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Changes in Contaminant Levels in New Jersey Osprey Eggs and Prey, 1989 to 1998

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Abstract. Ospreys are good indicators of the health of estuarine areas because they feed almost exclusively on fish with the balance on other aquatic biota. Through the 1980s, ospreys nesting on Delaware Bay in New Jersey had reduced reproductive success relative to those nesting on the Atlantic coast and the Maurice River, a tributary of Delaware Bay. Earlier research suggested that elevated levels of DDT and polychlorinated biphenyl (PCB) contaminants identified in addled osprey eggs contributed to this reduced productivity. We repeated egg and prey sampling initially conducted in 1989 to evaluate the trends of contaminants in the last decade. Most organochlorine contaminants declined in osprey eggs in 1998 relative to 1989. Across three study areas, PCBs decreased from 4.1–7.7 ppm in 1989 to 1.8–3.2 ppm in 1998; DDE decreased from 1.2–3.2 ppm in 1989 to 0.7–1.2 ppm in 1998. Lead in eggs increased from an average of 0.01 to 0.30 ppm wet weight, and mercury averaged 0.12 ppm and increased only in Atlantic coast eggs. Most of these contaminant changes were also found in typical prey fish: PCBs decreased from 0.18–1.2 ppm in 1989 to 0.06–0.43 ppm in 1998; DDE decreased from 0.05–0.69 ppm in 1989 to 0.03–0.13 ppm in 1998. Lead and mercury increased in most fish samples. The improvement in most organochlorine contaminants in osprey eggs and prey reflected improved nest success in the Delaware Bay study area, and the nesting populations in the Atlantic and Maurice River study areas increased approximately 200% since 1989. PCBs and DDE in osprey eggs were below levels considered to be toxic to egg development. This study documents significant improvements in organochlorine contaminants in southern New Jersey ospreys, but justifies continued monitoring of heavy metals, such as lead and mercury, in aquatic ecosystems.

Like many birds of prey, ospreys (*Pandion halieatus*) declined in the 1950s and 1960s due to DDT, which thinned eggshells and caused reproductive efforts to fail (Wiemeyer *et al.* 1978). In New Jersey, historic (pre-DDT) osprey populations were estimated at 350–450 pairs (Henny 1977), most of which were along the Atlantic coast. In 1975 the statewide population was 66 pairs (Spitzer *et al.* 1983), when biologists began restoration efforts. In recent years, ospreys have expanded their range in the state, west into Delaware Bay marshes and north into Raritan Bay (Figure 1). The state population in 1999 reached a post-DDT high of 331 nesting pairs, and productivity averaged 1.24 between 1994 and 1998 statewide.

Ospreys nesting along the mid-Atlantic coast have become valuable indicators of coastal ecosystem health for several reasons. First, they are high trophic-level predators and therefore vulnerable to the effects of biomagnification of environmental contaminants such as organochlorine pesticides and polychlorinated biphenyls (PCBs) (Furness 1993). Second, ospreys feed almost exclusively on fish and use many fish species also used by people; thus, their fate has implications for people. Third, they can be used as indicators of threats to other, more rare estuarine fish-eaters, such as bald eagles (*Haliaeetus leucocephalus*). Finally, eggs have been collected and analyzed for over 25 years along the Atlantic Coast, allowing for temporal and geographic comparisons.

Though ospreys have largely recovered in New Jersey, the recovery has not been evenly distributed. A colony in Salem County on Delaware Bay continues to have low productivity and a stagnant number of nests. In 1989, Steidl *et al.* (1991) found that contaminant levels in osprey eggs and prey fish were highest in this colony and accounted for the depressed productivity. They also reported moderate contaminant levels in a Maurice River osprey colony, located off Delaware Bay midway between the Salem and Atlantic colonies, and lowest contamination in Atlantic Coast ospreys.

In light of the slow recovery of osprey nesting in upper Delaware Bay (at Salem), we collected osprey eggs and typical prey fish from the same regions Steidl *et al.* (1991) sampled in 1989. We analyzed eggs and prey for contaminants to determine current levels and changes in residues between 1989 and 1998.

