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Osprey Distribution, Abundance, Reproductive Success and Contaminant Burdens Along Lower Columbia River, 1997/1998 Versus 2004

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Abstract The osprey (*Pandion haliaetus*) population nesting along the lower portion of the Columbia River (river mile 29 to 286) increased from 94 in 1997 to 103 occupied nests in 1998 (9.6% annual rate of increase) to 225 occupied nests in 2004 (13.9% annual rate of increase). The more recent rate of population increase was associated with higher reproductive rates than in 1997/1998, and significantly lower egg concentrations of most organochlorine (OC) pesticides, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). A comparison of observed egg residue concentrations in 2004 with effect-level information for ospreys indicated that reproduction at few, if any, nests was adversely affected. As recent as 1997/1998, dichlorodiphenyldichloroethylene (DDE) was still adversely affecting reproductive success for a portion of this population. Mercury was the only contaminant evaluated in both 1997/1998 and 2004 that showed a significant increase in eggs over time, but concentrations in 2004 (0.09 μg g^{-1} ww) remained below established effect levels for birds (generally reported at 0.50 μg g^{-1} ww or higher). The significant increase in mercury justifies the need for future monitoring. All contaminants mentioned that biomagnify up food chains can be effectively monitored in osprey eggs. The osprey has been shown to be an excellent sentinel species for long-term monitoring with their many useful traits described.

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Introduction

The osprey (*Pandion haliaetus)* is a large piscivorous bird of prey with a nearly worldwide breeding distribution (directly comparable reproductive and analytical data is available from many countries). This species is found nesting throughout much of the Columbia River system (Henny *et al.* 2004), including the Willamette River, a major tributary flowing into the Columbia River at Portland (Henny *et al.* 2003). Several osprey life history traits, in addition to considerable knowledge about contaminant-related effects, make this species useful for biomonitoring and research (see Elliott *et al.* 1998, Henny *et al.* 2004) including: (1) a diet comprised almost exclusively of fish which are captured within a relatively short distance of nest sites, (2) a long-lived species with high nest fidelity, (3) easily detectable nest sites, (4) often nest on artificial structures (e.g., channel markers, dolphins, power poles, light poles) which facilitate access for egg collections, (5) tolerance of brief visits to nest, (6) sample egg collections (one egg per nest) from small subset of nests has a negligible effect on productivity (Henny and Kaiser 1996, Henny *et al.* 2004), (7) sensitive to p,p'-DDE (DDE)-induced eggshell thinning and widely studied for effects from other persistent pollutants, (8) nests often spaced at regular intervals along rivers (i.e., not clumped in colonies like herons, egrets or cormorants), which permits collection of eggs at random, or at strategic sites (e.g., above and below known contaminant sources), (9) nesting pairs have recently pioneered into more-contaminated locations (e.g.,

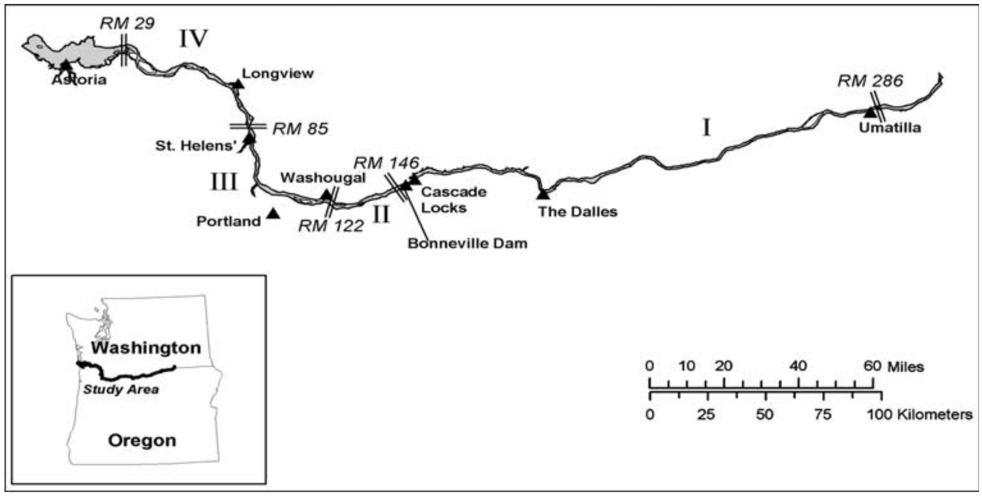

Fig. 1 Osprey study area along the lower Columbia River

lower Willamette River, OR and Duwamish Waterway, WA), and (10) although migratory, wintering grounds make no significant contribution to contaminant concentrations in eggs (Elliott *et al.* 2007). Because of these traits, the osprey ranked high for biomonitoring persistent lipophilic pollutants and mercury in a systematic evaluation of 25 terrestrial vertebrates commonly found in Atlantic Coast estuarine habitats (Golden and Rattner 2003).

The Columbia River drains a vast and ecologically complex region of British Columbia, Canada, and the Pacific Northwest of the United States (668,220 km^2), having the fourth largest water discharge of rivers in the contiguous United States (Kammerer 1990). As with many rivers elsewhere, the Columbia has been and continues to be used for the disposal of municipal and industrial wastes. The Columbia River and its tributaries also support large areas of intensive agriculture, including orchards, row crops, and cereal grains, which have been historically sprayed with persistent organochlorine pesticides (OCs). The development of relatively inexpensive hydroelectric power brought many aluminum smelters and other industries to the region and the vast forests support many bleached-kraft paper mills.

In the early to mid-1990s, a cooperative investigation between the Canadian Wildlife Service and the US Geological Survey (USGS) was conducted using the osprey as an indicator species. The study evaluated residue concentrations of OCs, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and total mercury from eggs of ospreys nesting all along the Columbia River in both Canada and the United States (Elliott *et al*. 1998; 2000). In addition, an artificial incubation experiment with osprey eggs from the Columbia River was conducted to investigate possible contaminant effects on this species (Elliott *et al.* 2001). Data from osprey eggs collected along the lower Columbia River (in the vicinity of Portland, OR) was limited, but provided comparisons with the upper reaches of the river in extreme northeastern Washington and British Columbia. Some OCs and PCB concentrations were highest in the lower portion of the river. Based upon this information, the USGS Biomonitoring Environmental Status and Trends Program supported a population study of ospreys along 410 km of the lower Columbia River (river mile [RM] 31 to 286) in 1997 and 1998 (Henny *et al.* 2004). No ospreys nested downstream of RM 31 at that time.

