospreys (*Pandion haliaetus*) nesting near Delaware Bay, we compared levels of organochlorines, mercury, and lead in addled and randomly collected eggs and potential prey from Delaware Bay to a successful population along the Atlantic Coast (<80 km from the Bay colony) and a geographically intermediate population along Maurice River (<40 km from the Bay colony), a tributary of Delaware Bay. Eggs from Delaware Bay contained significantly higher levels of DDE, DDD, PCB's, dieldrin, and heptachlor epoxide than did Atlantic Coast eggs ($P < 0.008$) and also had thinner eggshells ($P = 0.04$); eggs from Maurice River had intermediate contaminant levels and eggshell thickness. Contaminant levels in potential prey from each region reflected levels found in eggs, suggesting that ospreys accumulated contaminants on their breeding grounds. Eggshell thickness was most closely correlated with levels of DDD ($P = 0.002$) and DDE ($P = 0.06$) in eggs. With the exception of dieldrin ($P = 0.003$), addled and randomly collected eggs contained similar contaminant levels, although addled eggs contained mirex ($P < 0.0001$) and lead ($P = 0.04$) more frequently. Elevated contaminant levels in osprey eggs from Delaware Bay suggest that contaminants from within the Bay contributed to reduced hatching success in this population.

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Most osprey and other avian populations, once adversely affected by pesticide contamination, have progressively recovered (Henny 1977, Spitzer et al. 1978, Ratcliffe 1979). Productivity and population levels in many areas no longer seem restricted by the effects of these contaminants (Wiemeyer et al. 1988, Weseloh et al. 1989). For species such as the osprey and bald eagle (*Haliaeetus leucocephalus*), population recovery seems imminent. Recovery of several localized populations, however, continues to be affected by organochlorine and other environmental contaminants (White et al. 1983, Henny et al. 1984, Fleming and Cain 1985, Kubiak et al. 1989); one such area is Delaware Bay.

Ospreys nesting along Delaware Bay have not substantially increased their productivity or population size since at least 1974, and during 1987 and 1988 they had significantly lower reproductive success compared to ospreys nesting along New Jersey's Atlantic Coast, primarily due to poor hatching success (Steidl et al. 1991). Bald eagles nesting along Delaware Bay continue to lay thin-shelled eggs (L. J. Niles, unpubl. data), and addled eggs collected from this region during 1977 and 1978 contained some of the highest contaminant residues recorded in bald eagle eggs (Wiemeyer et al. 1984). Unlike most areas of the United States, fish collected near Delaware Bay have retained high levels of organochlorines since at least 1976 (Schmitt et al. 1990).

To determine if low hatching success and continued reproductive failure of Delaware Bay ospreys was influenced by environmental contaminants, we assessed levels of organochlorines (OC's), including polychlorinated biphenyls (PCB's), mercury, and lead in addled and randomly collected osprey eggs and prey from 3 regions of New Jersey. In addition to Delaware Bay, we examined eggs and prey from a reproductively successful population along the Atlantic Coast (<80 km from the Bay colony) and a geographically intermediate population along the Maurice River (<40 km from the Bay colony), a tributary of Delaware Bay.

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STUDY AREAS AND METHODS

We collected osprey eggs and prey from 3 regions in southern New Jersey: Delaware Bay, Maurice River, and the Atlantic Coast. Osprey nests near Delaware Bay were located along the northern reach of this estuary and were built atop 500-kV electric transmission towers. Maurice River is an estuarine river feeding Delaware Bay; nests were located 10–15-km upriver from the Bay and built on man-made nesting structures placed specifically for ospreys. The Atlantic Coast region consisted of 3 estuarine areas in northern Cape May County, located <4 km from the Atlantic Ocean, where ospreys nested on man-made nesting structures, in dead trees, or atop blinds for duck hunting (Steidl 1990).