Materials and Methods

We collected osprey eggs and prey from three regions in southern Ne
Jersey: the same regions sampled in 1989 (Steidl *et al.* 1991). T

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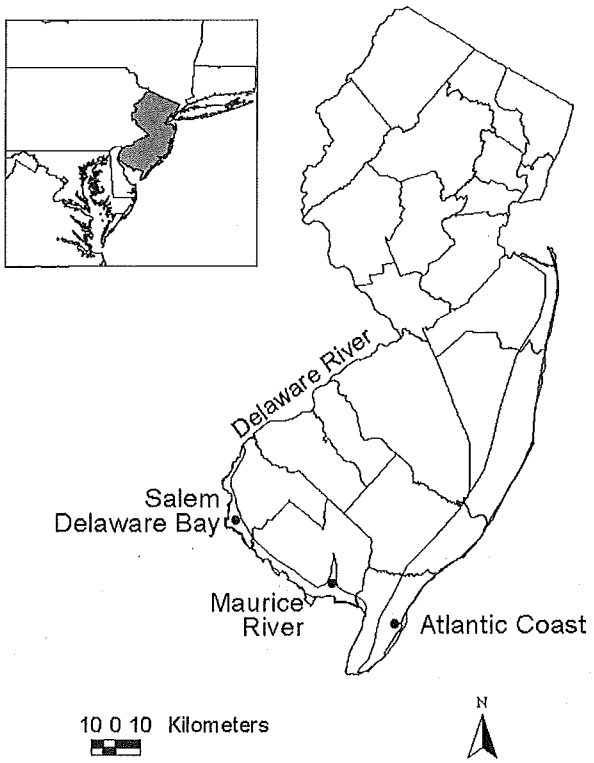

Fig. 1. Location of southern New Jersey osprey study areas (points), and the extent of osprey nesting in the state (shaded)

study areas included Delaware Bay (near Alloways Creek), the Maurice River, and the Atlantic coast (in Cape May County). Osprey nests representing Delaware Bay were located in Salem County in northern Delaware Bay and were built on electric transmission towers. Nests on the Maurice River, an estuarine tributary of Delaware Bay, were located 12–15 km upriver from the bay and built on 5-m-high platforms made for osprey nesting. Atlantic coast ospreys nested on 4-m-high platforms approximately 2 km from the ocean in Great Sound, west of the Avalon-Stone Harbor area.

Sample Collection and Preparation

In this study we analyzed "fresh" osprey eggs only, in contrast to fresh and addled eggs analyzed in 1989. We collected six eggs each from the Atlantic coast and Delaware Bay study areas and five eggs from the Maurice River area. We collected eggs within 10 days of clutch completion, one egg from each sample nest containing at least three eggs. Eggs were wrapped in foil and refrigerated and harvested within 48 hs. Contents were stored in chemically clean jars and kept frozen (−20°C). All samples were shipped to analytical laboratories on dry ice in February 1999.

Eggs were measured for length, breadth, and whole mass prior to harvesting contents. We opened eggs by scoring the egg's equator with a scalpel and emptying all contents into chemically clean jars. Eggshells were rinsed with tap water and allowed to dry for > 3 months prior to measuring for thickness.

Fish species were chosen for this study based on known or potential osprey prey fish, as well as a desire to duplicate sampling conducted in 1989. Whole fish were wrapped in aluminum foil and frozen; we removed viscera prior to contaminant analyses to duplicate the methods used in 1989. Two to five individual fish comprised each composite sample to represent a fish species in a region. We collected and analyzed three composite fish samples from Delaware Bay, two from the Atlantic area, and four from the Maurice River area.