The study was conducted on a river reach basis with four reaches delineated. The study objectives were to: (1) determine nesting population numbers and productivity rates for osprey, (2) evaluate spatial patterns of OCs, congener-specific PCBs, PCDDs, PCDFs, and total mercury residues in osprey eggs to improve the understanding of contaminant sources, and (3) evaluate egg residue concentrations and associated productivity on a nest basis, i.e., possible adverse effects, via the sample egg technique (Blus 1984), plus review contaminant literature to assess possible effects on productivity. Data from 1997/1998 (Henny *et al.* 2004) provides the basis for comparisons with the data collected in 2004 to determine the nesting osprey population status and changes, if any, in reproductive success, in contaminant burdens in eggs, and in possible adverse contaminant effects.

Study Area and Methods

The lower Columbia River study area was divided into reaches (reach I, II, II, and IV) as follows: (RM 146–286, 124–145, 85–122, and 29–84) (Fig. 1). RM 0 is at the mouth of the river at the Pacific Ocean and at the time of this study, no ospreys nested below RM 29. The river reach divisions were originally chosen based upon several characteristics including industrial boundaries or known pollution point sources (Rosetta and Borys 1996), the Bonneville Dam (river not free-flowing above dam), and spatial gaps in nesting ospreys along the river. The study area extended inland to Umatilla, OR (RM 286) with divisions in river reaches occurring at the Bonneville Dam (RM 146), near the mouth of the Sandy River (about 7 miles upstream of urban Portland and Vancouver) (RM 122), near the mouth of the Lewis River (RM 85), and within the boundary of the Lewis and Clark National Wildlife Refuge (RM 29).

We located occupied osprey nests by boat, car, and aircraft along the Columbia River study area in 2004, following survey methods used in 1997/1998. Classification of occupied (pair present) versus active nests (eggs laid or young present) followed the criteria of Postupalsky (1977). Nests were generally visited two to four times during the breeding season to determine activity and success (number of advanced-age young of 40–45 days at each nest). The final count of young in each nest was conducted by helicopter and car on 13 and 15 May 2004. Some successful nests located during the last survey each year were missed during initial surveys, or had one bird present early (by definition, not an occupied nest). These successful nests were included in the final count. The number of nests not located during initial surveys that might have failed prior to the later survey date was estimated by assuming the same success rate as occupied nests, e.g., 11 successful nests were not located during earlier surveys in 2004, so the success rate of 71.4% at known occupied nests implied that another 4.4 nests were missed and failed. Thus, four additional nests were added to the count in 2004.

One partially incubated egg was randomly collected from 40 nests in 2004 to determine contaminant concentrations. In an attempt to better document contaminant differences among river reaches, more eggs were collected in 2004 than in 1997/1998 (40 versus 29 eggs). Eggs were collected from accessible nests (usually those on channel markers) that represented the complete length of each reach. The nearest RM was recorded for each nest site. Egg contents were placed in chemically clean jars and frozen for subsequent contaminant analysis. Nearly equal numbers of eggs were collected from each reach during both study periods, allowing comparisons of individual egg residue concentrations for the combined reaches between the different study periods.

Eggshells were rinsed and dried for several months at room temperature. Eggshell thickness (including membranes) was measured at three sites on the equator with a rounded contact point micrometer (model 1010 M, L.S. Starrett and Co.) and the values were averaged.

Osprey eggs were sent to the Great Lakes Institute of Environmental Research (GLIER) at the University of Windsor, Windsor, Ontario, Canada for contract chemical analyses. Organic chemical analyses for osprey egg samples were conducted using the methods of Lazar *et al.* (1992), which are described in detail in GLIER (1995). Analyses of 2004 eggs were conducted for 19 OC pesticides, 39 PCB congeners including four coplanar congeners, seven PCDDs, 10 PCDFs, and total mercury. The ΣPCBs equals the sum of 39 congeners. Quantification was accomplished by comparing the sample-peak area with that of three standards supplied by the Canadian Wildlife Service. OCs and PCB fractions were analyzed separately on an electron-capture gas chromatograph. The method detection limit for OCs and PCBs was 0.05 μg kg^{-1} ww. OCs and PCBs were confirmed using gas chromatography/mass spectrometry (GC/MS). Coplanar PCBs, PCDDs, and PCDFs were analyzed by GC/MS; the method detection limit was 0.05 ng kg^{-1} ww. The methodology for extraction and cleanup was checked by running sample blanks, replicate samples, and certified reference samples provided by the Canadian Wildlife Service for OCs and PCBs, and a [^{13}C]-surrogate spike for each sample was run for coplanar PCBs, PCDDs, and PCDFs (GLIER 1995). QA/QC met Environment Canada standards. The 2,3,7,8-TCDD-toxic equivalent concentrations (TEQ) were derived from toxic equivalency factors (TEF) suggested by Van den Berg *et al.* (1998) for PCDDs, PCDFs, and PCBs. The TEQs presented in this paper for 1997/1998 are slightly different than previously reported (Henny *et al.* 2004), because mammal TEFs were initially used instead of bird TEFs. Eggs were analyzed for total mercury by atomic absorption spectrophotometry with a dry weight (dw) method detection limit of 0.03 μg g^{-1}. We converted contents of eggs to fresh ww (Stickel *et al.* 1973); all egg residues are reported as fresh ww, except mercury (reported as dw, but also converted to approximate ww).

