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An Evaluation of Osprey Eggs to Determine Spatial Residue Patterns and Effects of Contaminants along the Lower Columbia River, U.S.A.

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ABSTRACT

An Osprey *Pandion haliaetus* population nesting along the lower 410 km of the Columbia River (94 occupied nests in 1997; increased to 103 in 1998) was studied to evaluate the merit in using the species for monitoring selected contaminants that biomagnify in food chains. We collected a "sample egg" from 29 Osprey nests and analyzed egg contents for residue concentrations of organochlorine pesticides, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and total mercury. Reproductive success was monitored at all nests, including those with an egg collected, to evaluate possible contaminant effects on reproductive success. For purposes of this investigation, the lower Columbia River study area was subdivided into four distinct reaches primarily based on locations of major industrial areas, urban boundaries and other known sources of pollution. Residue concentrations in Osprey eggs for most contaminants did not vary significantly among reaches. However, eggs collected from Reach II (immediately below the Bonneville Dam hydroelectric facility) contained significantly higher concentrations of PCB 105 (nearly all PCB congeners were higher) compared to eggs collected in Reach I (upstream) or Reach III (downstream), although three other large hydroelectric dams are located in Reach I. An historic landfill of electrical equipment containing PCBs was reported at Bonneville Dam in 2000, two years after completion of this field study. Elevated hexachlorobenzene in eggs collected from Reach III appeared to be associated with an aluminum smelter located nearby. Osprey eggs contained the highest concentrations of p, p'-DDE (DDE) (geometric mean 4872 µg kg^{-1} wet weight,

with 24% of eggs > 8000 μg kg^{-1}) reported for the species in North America during the late 1980s and 1990s. Furthermore, DDE adversely influenced eggshell thickness and success at some nests. As expected, elevated DDE concentrations were found in fish from the Columbia River. Other contaminants appeared to have limited, if any, adverse effects on Osprey reproduction. The mean productivity for this population in all four river reaches was 1.64 young/active nest (nests without an egg collected) in 1997-1998, which was considered very good. A more comprehensive study of the fish-eating Osprey on the nearby Willamette River in 2001 (subject of future report) will provide a more complete understanding of the relationship between residue concentrations in Osprey eggs and fish species predominant in their diets. With most Osprey populations now increasing and pairs pioneering into more contaminated areas, with nests distributed at regular intervals (instead of clumped in colonies) along large rivers, with the spatial residue patterns observed during this and other studies and with reproductive effects observed during this study, we believe the Osprey may indeed be a useful indicator for the biomonitoring of selected contaminants in the United States and throughout its breeding range.

INTRODUCTION

The Columbia River drains a vast and ecologically complex region of British Columbia, Canada, and the Pacific Northwest of the United States (668,220km^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 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.

The Osprey *Pandion haliaetus* is a large piscivorus bird of prey with a nearly worldwide breeding distribution (directly comparable data may be obtained from many countries) and is found nesting throughout much of the Columbia River system, 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 contaminant biomonitoring and research (see Elliott *et al.* 1998), including: (1) a diet almost exclusively of fish which are captured within a relatively short distance of nest sites, (2) long-lived and high nest fidelity, (3) readily detectable nest sites, (4) often nest on artificial structures (e.g., channel markers, power poles, light poles) which facilitate access for egg collections, (5) tolerate brief nest disturbance, (6) sample egg collections have minimal effect on nesting populations, i.e., removal of one egg per nest from small subset of nests has negligible effect on productivity (Henny & Kaiser 1996), (7) sensitive to p,p'-DDE (DDE)-induced eggshell thinning and widely studied for effects of other chlorinated hydrocarbon and mercury pollutants, (8) nests often spaced at regular intervals along rivers (i.e., not clumped in colonies like herons, egrets or cormorants), which permits eggs to be collected at random in various segments of a river or at strategic sites (e.g., above and below known contaminant sources), and (9) nesting pairs now pioneering into more contaminated locations (e.g., lower Willamette River, Oregon: Duwamish Waterway, Washington [USGS unpublished data]). The Osprey also ranked high for monitoring of persistent organic pollutants and mercury in a systematic evaluation of 25 terrestrial vertebrates commonly found in Atlantic Coast estuarine habitats (Golden & Rattner 2003).

The use of a fish-eating bird as part of the Nationwide Contaminant Monitoring System in the United States for large rivers, bays and estuaries has been discussed for almost a decade. In the early to mid-1990s, a cooperative investigation between the Canadian Wildlife Service and the U.S. 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 throughout the Columbia River in both Canada and the United States (Elliott *et al.* 1998; Elliott *et al.* 2000). In addition, an artificial incubation experiment with eggs from the Columbia River was conducted to investigate contaminant effects on Ospreys (Elliott *et al.* 2001). Data from Osprey eggs collected along the lower Columbia River (in the vicinity of Portland, Oregon) was limited, but provided comparisons with the upper reaches of the river in extreme north-eastern Washington and British Columbia. Some OCs and PCB concentrations were highest in the lower portion of the river. The Biomonitoring Environmental Status and Trends Program of USGS agreed to further evaluate the Osprey as an indicator species for biomonitoring in 1997.