Sample Collection and Preparation

We collected osprey eggs after they failed to hatch ("addled") during 1985–88 and collected eggshell fragments (1 fragment/egg, representing $\geq$½ egg) found in and near nests ("fragments") during 1987–88 from each region. We collected fresh eggs ("random") during 1989 by removing 1 egg from complete clutches ($\geq$3 eggs) within 1 week of clutch completion. Addled eggs were wrapped in aluminum foil and frozen after collection, whereas random eggs were not frozen until contents were removed on the day of collection. We randomly subsampled addled eggs collected from Delaware Bay and Atlantic Coast nests for contaminant analyses. All addled eggs were used for eggshell thickness analyses.

We measured volume of eggs by water displacement and length and breadth with Vernier calipers. We opened eggs by scoring the egg's equator with a scalpel. Egg contents were placed into jars washed in nitric acid and rinsed with hexane. Eggshells (including fragments) were rinsed in tap water and allowed to dry for >3 months prior to measuring thickness and mass. We used a dial-gauge micrometer to measure eggshell thickness near the equator of the egg (whenever possible) and compared these measurements to mean pre-DDT thickness of 0.505 mm (Anderson and Hickey 1972). For each whole egg collected, we also calculated the Ratcliffe Thickness Index (Ratcliffe 1979). Because we removed egg contents using different methods than were used on pre-DDT eggs, which were blown through a small hole in the egg, our Ratcliffe Index values might not be comparable to pre-DDT values.

Fish species were chosen for analysis because they represented either known or potential osprey prey within each region. Although Atlantic menhaden (*Brevoortia tyrannus*) comprised a large percentage of the diets of Maurice River ospreys (R. J. Steidl, unpubl. data), we were unable to collect any for analysis. Whole fish were wrapped in aluminum foil and frozen. We removed viscera before compositing fish tissue for analyses.

Contaminant Analyses

Twenty-five eggs (17 random, 8 addled) and 6 fish composites (n = 25 fish) were analyzed by Mississippi State Chemical Laboratory (Mississippi State, Miss.) and Research Triangle Institute (Research Triangle Park, N.C.) for OC's and metals (mercury and lead), respectively. The OC's examined included oxychlordane, heptachlor epoxide, chlordane, *trans*-nonachlor, *cis*-nonachlor, toxaphene, DDT, DDE, DDD (both o,p' and p,p' for DDT and metabolites), dieldrin, endrin, mirex, BHC's, HCB's, and PCB's (total). We report p,p' isomers for DDT-related compounds unless otherwise specified. Analyses for OC's generally followed methods described in Cromartie et al. (1975) and Kaiser et al. (1980), whereas analyses for metals generally followed those described in Haseltine et al. (1981). Two egg samples were analyzed in duplicate for OC's, 3 for metals, and 2 fish composites in duplicate for metals. Detection limits (ppm) were 0.01 for OC's (wet mass) and 0.02 for mercury (dry mass) in eggs and fish; limits were 0.15 and 0.3 (dry mass) for lead in eggs and fish, respectively. Recoveries in spiked samples ranged from 85 to 100% for OC's and 97 to 102% for metals. We did not adjust residue levels for percent recovery.

All residue levels were adjusted for dehydration (Stickel et al. 1973) except levels in fish composites. All residues are reported in ppm fresh wet mass unless otherwise stated.

Statistical Analyses

Contaminant levels in eggs were $\log_{10}$ transformed because of skewed distributions; therefore we report geometric means throughout. Only contaminants detected in >50% of egg samples were retained for analyses. After adjusting for dehydration, we assigned a value of ½ the detection limit for egg samples in which contaminants occurred below these limits.

Univariate Comparisons.— We used a multiway ANOVA with region, egg type (random and addled), and year as main effects where appropriate to compare transformed residue levels, eggshell thickness, and Ratcliffe Indices. Because of small sample sizes, we excluded Maurice River eggs and eggshells from comparisons between regions but included these when we examined eggshells and contaminants for all regions. We compared occurrence of contaminants with log-likelihood ratio tests for contingency tables (G-tests). To determine those contaminants most related to eggshell thinning, we performed stepwise-multiple regressions and calculated Pearson correlation coefficients.