Residue concentrations were log-transformed for each reach prior to analysis and tested with the Shapiro–Wilk test for normality. For statistical purposes, the lower quantification limit was halved for eggs in which a contaminant was not detected. This value was used to calculate geometric means when ≥50% of the eggs contained detectable residues. When less than 50% of eggs from a river reach contained the contaminant, no statistical test was conducted with data from that reach. Because of unequal sample sizes, the general linear models procedure (SAS Institute 1999) was used for analysis of variance. Tukey's Studentized range test (P = 0.05) was used to separate means. Unless otherwise noted, differences were considered significant when $P \leq 0.05$.

Results

Population Numbers, 1997, 1998, 2004

As in 1997 and 1998, we believe our survey of osprey nests in 2004 on overwater structures and structures near the shoreline was nearly complete. Special efforts were also made to locate nearby tree nests, especially in the Columbia Gorge. The population in the study area consisted of 94 occupied nests in 1997 and increased to 103 occupied nests in 1998, an increase of 9.6% (Henny *et al.* 2004). In 2004, the population included 170 occupied nests monitored from the early nesting stage without an egg collected plus 40 active nests with one egg collected for chemical analyses. An additional 11 successful nests were located later in the nesting season with no early observation record, or only one adult was present (not in incubation position) during early visits (nest initially not classified as occupied). Thus, these 11 nests represent only successful nests. The success of all occupied nests adequately monitored in 2004 was 71.4% (Table 1); the additional 11 successful nests (assuming the same percentage nest success) imply that another 4.4 nests were not counted during the first visits and failed, with no birds present on later visits. Our best population estimate (using the same field methods and procedures as in 1997/1998) for the study area in 2004 was 225 occupied nests (170+40+11+4). Thus, the population more than doubled in the six years from 1998 to 2004, an annual increase rate of 13.9%.

The four river reaches are not equal in length and comparative statistics regarding total occupied nests/river mile (including nests with and without eggs collected) is instructive when interpreting population changes (Table 2). The lowest density of occupied nests consistently occurred above the Bonneville Dam (reach I) where fewer artificial structures (especially channel markers and dolphins) exist as potential building sites. The largest percentage increases since 1998 occurred at the two extreme ends of the study area (reaches I and IV), which both had the lowest nesting densities in 1998.

Productivity 1997/1998 and 2004

Henny *et al.* (2004) reported that ospreys nesting along the Columbia River study area in 1997/1998 produced 1.54 young/occupied nest, 1.64 young per active nest, or 2.11 young/successful nest (including successful nests with no early visit), when no egg was collected. The population in 2004 produced 1.59 young/occupied nest, 1.70 young/active nest, or 2.35 young/successful nest (again, including successful nests with no early visit) (Table 1). The 2004 reproductive parameters are all higher than in 1997/1998. The negative influence of collecting one egg from a nest was evaluated: (1) nests with one egg collected in 1997/1998 yielded 0.28 fewer young per active nest than nests without an egg collected, and (2) nests with one egg collected in 2004 yielded 0.20 fewer young per active nest.

Table 1 Summary of nesting success for ospreys nesting along the lower Columbia River in 2004, and combined 1997/1998

	Reach I			Reach II			Reach III			Reach IV			Combined		
	Egg collected		No early visit[a]	Egg collected		No early visit	Egg collected		No early visit	Egg collected		No early visit	Egg collected		No early visit
Year (category)	No	Yes		No	Yes		No	Yes		No	Yes		No	Yes	
2004															
Occupied nests	42	NA	NA	18	NA	NA	47	NA	NA	63	NA	NA	170	NA	NA
Active nests	41	9	NA	15	9	NA	45	11	NA	58	11	NA	159	40	NA
Successful nests	34	7	4	10	9	1	33	9	1	38	10	5	115	35	11
Adv. young	78	10	12	22	17	3	82	16	3	85	17	11	267	60	29
Yg./occ. nest	1.86	NA	NA	1.29[b]	NA	NA	1.74	NA	NA	1.37[b]	NA	NA	1.59[c]	NA	NA
Yg./active nest	1.90	1.11	NA	1.57[b]	1.89	NA	1.82	1.45	NA	1.49[b]	1.55	NA	1.70[c]	1.50	NA
Yg./succ. nest	2.29	1.43	3.00	2.20	1.89	3.00	2.48	1.78	3.00	2.24	1.70	2.20	2.32	1.71	2.64
1997/1998[d]															
Yg./occ. nest	1.47	NA	NA	1.23	NA	NA	1.46	NA	NA	1.79	NA	NA	1.54	NA	NA
Yg/active nest	1.56	1.38	NA	1.35	1.33	NA	1.54	1.14	NA	1.91	1.57	NA	1.64	1.36	NA
Yg./succ. nest	1.79	1.83	1.67	2.25	1.60	2.20	2.20	1.33	2.11	2.10	1.83	3.00	2.10	1.65	2.20

NA = not applicable. Either an egg was collected or advanced young observed (all nests active); or no visit was made early with only successful nests recorded late in the season, and/or no evidence of occupied nest (incubating bird, or two birds present) during early visits

[a] Only successful nests found late in the season

[b] Excludes one nest with fate unknown

[c] Excludes two nests with fate unknown

[d] From Henny *et al.* (2004)

Table 2 Total occupied osprey nests along the lower Columbia River in 1997, 1998, and 2004

Year	Occupied nests (per river mile)			
	Reach I	Reach II	Reach III	Reach IV
1997	21 (0.15)	17 (0.81)	29 (0.78)	27 (0.49)
1998	24 (0.17)	19 (0.90)	29 (0.78)	31 (0.56)
2004	57 (0.41)	28 (1.33)	59 (1.59)	81 (1.47)

Note: length of Columbia River reaches: I (140 miles), II (21 miles), III (37 miles), IV (55 miles)

Thus, the negative impact on fledged young to the population per nest with an egg collected was estimated at 0.20–0.28 young per egg collected, or eight fledged young in 1997/1998 and eight fledged young in 2004.