Table 1. Organochlorines, metals, and PCB congeners analyzed in osprey eggs (n = 17) and osprey prey fish (n = 10) collected in 1998 and their occurrence in those samples

Analyte	% Occurrence in eggs	% Occurrence in osprey prey fish
HCB	0	10
Alpha BHC	0	0
Gamma BHC	0	10
Beta BHC	0	0
Delta BHC	0	0
Oxychlordane	100	0
Heptachlor epoxide	100	0
Gamma chlordane	0	0
Alpha chlordane	12	70
Trans-nonachlor	24	60
Cis-nonachlor	100	10
Toxaphene	0	0
p-p′-DDE	100	90
o p′-DDE	0	0
p p′-DDD	100	90
o p′-DDD	0	50
p p′-DDT	12	0
o p′-DDT	6	0
Dieldrin	53	70
PCB-Total	100	100
PCB-1242	0	0
PCB-1248	0	0
PCB-1254	100	100
PCB-1260	100	100
Endrin	0	0
Mirex	6	0
p-p′-DDD olefin	100	0
Lead	100	100
Mercury	100	100
PCB 77	100	80
PCB 81	41	40
PCB 105	100	100
PCB 114	0	0
PCB 118	100	100
PCB 123	100	100
PCB 126	94	70
PCB 128	100	100
PCB 138	100	100
PCB 156	100	100
PCB 157	100	80
PCB 158	100	100
PCB 166	0	0
PCB 167	100	100
PCB 169	59	0
PCB 170	100	100
PCB 189	100	80

Contaminant Analyses

Seventeen osprey eggs and nine fish composites representing osprey forage were analyzed by Mississippi State Chemical Laboratory

(MSCL), Mississippi State, MS, the same laboratory used in the 1989 study, using identical methods. The exception was the metals analysis, which was done by MSCL in 1998 and Triangle Laboratories in 1989. Analytes included organochlorines (OCs), PCB Aroclors and 17 PCB congeners, mercury and lead (Table 1). Samples for chlorinated pesticides and total PCBs analyses were soxhlet extracted and the extracts were fractionated on a Florisil column. PCBs were further separated from other OCs 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. Detection limits (ppm) were 0.010 for most OCs, 0.050 for toxaphene, 0.020 for PCBs (total and Aroclors), and 0.00010 for PCB congeners. Recoveries in spiked samples ranged from 77% to 118% for OCs and 85% to 102% for metals.

For egg samples, wet weight concentrations reported by the lab were converted to fresh weight to correct for moisture loss (Stickel *et al.* 1973). Egg and fish samples containing less than the detection limit of a chemical were assigned a value of one-half the detection limit for statistical analyses.

PCB congener data were used to calculate 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (TCDD-Eqs, or TEQs) using the World Health Organization (WHO) toxic equivalency factors (TEFs) developed for birds and fish (Van den Berg *et al.* 1997).

We measured eggshell thickness (shell and membrane) at six to eight 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 pre-DDT thickness of 0.505 mm (Anderson and Hickey 1972).

We used one- and two-way analyses of variance (ANOVA) followed by Duncan's multiple range test to determine differences in contaminant levels among regions and between years. We used a Pearson correlation to detect relationships between eggshell thickness and contaminants. We used a significance acceptance level of $p = 0.05$ throughout. All contaminant data were log-10 transformed for analyses.

Results

Contaminants in Osprey Eggs

We detected these contaminants in all eggs: oxychlordane, heptachlor epoxide, total PCBs (sum of four Aroclors), p,p′-DDE, p,p′-DDD, p,p′-DDD olefin, and *cis*-nonachlor, as well as lead and mercury (Table 1). Dieldrin was detected in nine eggs (53%), and *trans*-nonachlor, alpha-chlordane, p,p′-DDT, mirex, and o,p′-DDT occurred in less than 50% of eggs. All eggs had detectable levels of 12 of the 17 PCB congeners: PCBs 77, 105, 118, 123, 128, 138, 156, 157, 158, 167, 170, and 189. PCB 126 was detected in 94% of eggs, PCB 169 in 59%, and PCB 81 in 41%.