Multivariate Comparisons.—We compared contaminant levels between regions and egg types with multi-response permutation procedure (MRPP), a multivariate-nonparametric test for differences between groups (Miekle et al. 1981). We performed 2 principal components analyses (PCA) on transformed data using (1) all contaminants to assess qualitatively the differences between regions and (2) only OC's to determine those OC's most related to eggshell thinning. For the latter PCA, we used a varimax rotation to facilitate interpretation (Kleinbaum and Kupper 1978).

RESULTS

Occurrence of Contaminants in Eggs

The contaminants DDE, DDD, oxychlordane, heptachlor epoxide, *trans*-nonachlor, PCB's, and mercury occurred in all eggs analyzed (n = 25), whereas dieldrin (88%), mirex (28%), lead (24%), and BHC (4%) occurred in lesser proportions. Contaminant occurrence in eggs was similar among regions, but mirex occurred more frequently in addled than randomly collected eggs (88 vs. 0%) (G = 23.6, P < 0.0001) as did lead (50 vs. 12%) (G = 4.1, P = 0.042). Dieldrin also occurred more frequently in addled eggs (100 vs. 82%), but the difference was not significant (G = 2.5, P = 0.11). Because of low frequency of occurrence, mirex, BHC, and lead were excluded from subsequent analyses.

Comparisons between Regions and Egg Types

Contaminant levels were generally highest in eggs from Delaware Bay (Table 1). Bay eggs

Table 1. Organochlorine and mercury residues (ppm fresh wet mass) in randomly collected (1989) and addled osprey eggs (1985–88) from 3 regions of New Jersey.

Region and egg type	n	DDE $\bar{x}$[a]	DDE Range	DDD $\bar{x}$	DDD Range	Dieldrin $\bar{x}$	Dieldrin Range	Heptachlor epoxide $\bar{x}$	Heptachlor epoxide Range	Oxychlordane $\bar{x}$	Oxychlordane Range	*trans*-Nonachlor $\bar{x}$	*trans*-Nonachlor Range	PCB's $\bar{x}$	PCB's Range	Mercury $\bar{x}$	Mercury Range
Delaware Bay																	
Random[b]	7	3.2	1.7–5.2	0.4	0.3–0.7	0.03	0.01–0.06	0.05	0.03–0.08	0.03	0.02–0.05	0.02	0.01–0.03	7.7	4.7–17	0.09	0.04–0.21
Addled[c]	4	2.9	1.6–4.7	0.4	0.3–0.6	0.04	0.04–0.07	0.05	0.04–0.10	0.03	0.02–0.05	0.02	0.01–0.03	9.6	4.1–26	0.10	0.05–0.16
All	11	3.1		0.4		0.03		0.05		0.03		0.02		8.4		0.09	
Atlantic Coast																	
Random	8	1.2	0.5–2.8	0.2	0.1–0.6	0.01	nd[d]–0.01	0.03	0.02–0.06	0.03	0.02–0.06	0.01	0.01–0.03	4.1	2.5–6.2	0.14	0.08–0.23
Addled[e]	4	1.6	1.4–1.8	0.2	0.2–0.3	0.02	0.02–0.05	0.03	0.02–0.05	0.02	0.02–0.04	0.01	0.01–0.07	4.4	3.1–5.8	0.23	0.07–0.70
All	12	1.4		0.2		0.01		0.03		0.02		0.01		4.2		0.17	
Maurice River																	
Random	2	1.9	1.6–2.3	0.2	0.2–0.2	0.02	0.01–0.04	0.04	0.03–0.05	0.02	0.02–0.03	0.01	nd–0.02	5.7	3.6–9.1	0.10	0.07–0.16

[a] Geometric mean.
[b] 1 egg contained 0.02 ppm β-BHC.
[c] 3 eggs contained 0.01–0.07 ppm mirex.
[d] None detected.
[e] 4 eggs contained 0.01–0.02 ppm mirex.