Perhaps the best comparison of productivity among the reaches is the combined data (at nests without an egg collected) for 1997 and 1998 and for 2004 (Table 1). The number of young per occupied and active nest in 1997/1998 (1.47 and 1.56) in reach I was nearly identical to reach III (1.46 and 1.54) with reach II (below the Bonneville Dam) being somewhat lower (1.23 and 1.35) and reach IV (the lower reach) the highest (1.79 and 1.91). Again, productivity in 2004 in reach I (1.86 and 1.90) was nearly identical to reach III (1.74 and 1.82), but consistently higher (+0.28 to +0.39 young) than in 1997/1998. Reach II in 2004 was slightly improved (+0.06 and +0.22 young) (1.29 and 1.57) from 1997/1988 (1.23 and 1.35). Contrary to this pattern, the production rate decreased in reach IV (the lower reach), which had the highest productivity in 1997/1998 (1.79 and 1.91) but decreased to 1.37 and 1.49 in 2004 (–0.42 young).

Mercury and OC Pesticides in Osprey Eggs, 1997/1998 and 2004

No significant differences in mercury or OC pesticide concentrations were found among the reaches in 1997/1998 (Henny *et al.* 2004), and only dieldrin (at extremely low concentrations) varied among the reaches in 2004, being significantly lower in reach I (0.69 μg kg^{-1} ww) than in reach III (2.19 μg kg^{-1} ww) (Table 3). A direct comparison of concentrations for the combined reaches was made between 1997/1998 and 2004 (Table 4). Mercury was the only contaminant in this series that increased significantly from 1997/1998 to 2004. The mercury increase from 0.29 μg g^{-1} to 0.45 μg g^{-1} dw was equivalent to about 0.058 and 0.090 μg g^{-1} ww, respectively, assuming a fresh egg moisture content of 80%.

All OC pesticides decreased from 1997/1998 to 2004, with seven of the eight decreases significant (Table 3). Wiemeyer *et al.* (1988) reported that 15% and 20% eggshell thinning of osprey eggs was associated with 4200 and 8700 μg kg^{-1} DDE, respectively. Lincer (1975) reported that no North American raptor population exhibiting ≥ 18% eggshell thinning was able to maintain a stable population. Henny *et al.* (2004) reported in 1997/1998 reduced reproductive success and 12.7% shell thinning along the Columbia River at nests where the sample egg contained 4200–8000 μg kg^{-1} DDE, and even lower success and 17.0% shell thinning at nests where the sample egg contained > 8000 μg kg^{-1} DDE. These two DDE categories represented 11 (38%) and seven (24%) of the 29 nests sampled in 1997/1998. In 2004, the highest egg DDE concentration was 2294 μg kg^{-1} (well below the effect

Table 3 Comparison of mercury and organochlorine pesticides in osprey eggs by river reach from the lower Columbia River, 2004

Contaminant	River reach (geometric mean)				
	I	II	III	IV	Combined (extremes)
N	9	9	11	11	40
Mercury	0.35 A	0.40 A	0.52 A	0.51 A	0.45 (0.16–1.01)
DDE	1705 A	1487 A	1481 A	1449 A	1521 (985–2294)
DDD	91.6 A	61.5 A	67.8 A	63.5 A	69.7 (23.9–281)
DDT	7.56 A	6.00 A	3.96 A	3.65 A	4.92 (0.74–43.9)
HCB	1.62 A	2.54 A	1.22 A	1.88 A	1.73 (0.68–184)
β-HCH	0.25 A	0.20 A	0.28 A	0.39 A	0.28 (ND-2.17)
Total chlordanes[a]	15.9 A	13.2 A	14.1 A	15.5 A	14.7 (4.08–108)
Heptachlor epoxide	2.48 A	2.57 A	2.87 A	2.92 A	2.72 (1.03–14.3)
Dieldrin	0.69 B	1.63 AB	2.19 A	1.57 AB	1.44 (0.34–8.12)

Note: mercury (μg g^{-1}, dw), organochlorine contaminants (μg kg^{-1}, ww). ND = not detected. Values in rows sharing the same letters are not statistically significant

[a] Total chordanes = Σ *trans*-nonachlor, *cis*-nonachlor, oxychlordane, *trans*-chlordane, and *cis*-chlordane

DDT = dichlorodiphenyltrichloroethane, HCB = hexachlorobenzene, HCH = hexachlorocyclohexane, DDD = 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane

Table 4 Comparison of mercury and organochlorine pesticides (geometric means) in osprey eggs by collection years 1997/1998 and 2004 from the lower Columbia River

Contaminant	1997/1998	2004	*P*
N	29	40	
Mercury	0.29 B	0.45 A	0.0028
DDE	4872 A	1521 B	<0.0001
DDD	199 A	69.7 B	<0.0001
DDT	19.8 A	4.92 B	0.0006
HCB	3.66 A	1.73 B	0.0002
β-HCH	0.43 A	0.28 A	0.1685
Chlordanes[a]	26.8 A	14.7 B	0.0004
Heptachlor epoxide	7.21 A	2.72 B	<0.0001
Dieldrin	6.47 A	1.44 B	<0.0001

Note: Mercury in μg g^{-1} (dw) and OCs in μg kg^{-1} (ww). Values in rows sharing the same letter are not statistically significant

[a] Total chlordanes = Σ *trans*-nonachlor, *cis*-nonachlor, oxychlordane, *trans*-chlordane and *cis*-chlordane

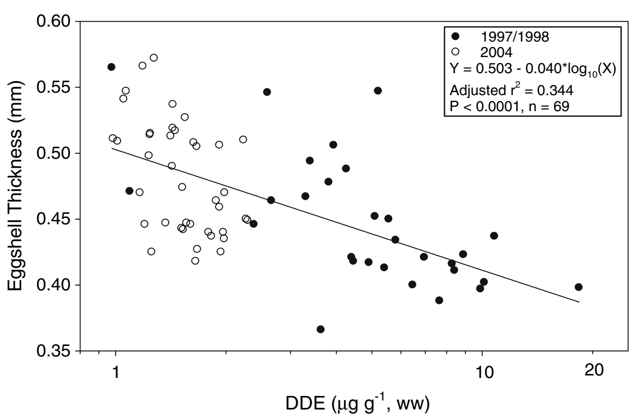

Fig. 2 Relationship between DDE concentrations (μg g^{-1}) and eggshell thickness (mm) of osprey eggs from the lower Columbia River, 1997/1998 and 2004

level), with improvement in eggshell thickness at the lower DDE concentrations readily apparent (Fig. 2). All other OC pesticides were below known effect levels in both 1997/1998 and 2004.