Levels of total PCBs and p,p′-DDE averaged 2.28 and 0.84 ppm, respectively, for all eggs combined. Residues of Aroclor 1260 averaged 1.61, accounting for 71% of total PCBs. Mercury averaged 0.12 ppm, and lead averaged 0.30 ppm, for all eggs combined.

Most contaminant levels were similar among regions (Table 2). Only residues of PCB 1260 were significantly different among regions, with the highest levels found in Delaware Bay eggs ($F = 4.71$, $p = 0.027$).

PCB Congener Analysis

PCB 126 averaged 685, 574, and 474 ppt in Maurice River, Atlantic, and Delaware Bay eggs, respectively, and was the highest of the non-*ortho*-substituted PCBs, except PCB 77 in Atlantic eggs (Table 3). Total TCDD-EQs in eggs averaged 90.9 ppt. TCDD-EQs for non-*ortho*- and mono-*ortho*-substituted PCBs averaged 74.0 and 14.8 ppt, respectively.

PCB 126 and combined non-*ortho*-substituted PCBs accounted for 46–81% and 75–90%, respectively, of the total TEQs in osprey eggs. There was no difference in non-*ortho* ($F = 0.09$, $p = 0.92$), mono-*ortho* ($F = 3.16$, $p = 0.07$), or total TEQs ($F = 0.01$, $p = 0.99$) among regions. In prey fish, PCB 126 and combined non-*ortho*-substituted PCBs accounted for 61–80% and 71–86%, respectively, of total TEQs. In fish samples, only total mono-*ortho*-substituted PCBs were different among regions ($F = 5.58$, $p = 0.036$), with Delaware Bay fish significantly lower than Atlantic fish, and Maurice River falling in between. Eggs contained higher levels of total TEQs than fish ($F = 537.48$, $p = 0.0001$), and had a higher proportion of non-*ortho*-substituted TEQs than fish, due to a higher percentage of PCB 126 ($F = 4.15$, $p = 0.042$).

Contaminants in Prey Fish

We analyzed samples of channel catfish, white perch, and shad from Salem County, Delaware Bay; channel catfish, white perch, shad, and menhaden from Maurice River; and menhaden and flounder from the Atlantic coast area. Occurrence of contaminants in osprey prey fish generally reflected occurrence in eggs (Table 1). The exceptions were oxychlordane, heptachlor epoxide, and p,p′-DDD olefin, which were found in all eggs but in no fish samples. Conversely, few contaminants (HCB, gamma-chlordane, o,p′-DDE) were found in fish and not in eggs.

As in eggs, total PCBs (Aroclors 1254 and 1260), and p,p′-DDE were found in highest concentrations (Table 4). Residues of p,p′-DDE were significantly higher in Delaware Bay and Maurice River fish than in Atlantic fish ($F = 6.27$, $p = 0.03$). p,p′-DDD was higher in Delaware Bay than in Atlantic fish ($F = 5.42$, $p = 0.04$), with Maurice River fish in between. Although the Maurice River catfish sample was higher in many OCs than other Maurice fish, removal of this sample from analysis did not change these results.

Mercury in fish averaged 0.06, 0.09, and 0.43 ppm in Atlantic, Maurice River, and Delaware Bay, respectively. Lead in fish averaged 0.33, 0.36, and 0.97 ppm in Atlantic, Maurice River, and Delaware Bay, respectively. Differences among regions were not significant for mercury ($F = 2.49$, $p = 0.15$) or lead ($F = 2.02$, $p = 0.20$). One sample, Delaware Bay shad, was 10-fold higher in both mercury and lead than other fish samples.