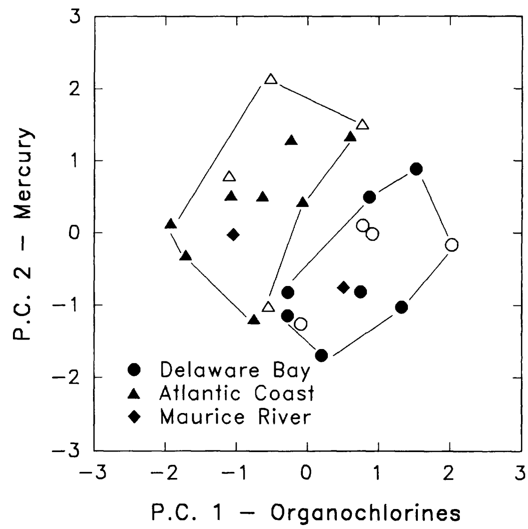

Fig. 1. Separation of Delaware Bay and Atlantic Coast osprey populations in contaminant space. Plot of first and second principal components based on OC's in random and addled osprey eggs from 3 colonies in New Jersey (n = 25). Filled symbols represent random eggs and open symbols addled eggs.

contained significantly higher levels of DDE, DDD, PCB's, dieldrin, and heptachlor epoxide when compared to Atlantic Coast eggs ($F > 7.8$, $P < 0.008$ for all comparisons), although mercury residues were higher in Atlantic Coast eggs ($F = 6.7$, $P = 0.02$). Dieldrin was the only contaminant that differed significantly between addled and random eggs and was higher in addled eggs ($F = 11.6$, $P = 0.003$).

Results from multivariate tests were similar. Contaminant levels in eggs from Delaware Bay were higher than those from the Atlantic Coast for random ($T = 5.21$, $P = 0.002$) and addled eggs ($T = 2.33$, $P = 0.03$) considered separately and both egg types combined ($T = 7.93$, $P = 0.0001$). There was no difference in overall contaminant loads between random and addled eggs ($T = 0.29$, $P = 0.28$).

Colonies differed strongly along the first principal component (derived from all contaminants), which we interpreted as a summary of OC's, and were completely separated along the first 2 components, largely OC's versus mercury (Fig. 1). Although based on a small sample, Maurice River egg contaminant levels were intermediate to Delaware Bay and Atlantic Coast colonies (Fig. 1). Reproductive success of ospreys from each region (Table 2) reflected contaminant levels found in eggs (Table 1).

Eggshell thickness and Ratcliffe Indices did not differ between years within region ($F < 0.48$, $P > 0.74$ for all comparisons), nor did thickness differ between eggshell type (random, addled, fragment) ($F < 0.75$, $P > 0.49$ for all comparisons), so we pooled years and eggshell types for regional comparisons. Eggshell thickness and Ratcliffe Indices paralleled contaminant levels and were significantly thinner for Delaware Bay than for Atlantic Coast eggshells (Table 3) (thickness: $F = 4.3$, $P = 0.04$; Ratcliffe Index: $F = 6.5$, $P = 0.01$). Although there were no statistical differences between thickness of eggshell types, random eggshells were consistently thinner than addled eggshells, whereas eggshell fragments were thinnest (Table 3).

Table 2. Reproductive parameters of ospreys nesting in 3 regions of New Jersey, 1987–88.

Region	n	% eggs hatched	$\bar{x}$ young fledged/pair	% nest success[a]
Delaware Bay[b]	24	50.0[c]	1.08	50.0
Atlantic Coast[b]	38	68.5	1.61	78.9
Maurice River	6	62.5	1.33	66.7

[a] Nests fledging ≥1 young.
[b] Data from Steidl et al. (1991).
[c] n = 12 nests.