PCBs in Osprey Eggs 1997/1998 and 2004

PCB concentrations in 1997/1998 were not significantly different among the reaches except for PCB 105, which was higher in reach II (below the Bonneville Dam) than immediately above (reach I) or immediately below (reach III) (Henny *et al.* 2004). The ΣPCBs and PCB TEQs were not significantly different among reaches in 2004 (Table 5). Only one congener in 2004 was significantly different among reaches, i.e., PCB 99 at reach I was significantly lower than at reaches II and IV. A comparison between 1997/1998 and 2004 PCB concentrations for the combined study area showed that most PCB congeners decreased significantly by 2004, with the notable exception the coplanars (PCB 77, 81, 126 and 169) (Table 6). While the ΣPCBs showed a significant decrease (–45%), the PCB TEQ (heavily weighted to the coplanars) decrease (–27%), was not significant.

PCDDs and PCDFs in Osprey Eggs 1997/1998 and 2004

PCDD concentrations in 1997/1998 were not significantly different among reaches except OCDD, which was lower in reach IV than in reach III (Henny *et al.* 2004). The PCDD TEQ was not significantly different among reaches in 1997/1998. By 2004, a general pattern emerged with reach I generally the highest (seven of nine comparisons) and reach IV generally the lowest or equally lowest (nine of nine comparisons) (Table 7). Six of the nine comparisons between reach I (the highest) and reach IV were significantly different, with reach II and reach III yielding intermediate concentrations, which were generally not significantly different from each other. When comparing PCDD concentrations from 1997/1998 and 2004 for the whole study area, the tetra-, hepta-, and octa-congeners decreased significantly by 71%, 62%, and 81%, respectively (Table 8). In contrast, penta- and hexa-congeners showed either no significant change (–18%) or a nearly significant change (–39%), respectively. The PCDD TEQ also decreased significantly by 69% from 1997/1998 to 2004.

PCDF concentrations and PCDF TEQs in 1997/1998 were not significantly different among reaches (Henny *et al.* 2004). By 2004 as with PCDDs, a PCDF pattern emerged with reach I generally the highest (Table 9). All concentrations were low, with the hexa-, hepta- ,and octa-congeners all generally decreasing downstream (region IV significantly lower than region I or fewer than 50% of eggs in region IV containing contaminant). The pattern among reaches for tetra- and penta- congeners was not nearly as clear, i.e., reach III was the lowest for tetra-congeners with no significant difference among reaches for penta-congeners. When comparing PCDF concentrations from 1997/1998 with 2004 for the whole study area, the tetra-, hepta-, and octa- congeners decreased significantly by 59%, 74%, and 54%, respectively (Table 10). The decrease in penta- and hexa-congeners (–43% and –27%) was not statistically significant. The PCDF TEQ did not significantly change from 1997/1998 to 2004, but the total TEQ (for PCBs, PCDDs, and PCDFs) decreased significantly (–30%) from 62.5 to 43.8 ng kg^{-1} ww. The geometric mean TEQ for

Table 5 Comparison of PCB concentrations in osprey eggs by River Reach from the lower Columbia River, 2004

PCB	River Reach (geometric mean)				
	I	II	III	IV	Combined (extremes)
N	9	9	11	11	40
ΣPCBs[a]	492 A	841 A	828 A	1022 A	783 (159–8419)
Aroclor 1254:1260	1005 A	1997 A	1793 A	2284 A	1723 (354–13932)
PCB 77	194 A	131 A	134 A	334 A	186 (25.9–2512)
PCB 81	14.0 A	24.4 A	30.0 A	53.6 A	28.3 (ND–358)
PCB 126	164 A	212 A	179 A	291 A	208 (25.9–6931)
PCB 169	18.9 A	27.1 A	16.5 A	26.7 A	21.7 (4.39–218)
PCB 99	12.5 B	27.7 A	25.0 AB	32.4 A	23.5 (3.98–122)
PCB 118	38.0 A	78.5 A	66.2 A	78.7 A	63.7 (11.7–1002)
PCB 153	91.5 A	154 A	144 A	188 A	142 (29.8–1028)
PCB 105	3.36 A	7.73 A	5.65 A	3.70 A	4.80 (0.13–20.2)
PCB 138	73.3 A	146 A	132 A	163 A	125 (25.8–1017)
PCB 183	11.7 A	19.3 A	20.2 A	25.8 A	18.9 (3.10–182)
PCB 180	44.2 A	77.9 A	80.7 A	99.0 A	74.0 (11.9–611)
PCB TEQs[b]	33.4 A	32.5 A	29.7 A	54.1 A	36.7 (6.64–866)

Note: PCBs in μg kg^{-1} (ww), except for PCBs 77, 81, 126, and PCB TEQs which are in ng kg^{-1} (ww). ND = not detected. Values in rows sharing the same letters are not statistically significant

[a] Sum of 39 congeners

[b] Van den Berg *et al.* (1998)

PCBs, PCDDs, and PCDFs was below the no observable adverse effect level (NOAEL) for hatching of osprey eggs (136 ng kg $^{-1}$ ww) as suggested by Woodford *et al.* (1998) and supported by Elliott *et al.* (2001) in both 1997/1998 and 2004 (with only one egg above the NOAEL in 1998 and three eggs in 2004).