Comparisons Between Years

Most contaminants in osprey eggs declined between 1989 and 1998 (Table 5). Levels of p,p′-DDE, p,p′-DDD, total PCBs,

Table 2. OCs, mercury, and lead (ppm, fresh wet weight) in fresh osprey eggs collected in 1998 in three regions of New Jersey

		p,p′-DDE		p,p′-DDD		p,p′-DDT		Heptachlor Epoxide		Oxychlordane		Total PCBs		PCB-1254		PCB-1260[c]	
	n	×[a]	Range	×	Range	×	Range	×	Range	×	Range	×	Range	×	Range	×	Range
Delaware Bay	6	1.19	0.87–1.61	0.18	0.14–0.24	0.01	0.01–0.02	0.02	0.01–0.03	0.01	0.01–0.02	3.29	1.85–4.45	0.79	0.53–1.10	2.79	1.50–4.00
Maurice River	5	0.74	0.68–1.40	0.07	0.04–0.24	ND[b]	ND	0.01	0.01–0.02	0.01	ND–0.01	2.00	1.09–2.91	0.61	0.39–0.74	1.58	0.76–2.50
Atlantic Coast	6	0.66	0.31–1.70	0.07	0.03–0.37	0.01	ND–0.02	0.01	ND–0.07	0.01	ND–0.04	1.76	1.10–3.60	0.69	0.30–1.40	1.27	0.71–2.60
All regions	17	0.93		0.11		0.01		0.02		0.01		2.53		0.70		1.79	

[a] Geometric mean
[b] None detected
[c] Regional levels significantly different ($p = 0.05$)
[d] Compared to pre-DDT thickness of 0.505 mm (Anderson and Hickey 1972)

		t-Nonachlor		*cis*-Nonachlor		Dieldrin		p,p′-DDD olefin		Mercury		Lead		Eggshell Thickness		
	n	×	Range	×	Range	×	Range	×	Range	×	Range	×	Range	×	Range	%Change[d]
Delaware Bay	6	0.01	ND–0.01	0.02	0.02–0.03	0.02	0.01–0.02	0.04	0.03–0.05	0.08	0.04–0.26	0.29	0.20–0.45	0.470	0.43–0.54	−6.93
Maurice River	5	0.01	ND–0.01	0.01	ND–0.03	0.01	ND–0.03	0.01	ND–0.01	0.14	0.08–0.20	0.32	0.20–0.68	0.506	0.43–0.59	0.27
Atlantic Coast	6	0.01	ND–0.05	0.01	ND–0.12	0.01	ND–0.01	0.02	ND–0.03	0.15	0.09–0.23	0.31	0.23–0.42	0.496	0.44–0.54	−1.88
All regions	17	0.01		0.01		0.01		0.02		0.12		0.30		0.489		−3.08

[a] Geometric mean
[b] None detected
[c] Regional levels significantly different ($p = 0.05$)
[d] Compared to pre-DDT thickness of 0.505 mm (Anderson and Hickey 1972)

Table 3. Geometric means for PCB congeners and TCDD-EQs (ppt) in osprey eggs and prey fish collected in NJ in 1998

	Osprey Eggs			Fish		
	Del Bay	Maurice	Atlantic	Del Bay	Maurice	Atlantic
n	6	5	6	3	5	2
Non-*ortho*-substituted PCB congeners (ppt)						
PCB 77	321.7	328.2	583.4	281.5	273.6	159.7
PCB 81	97.9	73.9	50.8	63.0	71.9	74.2
PCB 126	474.2	685.0	574.2	158.2	103.7	70.7
PCB 169	161.3	142.8	59.7	ND	ND	ND
Σ TCDD-Eqs (ppt)	69.01	96.72	63.43	0.86	0.61	0.41
Mono-*ortho*-substituted PCB congeners (ppt)						
PCB 105	125,331.2	67,903.6	65,214.3	17,289.2	8,000.2	4,284.9
PCB 114	ND	ND	ND	ND	ND	ND
PCB 118	179,305.8	131,584.4	131,724.1	24,874.0	13,101.5	8,282.5
PCB 123	15,510.8	10,537.4	13,025.3	4,346.9	1,745.7	1,150.2
PCB 156	63,690.5	34,057.8	30,346.6	5,365.9	2,375.4	958.1
PCB 157	5,992.8	3,603.8	3,933.2	757.9	302.5	102.5
PCB 167	29,045.2	17,161.5	14,994.0	2,961.5	1,289.1	2,156.4
PCB 189	4,955.6	2,613.4	2,307.9	503.6	244.0	74.2
Σ TCDD-EQs	21.91	12.25	11.64	0.283	0.137	0.085
Total TCDD-EQs (ppt)	93.88	109.14	75.53	1.15	0.75	0.50