Contaminants Influencing Eggshell Thickness

Several OC's were inversely correlated with eggshell thickness of random eggs and both addled and random eggs combined for all regions, but not with thickness of addled eggs alone (Table 4). The apparent influence of specific contaminants on eggshell thickness also differed between regions. Using data from random eggs only, several contaminants were correlated with eggshell thickness for the Atlantic Coast region but not for the Delaware Bay region (Table 4). A multiple regression of all OC's on both addled and random eggs combined indicated that DDD was the only contaminant significantly related to eggshell thickness ($F = 13.45$, $P = 0.0013$, $n = 25$).

There was a significant inverse correlation between eggshell thickness and the first principal component (derived from OC's only) for all egg types ($r = -0.53$, $P = 0.007$). This component was significantly related to DDD, DDE, PCB's, heptachlor epoxide, and oxychlordane in decreasing order ($r \geq 0.70$, $P \leq 0.01$ for all correlations).

Contaminant Levels in Prey

Contaminant levels in prey (Table 5) reflected those in eggs from each region (Table 1) and

Table 3. Eggshell thickness and Ratcliffe Index of random (1989) and addled (1985–88) osprey eggs, and eggshell fragments (1987–88), from 3 regions of New Jersey.

Region and shell type	n	Eggshell thickness (mm) $\bar{x}$	Eggshell thickness (mm) SE	% below pre-1947 thickness[a] $\bar{x}$	% below pre-1947 thickness[a] SE	Ratcliffe[b] index $\bar{x}$	Ratcliffe[b] index SE
Delaware Bay							
Random	7	0.444	0.020	12.0	3.9	2.10	0.11
Addled	8	0.466	0.014	7.8	2.7	2.19	0.07
Fragment	2	0.430	0.005	14.9	1.0		
All types	17	0.453	0.011	10.4	2.1	2.15	0.06
Atlantic Coast							
Random	8	0.485	0.020	4.0	3.9	2.34	0.09
Addled	22	0.488	0.011	3.3	2.2	2.36	0.05
Fragment	19	0.472	0.011	6.5	2.1		
All types	49	0.482	0.007	4.7	1.4	2.36	0.05
Maurice River							
Random	2	0.490	0.045	3.0	8.9	2.43	0.16
Fragment	2	0.465	0.005	7.9	1.0		
All types	4	0.478	0.020	5.5	3.9	2.43	0.16

[a] Compared to data from Anderson and Hickey (1972).
[b] Our Ratcliffe Index values might not be comparable to pre-DDT values because methods of removing egg contents differed.

were generally highest in Delaware Bay, intermediate in Maurice River, and lowest in Atlantic Coast composites. Notably, *o,p'*-DDE, *o,p'*-DDD, *o,p'*-DDT were detected in several fish samples but in no egg samples, α-chlordane in all fish samples but in no egg samples, and oxychlordane in all egg samples but in no fish samples. The biomagnification (i.e., the mean residue levels in eggs relative to residue levels in prey) from menhaden, the major prey species for these ospreys (Steidl 1990), to random osprey eggs from Delaware Bay and the Atlantic Coast were comparable for all contaminants and regions. Biomagnification for Delaware Bay and Atlantic Coast eggs, respectively, was 19 and 25 for DDE, 4 and 6 for DDD, and 17 and 15 for PCB's.

DISCUSSION

Regional Differences

Eggs collected from ospreys nesting along Delaware Bay had substantially higher levels of organochlorines and thinner eggshells than eggs from ospreys nesting along the Atlantic Coast <80 km away, indicating continued exposure of Bay ospreys to these contaminants. Residue levels in Bay eggs were comparable to those reported for Atlantic Coast ospreys during 1976–79 (Wiemeyer et al. 1988). In the osprey populations we studied, productivity diminished with increasing contaminant burdens in eggs and prey.

Reproductive success of ospreys along Delaware Bay has been below that of ospreys along the Atlantic Coast since at least 1974 (Steidl et al. 1991). Contaminant levels in the most contaminated eggs from Delaware Bay were within the range that could adversely affect reproductive success of ospreys (Wiemeyer et al. 1988). Of particular importance are those eggs with high levels of DDE and PCB contamination. Levels of other OC's, mercury, and lead appeared too low to have adversely affected osprey

Table 4. Pearson correlation coefficients (r) between eggshell thickness and selected organochlorines in randomly collected eggs from 2 regions of New Jersey, and addled, randomly collected, and all osprey eggs combined from 3 regions of New Jersey, 1987–89.