Table 6 Comparison of PCB concentrations (geometric means) in osprey eggs by collection years 1997/1998 and 2004 from the lower Columbia River

PCB	1997/1998	2004	*P*
N	29	40	
ΣPCBs[a]	1435 A	783 B	0.0013
Aroclor 1254:1260	3002 A	1723 B	0.0033
PCB 77	199 A	186 A	0.7319
PCB 81	15.8 A	28.3 A	0.1759
PCB 126	302 A	208 A	0.0636
PCB 169	20.1 A	21.7 A	0.7419
PCB 99	53.3 A	23.5 B	<0.0001
PCB118	130 A	63.7 B	0.0005
PCB 153	242 A	142 B	0.0026
PCB 105	36.6 A	4.80 B	<0.0001
PCB 138	222 A	125 B	0.0024
PCB 183	30.5 A	18.9 B	0.0153
PCB 180	120 A	74.0 B	0.0210
PCB TEQ	50.0 A	36.7 A	0.0959

Note: PCBs in μg kg^{-1} (ww), except PCBs 77, 81, 126 and 169 and PCB TEQs in ng kg^{-1} (ww). Values in rows sharing the same letter are not statistically significant

[a] Sum of 39 congeners

Discussion and Conclusions

Fish-eating osprey were selected for biomonitoring OC pesticides, PCBs, PCDDs, and PCDFs in the aquatic environment because these contaminants in fish are usually biomagnified, at least to some extent, and often 10- to 20-fold or more in osprey eggs (Henny *et al.* 2003). Thus, many contaminants found at low concentrations or not detected in water or fish are consistently detected in osprey eggs. Henny *et al.* (2004) reported that eggs from the Osprey population nesting along the lower Columbia River in 1997/1998 still had the highest DDE concentrations reported in North America during the late 1980s and 1990s, and correspondingly high DDE concentrations were found in a key fish species in their diet, the large-scale sucker (*Catostomus macrocheilus*). Although DDE was still affecting reproductive success at a portion of the nests in 1997/1998, productivity was above the rate believed necessary to maintain a stable population and an observed population increase of 9.6% was documented between 1997 and 1998 (Henny *et al.* 2004).

Between 1998 and 2004, when the most recent population study was completed, ospreys nesting along the

Table 7 Comparison of PCDD concentrations in osprey eggs by river reach from the lower Columbia River, 2004

Dioxin	River reach (geometric mean)				
	I	II	III	IV	Combined (extremes)
N	9	9	11	11	40
2378 TCDD	2.20 A	1.46 A	0.64 B	0.64 AB	1.18 (0.27–17.8)
12378 PeCDD	1.66 AB	2.99 A	1.17 AB	0.52 B	1.25 (ND–13.4)
123478 HxCDD	NC	0.18 A	0.11 A	NC	NC (ND–4.87)
123678 HxCDD	8.69 A	4.21 AB	2.05 BC	1.65 C	3.14 (2.00–23.7)
123789 HxCDD	2.98 A	1.14 AB	0.49 B	0.47 B	0.88 (0.10–9.94)
Total HxCDD	13.0 A	6.00 AB	2.88 BC	2.50 C	4.59 (0.68–32.5)
1234678 HpCDD	52.3 A	10.3 AB	4.39 BC	1.38 C	6.76 (ND–222)
Total HpCDD	52.5 A	10.3 AB	4.39 BC	1.39 C	6.78 (ND–222)
OCDD	83.9 A	25.9 AB	10.5 BC	3.34 C	15.0 (0.96–896)
PCDD TEQs	6.07 A	5.63 A	2.67 B	2.67 B	3.80 (1.18–23.0)

Note: No significant differences among river reaches in 1997/1998, except OCDD which was significantly higher in reach III than in reach IV

PCDD contaminants ng kg^{-1} (ww). NC = not calculated, contaminant detected in fewer than 50% of eggs. ND = not detected. Values in rows sharing the same letters are not statistically significant

TCDD = tetrachlorodibenzofuran, PeCDD = pentachlorodibenzo-p-dioxin, HxCDD = hexachlorodibenzo-p-dioxin, HpCDD = heptachlorodibenzo-p-dioxin, OCDD = octachlorodibenzo-p-dioxin

lower Columbia River increased from 103 to 225 occupied nests, a 13.9% annual rate of population increase. This increase occurred throughout the 410 km study area, but was more pronounced at the two extreme reaches where osprey density/river mile in 1998 was the lowest. Also, nesting was extended downstream to RM29 (in 2004) from RM31 (in 1997/1998). The nesting density by 2004 was similar among the three reaches below the Bonneville Dam, but was considerably less above the dam, where fewer channel markers, dolphins, and other suitable structures for nesting exist. Only a few ospreys nested in trees, i.e., their historic nest sites, in 2004.

Table 8 Comparison of PCDD concentrations (geometric means) in osprey eggs by collection years 1997/1998 and 2004 from the lower Columbia River

Dioxin	1997/1998	2004	*P*
N	29	40	
2378 TCDD	4.09 A	1.18 B	<0.0001
12378 PeCDD	1.53 A	1.25 A	0.6362
123678 HxCDD	3.03 A	3.14 A	0.9246
123789 HxCDD	0.49 A	0.88 A	0.1116
Total HxCDD	7.52 A	4.59 A	0.0658
1234678 HpCDD	16.3 A	6.76 B	0.0331
Total HpCDD	18.0 A	6.78 B	0.0208
OCDD	78.7 A	15.0 B	0.0002
PCDD TEQs	12.4 A	3.80 B	<0.0001

Note: PCDDs and PCDD TEQs in ng kg^{-1} (ww). Values in rows sharing the same letter are not statistically significant

The higher rate of annual population increase since 1998 was associated with a higher productivity in 2004 compared to both 1997 and 1998. It is important to recognize that 62% of the nests sampled in 1997/1998 contained DDE concentrations above 4200 μg kg^{-1}, which is where DDE begins adversely influencing reproductive success. No eggs contained DDE concentrations above 2294 μg kg^{-1} in 2004, thus DDE was no longer adversely affecting osprey production along the lower Columbia River. The other OC pesticides were no longer affecting osprey reproduction in 1997/1998 and concentrations continued to decrease to 2004. Most PCBs, PCDDs, and PCDFs also decreased by 2004 with the combined TEQs for PCBs, PCDDs, and PCDFs decreasing significantly from 1997/1998 to 2004 (62.5 to 43.8 ng kg^{-1}). TEQ values may be used to evaluate the combined effects of these groups of contaminants on osprey productivity. The combined TEQ NOAEL for hatching of osprey eggs is 136 ng kg^{1}. Only three of the 40 nests (7.5%) sampled in 2004 contained values above the NOAEL, and those ospreys produced 1.33 young/nest (2, 0, 2 young). The other 37 nests produced a slightly higher 1.51 young/nest. Thus, the combined effects of PCBs, PCDDs, and PCDFs on osprey production in 2004 were believed to be minimal or negligible. Only one nest in 1997/1998 was above the TEQ NOAEL, with one young produced, but the DDE concentration was also above the effect level (Henny *et al.* 2004). Again, no eggs contained DDE above the effect level in 2004 (Table 3).