ND = None detected

Table 4. OCs, lead, and mercury residues (ppm, wet weight) in fish collected from osprey nesting regions in NJ, 1998

Region Species	n	p,p′-DDE	p,p′-DDD	Dieldrin	a-Chlordane	t-Nonachlor	Total PCBs	PCB 1254	PCB 1260	Hg	Pb
Delaware Bay											
Channel catfish	2	0.130	0.066	0.020	0.017	0.018	0.44	0.16	0.28	0.17	0.54
White perch	3	0.120	0.059	0.020	0.014	0.012	0.37	0.11	0.26	0.14	0.40
Shad	3	0.150	0.078	0.041	0.030	0.018	0.42	0.15	0.27	3.40	4.20
Maurice River											
Channel catfish	3	0.130	0.066	0.020	0.018	0.017	0.43	0.14	0.29	0.09	0.27
White perch[a]	6	0.033	0.014	ND[b]	ND	ND	0.06	0.03	0.03	0.17	0.32
Menhaden	3	0.073	0.033	0.010	0.011	0.011	0.26	0.14	0.12	0.09	0.47
Shad	3	0.048	0.023	0.020	0.027	0.018	0.28	0.10	0.18	0.04	0.39
Atlantic Coast											
Flounder	3	ND	ND	ND	ND	ND	0.02	0.022	0.01	0.10	0.22
Menhaden	5	0.037	0.021	0.014	0.011	0.005	0.14	0.080	0.064	0.04	0.50

[a] Reflects mean of two samples
[b] None detected

oxychlordane, heptachlor epoxide, and *trans*-nonachlor were all significantly lower ($p = 0.0001$) in 1998 eggs. Dieldrin was somewhat lower, but was not significant ($F = 2.70$, $p = 0.1092$). Mercury increased in 1998 in Atlantic coast eggs ($F = 30.98$, $p = 0.0001$), but the change was insignificant in the other areas. Lead increased substantially between 1989 and 1998 in all study areas ($F = 352.07$, $p = 0.0001$).

Contaminants in fish generally declined between 1989 and 1998 but varied among regions (Table 6). Average declines were between 35% and 62% for DDE, DDD, total PCBs, dieldrin, alpha-chlordane, and *trans*-nonachlor. Mercury and lead increased in 1998 samples, with median increases of 33% and 64%, respectively. One sample deviated from the overall pattern of declining residues: channel catfish from Maurice River increased in all contaminants except mercury and alpha-chlordane.

Eggshell Thickness

Eggshell thickness was not significantly different among regions (Table 2), following the pattern of most contaminant residues in egg contents. Eggshell thickness was inversely correlated with levels of p,p′-DDE ($R = -0.65$, $p = 0.005$) and total PCBs ($R = -0.73$, $p = 0.0008$). We noted, however, that p,p′-DDE, total PCBs and p,p′-DDD were correlated with each other as well.

Discussion

Organochlorine contaminants in NJ osprey eggs were significantly lower in 1998 than in 1989. Other studies report declines in some contaminants (*e.g.*, Wiemeyer *et al.* 1988), or mixed