Region	Egg type	n	DDE	DDD	PCB's
Delaware Bay	Random	7	0.63	0.13	0.20
Atlantic Coast	Random	8	−0.80*	−0.93***	−0.65*
All regions	Random[a]	17	−0.47*	−0.70**	−0.45*
	Addled	8	−0.17	−0.37	−0.17
	All	25	−0.37*	−0.61**	−0.32

* $P \leq 0.08$, ** $P \leq 0.002$, *** $P = 0.0009$.
[a] Includes 2 eggs from Maurice River ospreys.

Table 5. Organochlorine, lead, and mercury residues (ppm fresh wet mass) in fish collected from 3 regions of New Jersey, 1989.

Region and species	n[a]	DDE	DDD	Dieldrin	α-Chlordane	*trans*-Nonachlor	PCB's	Mercury	Lead	% moisture
Atlantic Coast										
Menhaden	5	0.05	0.04	nd[b]	0.02	0.01	0.28	0.03	0.29	62.8
Delaware Bay										
Menhaden[c]	5	0.17	0.12	0.04	0.08	0.03	0.46	0.04	0.30	66.2
White perch[d]	5	0.68	0.27	0.04	0.12	0.07	1.20	0.08	0.55	71.8
Channel catfish[e]	2	0.25	0.14	0.05	0.06	0.03	0.67	0.06	0.33	71.4
Maurice River										
White perch	6	0.05	0.03	0.01	0.01	0.01	0.18	0.20	0.24	72.2
Channel catfish	2	0.08	0.03	nd	0.02	0.01	0.34	0.24	0.10	76.0

[a] Number of fish in composite sample.
[b] None detected.
[c] Composite contained (ppm) 0.02 *p,p'*-DDT, 0.03 *o,p'*-DDE, 0.08 *o,p'*-DDD.
[d] Composite contained (ppm) 0.11 *o,p'*-DDE, 0.27 *o,p'*-DDD.
[e] Composite contained (ppm) 0.03 *o,p'*-DDE, 0.05 *o,p'*-DDD.

productivity (Scheuhammer 1987, Wiemeyer et al. 1988).

The DDT metabolite DDE consistently has been reported as most responsible for eggshell thinning and has also been negatively correlated with osprey productivity (Spitzer et al. 1978, Wiemeyer et al. 1988). Predictive equations (Wiemeyer et al. 1988) suggest that DDE levels found in the most contaminated eggs from Delaware Bay would result in severely thin eggshells (>15% below normal) and could result in breakage by incubating adults, thereby reducing reproductive success.

Hatchability has been reduced when PCB's in eggs exceed 5 ppm (Platonow and Reinhart 1973), and at levels ≥15 ppm, PCB's have caused embryotoxicity, edema, growth retardation, and deformities in laboratory studies of birds (Kubiak et al. 1989). Specific PCB congeners have reduced hatching success and hatchling mass and impaired the behavior of wild Forster's terns (*Sterna forsteri*) (Kubiak et al. 1989). Because we examined only total PCB's and not isomer-specific ones, we cannot speculate on the relative toxicity of specific PCB compounds on the populations we sampled (Schmitt et al. 1990).

Contaminant Levels and Eggshell Thickness

The strong correlations between DDD and DDE with eggshell thickness (Table 4) and the importance of DDD in PCA and regression analyses suggest that eggshell thickness was most influenced by these specific contaminants rather than the combined effects of the suite of OC's contained in eggs. We found the strongest correlation between DDD and eggshell thickness, as did Wiemeyer et al. (1988) in addled eggs. Most studies that reported an association between eggshell thickness and contaminants found DDE most responsible for thinning (Lincer 1975, Spitzer et al. 1978, Wiemeyer et al. 1984). Although osprey eggs from Delaware Bay contained elevated levels of DDE and other OC's, residue levels were within a narrow range, which may explain the weaker relationship between DDE and eggshell thickness in this population versus the Atlantic Coast population.