Mercury was the only contaminant monitored that significantly increased in Osprey eggs between 1997/1998 and 2004. The increase was from 0.058 to 0.090 μg g^{-1} ww.

Table 9 Comparison of PCDF concentrations in osprey eggs by river reach from the lower Columbia River, 2004

Furan	River reach (geometric mean)				
	I	II	III	IV	Combined (extremes)
N	9	9	11	11	40
2378 TCDF	1.23 A	0.64 AB	0.26 B	0.58 AB	0.56 (ND–4.94)
Total TCDF	1.26 A	0.69 A	0.27 B	0.88 A	0.65 (0.08–4.94)
23478 PeCDF	0.56 A	1.72 A	0.60 A	0.65 A	0.76 (ND–27.5)
Total PeCDF	1.55 A	2.03 A	0.68 A	0.71 A	1.06 (ND–28.1)
123478 HxCDF	0.63 A	0.42 AB	0.20 AB	0.11 B	0.26 (ND–4.11)
234678 HxCDF	0.46 A	0.29 AB	0.12 AB	0.09 B	0.18 (ND–2.25)
123678 HxCDF	0.62 A	0.52 A	0.13 B	0.10 B	0.23 (ND–3.78)
Total HxCDF	1.75 A	1.74 A	0.54 AB	0.33 B	0.80 (ND–10.7)
1234678 HpCDF	NC	NC	NC	NC	NC (ND–2.59)
1234789 HpCDF	NC	NC	NC	NC	NC (ND–2.70)
Total HpCDF	0.49 A	0.14 A	NC	NC	0.16 (ND–28.26)
OCDF	0.21 A	0.15 A	0.08 A	NC	0.11 (ND–11.4)
PCDF TEQs	2.95 A	2.66 A	0.94 B	1.46 AB	2.64 (0.22–29.3)
Combined TEQs[a]	47.4 A	40.9 A	32.8 A	57.9 A	43.8 (9.86–910)

Note: PCDF contaminants and TEQs in ng kg^{-1} (ww). NC = not calculated, contaminant detected in fewer than 50% of eggs. ND = not detected. Values in rows sharing the same letters are not statistically significant

[a] Includes PCB, PCDD, and PCDF TEQs. NOAEL for ospreys, 136 ng kg^{-1} (ww) Woodford *et al.* (1998)

TCDF = tetrachlorodibenzofuran, PeCDF = pentachlorodibenzofuran, HxCDF = hexachlorodibenzofuran, HpCDF = heptachlorodibenzofuran, OCDF = octachlorodibenzofuran

Adverse reproductive effects of mercury in birds occur at higher egg concentrations, i.e., generally above 0.50 µg g^{-1} ww, or perhaps somewhat higher with species-specific sensitivity important (Burger and Gotchfeld 1997, Henny *et al.* 2002). Although mercury concentrations are now generally low, increasing concentrations of mercury over time justifies future monitoring.

Table 10 Comparison of PCDF concentrations (geometric means) in osprey eggs by collection years 1997/1998 and 2004 from the lower Columbia River

Furans	1997/1998	2004	*P*
N	29	40	
2378 TCDF	0.96 A	0.56 A	0.1203
Total TCDF	1.59 A	0.65 B	0.0098
23478 PeCDF	NC	0.76	NC
Total PeCDF	1.85 A	1.06 A	0.1707
123478 HxCDF	0.20 A	0.26 A	0.4648
Total HxCDF	1.09 A	0.80 A	0.4374
Total HpCDF	0.61 A	0.16 B	0.0097
OCDF	0.24 A	0.11 B	0.0443
PCDF TEQs	1.48 A	1.74 A	0.6838
Total TEQs[a]	62.5 A	43.8 B	0.0385

Note: NC = not calculated. PCDF and PCDF TEQ in ng kg^{-1} (ww). Values in rows sharing the same letter are not statistically significant

[a] Includes PCBs, PCDDs, and PCDFs

Osprey eggs were also evaluated for flame retardants (polybrominated diphenyl ethers, i.e., PBDEs) in 2004, but not during 1997/1998, and those findings (PBDEs were present) will be the subject of a separate report. PBDEs have been exponentially increasing over the last 20 years in eggs of double-crested cormorants (*Phalacrocorax auritus*) and great blue herons (*Ardea herodias*) in nearby southwestern British Columbia (Elliott *et al.* 2005) and in fish from the upper Columbia River (Rayne *et al.* 2003).

Ospreys have proved themselves to be a useful sentinel or indicator species for contaminants that biomagnify up food chains such as those reported in this study and other contemporary studies (e.g., Rattner *et al.* 2004, Toschik *et al.* 2005), but a single species cannot fulfill all objectives. A combination of techniques and species are required to understand fully the many contaminants and their effects on a diverse system such as the Columbia River. In 2004, none of the evaluated contaminants had an adverse effect on Osprey productivity except perhaps a minimal effect by PCBs, PCDDs, and PCDFs (with eggs at three nests above NOAEL, but nests still productive).