Table 5. Comparison of selected organochlorines, mercury, and lead (ppm, fresh wet weight) in osprey eggs collected in 1989[a] and 1998 in three regions of New Jersey

	n	n	p,p′-DDE[b]			p,p′-DDD[b]			Dieldrin			Heptachlor Epoxide[b]			Oxychlordane[b]			Total PCBs[b]			Mercury			Lead[b]		
	1998	1989	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)
Delaware Bay	6	7	1.19	3.20	−63	0.18	0.40	−55	0.02	0.03	−33	0.02	0.05	−60	0.01	0.03	−67	3.29	7.70	−57	0.08	0.09	−9	0.29	0.01	1,943
Maurice River	5	2	0.74	1.90	−61	0.07	0.20	−65	0.01	0.02	−50	0.01	0.04	−75	0.01	0.02	−50	2.00	5.70	−65	0.14	0.14	−1	0.32	ND	2,818
Atlantic Coast	6	8	0.66	1.20	−45	0.07	0.20	−65	0.01	0.01	0	0.01	0.03	−67	0.01	0.03	−67	1.76	4.10	−57	0.15	0.10	48	0.31	0.01	2,292

ND = not detected

[a] Data from Steidl *et al.* (1991) for "random" eggs

[b] Significant difference between years (p = 0.0001)

Table 6. Comparison of selected organochlorines, mercury, and lead (ppm, fresh wet weight) in prey fish collected in 1989[a] and 1998 in three regions of New Jersey

		p,p′-DDE			p,p′-DDD			Total PCBs			Dieldrin			a-Chlordane			t-Nonachlor			Hg			Pb		
Region	Species	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)	1998	1989	Change (%)
Del Bay	Channel catfish	0.130	0.250	−48	0.066	0.140	−53	0.44	0.670	−34	0.020	0.050	−60	0.017	0.060	−72	0.018	0.030	−40	0.17	0.060	183	0.54	0.330	64
	White perch	0.120	0.680	−82	0.059	0.270	−78	0.37	1.200	−69	0.020	0.040	−50	0.014	0.120	−88	0.012	0.070	−83	0.14	0.080	75	0.40	0.550	−27
M. River	Channel catfish	0.130	0.080	63	0.066	0.030	120	0.43	0.340	26	0.020	*0.005*	300	0.018	0.020	−10	0.017	0.010	70	0.09	0.240	−63	0.27	0.100	170
	White perch[b]	0.033	0.050	−35	0.014	0.030	−53	0.06	0.180	−66	ND[c]	0.010	−50	ND	0.010	−50	ND	0.010	−50	0.17	0.200	−18	0.32	0.240	33
Atlantic	Menhaden	0.037	0.050	−26	0.021	0.040	−48	0.14	0.280	−50	0.014	*0.005*	180	0.011	0.020	−45	0.005	0.010	−50	0.04	0.030	33	0.50	0.290	72

[a] Data from Steidl *et al.* (1991)

[b] Reflects mean of two samples

[c] ND = None detected

trends in organochlorines (*e.g.*, Audet *et al.* 1992), but our results were very clear in documenting declines in those analytes tested in both years (except dieldrin, for which the decline was significant at a lower acceptance level near 90%). Most OCs in typical prey fish were similarly lower in 1998 compared to 1989. Size differences in prey fish sampled did not contribute to the observed decreases in most contaminants, as fish in 1998 were 10–35% larger than those analyzed in 1989. Since eggs and fish samples showed similar patterns of decline since 1989, we suggest that sampling typical prey fish resulted in good indicators of organochlorine contamination in these ospreys.

We found DDE levels around 1 ppm in eggs (slightly higher in Delaware Bay and lower on the Atlantic), which may be related to the moderate eggshell thinning observed in Delaware Bay eggs. However, this level of DDE is not likely to impair reproduction (Blus 1996). Total PCBs declined about 60% in eggs and 35% in fish between 1989 and 1998. PCBs remained lowest in Atlantic Coast eggs and highest in Delaware Bay eggs, a pattern similar to 1989 findings. Most (71%) of the total PCBs consisted of Aroclor 1260. PCBs in NJ osprey eggs were below the 4.0 ppm no observable adverse effect concentration (NOAEC) established for bald eagles (Wiemeyer *et al.* 1984). Further, total PCBs < 13 ppm in eagle eggs have been associated with adequate reproduction at the population level (Kubiak and Best 1991; Hoffman *et al.* 1996). Thus we do not expect PCBs to cause reduced productivity in ospreys in southern New Jersey.