Egg and Prey Contaminant Relations

Contaminant levels in ospreys eggs reflected levels in potential prey items from all regions. Similar relationships among residue levels in birds, their eggs, and prey have been reported (Wiemeyer et al. 1975, White et al. 1983, Weseloh et al. 1989). These studies and the consistency of biomagnification across the regions we studied suggest that ospreys are accumulating most of their contaminant burdens on their respective breeding grounds. The association between contaminant loads of fish samples and their life-history characteristics also supports this contention. For example, menhaden spend little time in estuaries (where osprey forage), entering them only to spawn, and these fish had the lowest contaminant load of all prey sampled. In contrast, white perch (*Morone americana*) and channel catfish (*Ictalurus punctatus*) spend their entire life cycles in these estuaries and had higher contaminant loads. Because white perch are piscivorous, they apparently accumulated greater contaminant loads from their highertrophic level prey than did detritus-eating catfish.

Sources of Contaminants

Ospreys nesting along Delaware Bay probably accumulated contaminants from prey captured in this estuary. Environmental pollutants, as well as fish, accumulate in the upper, lower-salinity reaches of estuaries (Moyle and Cech 1988:413), which is where ospreys nest and forage along Delaware Bay. Fish sampled near this area of Delaware Bay from 1976 to 1984 had consistently high levels of DDE (and related homologs) and PCB's; unlike most areas of the United States, residues from this area have not declined since at least 1976 (Schmitt et al. 1990).

Delaware Bay, unlike our study areas on the Atlantic Coast and Maurice River, is routinely dredged to maintain a channel to allow passage of large vessels to ports near the mouth of the Delaware River, the Bay's primary influent source. Dredging activities resuspend contaminants lodged in sediment which are then accumulated by fish (Seelye et al. 1982). Because ospreys nest near this industrial and agricultural portion of the Bay, an area once heavily applied with DDT (Henny et al. 1977), we believe the release and resuspension of contaminants through dredging, and their concentration in the upper reaches of this estuary is the likely source of contaminants found in Bay osprey eggs.

Breeding bird populations previously affected by organochlorine contamination have generally recovered, except in particular "hot spots" of environmental contamination. In these areas, which include Delaware Bay, organisms continue to be threatened by contaminants. Contaminant levels in osprey eggs from Delaware Bay and the difference in levels between this and a reproductively successful colony along the Atlantic Coast suggest that contaminants were at least partially responsible for reduced hatching success observed in Bay ospreys.

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SURVIVAL RATES AND POPULATION DYNAMICS OF BALD EAGLES ON CHESAPEAKE BAY

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Abstract: Survival of 39 radio-tagged bald eagles (*Haliaeetus leucocephalus*) in the Chesapeake Bay region was 100% in the first year of life. Mean minimum survival per year of all eagles was 91% (95% CI = 86–96%); mean maximum survival was 98% (95% CI = 96–100%). A deterministic life-table model predicted a finite growth rate of 5.8% per year, whereas the growth rate based on the maximum survival estimates was 16.6% per year. The breeding population actually increased 12.6% per year from 1986 to 1990. We estimated the intrinsic growth rate at 6.9% based on natality and minimum survival data and 19.2% based on maximum survival data. Because eagle habitat is being converted to human developments at a rapid rate on the Chesapeake, models incorporating these habitat losses are needed to accurately predict future population trends.

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Many bald eagle populations in the contiguous United States appear to be increasing in numbers (Henny and Anthony 1989, Nickerson 1989, Bohall Wood et al. 1990). The U.S. Fish and Wildlife Service (USFWS), as a result, initiated a status review of this species. The Service proposed to change the bald eagle's status from endangered to threatened or from threatened to being taken off the endangered species list entirely in areas where populations have increased sufficiently (55 Fed. Register 4209).

Eagle productivity data were collected in very