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References

Blus LJ (1984) DDE in birds' eggs: Comparison of two methods for estimating critical levels. Wilson Bull 96:268–276

Burger J, Gochfeld M (1997) Risk, mercury levels, and birds: Relating adverse laboratory effects to field biomonitoring. Environ Res 75:160–172

Elliott JE, Wilson LK, Wakeford B (2005) Polybrominated diphenyl ether trends in eggs of marine and freshwater birds from British Columbia, Canada, 1979–2002. Environ Sci Tech 39:5584–5591

Elliott JE, Morrissey CA, Henny CJ, Inzunza ER, Shaw P (2007) Satellite telemetry and prey sampling reveal contaminant sources to Pacific Northwest ospreys. Ecol Appl 17:1223–1233

Elliott JE, Machmer MM, Henny CJ, Wilson LK, Norstrom RJ (1998) Contaminants in ospreys from the Pacific Northwest: I. Trends and patterns in polychlorinated dibenzo-p-dioxins and dibenzofurans in eggs and plasma. Arch Environ Contam Toxicol 35:620–631

Elliott JE, Machmer MM, Wilson LK, Henny CJ (2000) Contaminants in ospreys from the Pacific Northwest: II. Organochlorine pesticides, polychlorinated biphenyls and mercury, 1991–1997. Arch Environ Contam Toxicol 38:93–106

Elliott JE, Wilson LK, Henny CJ, Trudeau SF, Leighton FA, Kennedy SW, Cheng KM (2001) Assessment of biological effects of chlorinated hydrocarbons in osprey chicks. Environ Toxicol Chem 20:866–879

GLIER (1995) Methods and Procedures Quality Manual, 1st ed., O Revision. Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, Canada (July 1995)

Golden NH, Rattner BA (2003) Ranking terrestrial vertebrate species for utility in biomonitoring and vulnerability to environmental contaminants. Rev Environ Contam Toxicol 176:67–136

Henny CJ, Kaiser JL (1996) Osprey population increase along the Willamette River, Oregon, and the role of utility structures, 1976–1993. In: Bird DM, Varland DE, Negro JJ (eds) Raptors in Human Landscapes. Academic, London, pp. 97–108

Henny CJ, Grove RA, Kaiser JL, Bentley VR (2004) An evaluation of osprey eggs to determine spatial residue patterns and effects of contaminants along the lower Columbia River, USA. In: Chancellor RD, Meyburg BY (eds) Raptors Worldwide, WWGBP/MME, Budapest, Hungary, pp 369–388

Henny CJ, Hill EF, Hoffman DJ, Spalding MG, Grove RA (2002) Nineteenth century mercury: Hazard to wading birds and cormorants of the Carson River, Nevada. Ecotoxicology 11:213–231

Henny CJ, Kaiser JL, Grove RA, Bentley VR, Elliott JE (2003) Biomagnification factors (fish to osprey eggs from the Willamette River, Oregon, USA) for PCDDs, PCDFs, PCBs and OC pesticides. Environ Monitor Assess 84:275–315

Kammerer JC (1990) Largest rivers in the United States. US Geological Survey, Water Fact Sheet Open-File Report 87–242 (Revised), Reston, VA

Lazar R, Edwards RC, Metcalfe CD, Metcalfe T, Gobas FAPC, Haffner GD (1992) A simple, novel method for the quantitative analysis of coplanar (non-ortho substituted) polychlorinated biphenyls in environmental samples. Chemosphere 25:493–504

Lincer JL (1975) DDE-induced eggshell thinning in the American kestrel: A comparison of the field situation with laboratory results. J Appl Ecol 12:781–793

Martell MS, Henny CJ, Nye PE, Solensky MJ (2001) Fall migration routes, timing, and wintering sites of North American ospreys as determined by satellite telemetry. Condor 103:715–724

Postupalsky S (1977) A critical review of problems in calculating osprey reproductive success. In: Ogden JC (ed) Transactions No. American Osprey Research Conf., Trans. and Proc. Series, No. 2. Natl Park Serv, Washington DC, pp. 1–11

Rattner BA, McGowan PC, Golden NH, Hatfield JS, Toschik PC, Lukei RF, Hale RC, Schmitz-Afonso I, Rice CP (2004) Contaminant exposure and reproductive success of ospreys (*Pandion haliaetus*) nesting in Chesapeake Bay regions of concern. Arch Environ Contam Toxicol 47:126–140

Rayne S, Ikonomou MG, Antcliffe B (2003) Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000. Environ Sci Tech 37:2847–2854

Rosetta T, Borys D (1996) Identification of sources of pollutants in the lower Columbia River Basin. Lower Columbia Bi-State Water Quality Program, Portland, OR, 158 pp + Appendices

SAS Institute (1999) SAS User's Guide: Statistics, Version 8.0 Edition, SAS Institute, Inc., Cary, NC

Stickel LF, Wiemeyer SN, Blus LJ (1973) Pesticide residues in eggs of wild birds: Adjustment for loss of moisture and lipid. Bull Environ Contam Toxicol 9:193–196

Toschik PC, Rattner BA, McGowan PC, Christman MC, Carter DB, Hale RC, Matson CW, Ottinger MA (2005) Effects of contaminant exposure on reproductive success of ospreys (*Pandion haliaetus*) nesting in Delaware River and Bay, USA. Environ Toxicol Chem 24:617–628

Van den Berg M, Birnbaum L, Bosveld AT, Brunstrom B, Cook P, Feeley M, Giesy JP, Hanberg A, Hasegawa R, Kennedy SW, Kubiak T, Larsen JC, van Leeuwen FX, Liem AK, Nolt C, Peterson RE, Poellinger L, Safe S, Schrenk D, Tillitt D, Tysklind M, Younes M, Waern F, Zacharwski T (1998). Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ Health Perspect 106:775–792

Wiemeyer SN, Bunck CM, Krynitsky AJ (1988) Organochlorine pesticides, polychlorinated biphenyls, and mercury in osprey eggs –1970–1979– and their relationships to shell thinning and productivity. Arch Environ Contam Toxicol 17:767–787

Woodford JE, Krasov WH, Meyer ME, Chambers L (1998) Impact of 2,3,7,8-TCDD exposure on survival, growth, and behaviour of ospreys breeding in Wisconsin, USA. Environ Toxicol Chem 17:1323–1331