The magnification of PCBs from fish to osprey eggs in each region was close to 32, the factor suggested for bald eagles (Kubiak and Best 1991). For DDE, however, the magnification from fish to eggs varied by region, at 9 in Delaware Bay, 11 in Maurice River, and 18 in Atlantic Coast. These biomagnification factors were lower than the factor of 22 found by Bowerman *et al.* (1995). We suggest that additional sampling of prey fish is needed to determine, with greater certainty, risk from different fish species within osprey nesting regions.

Mercury increased in 1998 only in Atlantic coast eggs, where it continues to be highest among southern New Jersey study areas. Mercury in Delaware Bay eggs was unchanged in 1998 compared to 1989 and 1992 samples from the same study area (Hughes *et al.* 1997). Hughes *et al.* (1997) also documented the same pattern of higher mercury levels on the Atlantic coast, as measured in osprey feathers. Overall, residues of 0.08 to 0.15 ppm reported here are comparable to eastern U.S. ospreys reported in the late 1970s (Wiemeyer *et al.* 1988), and are also well below the 0.5 ppm (WW) threshold associated with effects (Thompson 1996). Mercury in fish was also below the level likely to cause effects (0.5 ppm minimum; Thompson 1996), at < 0.2 ppm for all samples.

Lead concentrations in eggs increased substantially, averaging 0.31 ppm in all regions in 1998. In 1989, lead was detected in just 12% of randomly collected (fresh) eggs (Steidl *et al.* 1991), but was found in all eggs in 1998. The reasons for the large increase are not clear, because a correspondingly large increase was not observed in prey fish. In contrast to the 20-fold increase in eggs, lead in fish samples increased by an average of 52% since 1989. Little information is available on the toxicological significance of lead in raptor eggs. Pattee (1984) found that lead was not readily transferred from female American kestrels (*Falco sparverius*) to their eggs, and no reproductive effects were observed at dietary levels up to 50 ppm. In a literature review, Scheuhammer (1987) reported that dietary lead levels < 100 ppm are not known to cause significant reproductive impairment in birds. Henny *et al.* (1991) reported normal reproduction of ospreys (through fledging) in a contaminated Idaho river where whole fish contained up to 21 ppm lead, 5 to 20 times the levels in the present study. Therefore, we do not expect lead to present a hazard to ospreys, since lead levels in sampled fish were well below known thresholds for adverse effects.

We calculated the total TCDD toxic equivalency for coplanar PCBs as 91 ppt in osprey eggs and < 1 ppt in prey fish. In both egg and fish samples, about 70% of the toxicity was from PCB 126. There may be additional toxicity contributed by PCDDs and PCDFs, which were not measured in this study. Analysis of bald eagle eggs from southern New Jersey suggests that PCB toxicity comprises about 80% of the TEQ (Clark, unpublished data). Applied to ospreys, we might expect egg TEQs to be 113 ppt (ranging 94–136 among regions). Elliott *et al.* (1996) suggested that the no observed effect level (NOEL) and lowest observed effect level (LOEL) based on CYP1A induction in bald eagles is 100 and 210 ppt TEQs, respectively. Applying these guidelines to ospreys, we would not expect southern New Jersey ospreys to experience detrimental effects due to dioxin-like toxicity of coplanar PCBs.

The improved levels of OCs in osprey eggs and prey fish mirrored improved productivity in the Delaware Bay osprey population, where contaminants were impairing nest success in 1989. Productivity in the Delaware Bay colony has increased from < 0.8 young per nest in the 1980s to 1.1 in the period 1994–1998. Number of nests, however, has remained about the same since 1989, in contrast to the Maurice River and Atlantic study areas, where number of nests has grown approximately 200% since 1989. Contamination in the Delaware Bay study area remains slightly higher than other areas, but we do not expect that this is impairing osprey reproduction. Other factors, such as limited availability of nest structures (predominantly high-tension transmission towers) and great horned owl (*Bubo virginianus*) predation, may continue to moderate population growth.

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