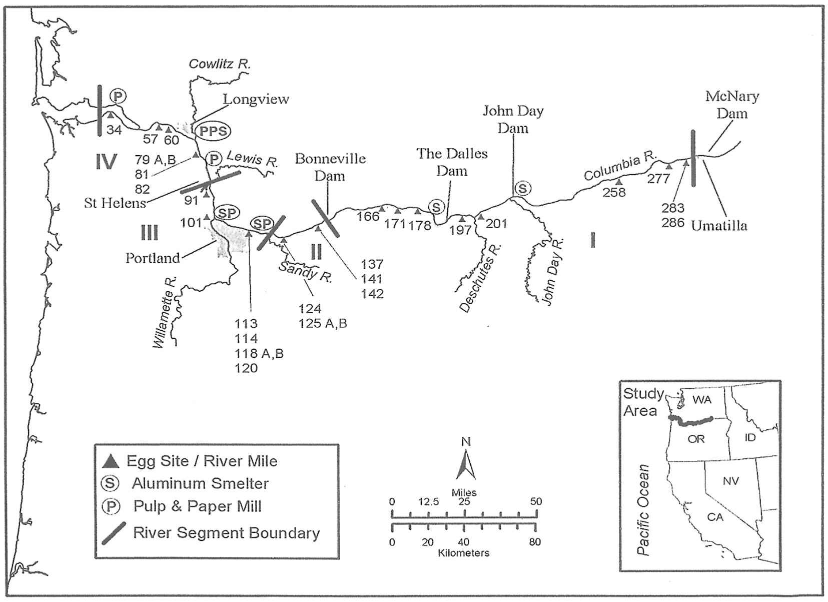
Preliminary studies along the Willamette River in 1993 showed variable residue concentrations in different species of fish, with Biomagnification Factors (BMFs) from fish (weighted by percent biomass of each fish species in Osprey diet) to Osprey eggs (wet weight [ww]) that range from 0 to 174, depending upon the contaminant (Henny *et al.* 2003). Most contaminants studied had BMFs in the range of 10 to 100-fold. Therefore, Ospreys integrated residues from the tissues of several fish species they preyed upon (prey species consumed were fairly consistent from nest to nest along the Willamette River), and their eggs have much higher residue concentrations than fish, which result in far fewer non-detections than commonly found in fish or other sampling approaches. Note that the Osprey is used as an indicator species for lipophilic contaminants, but not for hydrophilic contaminants. We do not believe that one species can be used to effectively monitor all groups of contaminants.

In this study, we analyzed contaminant residue concentrations in Osprey eggs collected from a total of 29 nests between River Mile (RM) 31 and 286 of the lower Columbia River in 1997 and 1998. The objectives of our study on a river reach basis were to: (1) present 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 for possible identification of contaminant sources, and provide a baseline for the long-term biomonitoring of contaminant trends, and (3) evaluate egg residue concentrations and associated productivity on a nest basis via the sample egg technique (Blus 1984) in addition to reviewing literature to assess possible adverse contaminant effects on productivity. Finally, we discuss the merit in using the Osprey for the long-term biomonitoring of selected contaminants in large river systems.

STUDY AREA AND METHODS

The lower Columbia River study area was divided into reaches (Reach I, II, III and IV) as follows: (RM 149-286, 124-143, 86-122, and 31-82) (Fig. 1). RM 0 is at the mouth of the river at the Pacific Ocean and at the time of the study, no Ospreys nested below RM 31. The river reach divisions were chosen based upon several characteristics including industrial boundaries or known pollution point sources (Rosetta & Borys 1996), Bonneville Dam (river not free-flowing above dam), and spatial gaps in nesting Ospreys along the river. The study area extended inland to Umatilla, Oregon (RM 286) with divisions in river reaches occurring at Bonneville Dam (RM 146), about one mile upstream from the mouth of Sandy River (prior to the river reaching urban Portland and Vancouver) (RM 122), at the mouth of the Lewis River (RM 86), and at the upstream boundary of the Lewis and Clark National Wildlife Refuge (RM 31).

Figure 1. Osprey egg collection sites, major industrial outfalls, hydroelectric dams and river reach boundaries, Columbia River, Oregon and Washington, 1997-1998.



We located occupied Osprey nests by boat and aircraft along the Columbia River study area in 1997 and in 1998. Classification of occupied vs. active nests followed the criteria of Postupalsky (1977). Nests were generally visited

2 to 4 times during the breeding season to determine activity and success (number large young [40-45 days] at each nest). One partially incubated egg was collected from 13 nests in 1997 and 16 different nests in 1998 to determine contaminant concentrations. The nearest RM was recorded for each nest site. Egg contents were placed in chemically cleaned jars and frozen for subsequent contaminant analysis.

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 Co.) and 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 29 Osprey egg samples were conducted using methods of Lazar *et al.* (1992), which are described in detail in GLIER (1995). Analyses were conducted for 20 OC pesticides, 42 PCB congeners including 4 co-planar congeners, 7 PCDDs, 10 PCDFs, and total mercury. The $\sum$ PCBs equals the sum of 42 congeners. Quantification was accomplished by comparing sample-peak area against standard-peak area of three standards supplied by the Canadian Wildlife Service. OCs and PCB fractions were analysed separately on an electron-capture gas chromatograph. The detection limit for OCs and PCBs was 0.1 $\mu g\ kg^{-1}$ ww. OCs and PCBs were confirmed using gas chromatography/mass spectrometry (GC/MS). Co-planar PCBs, PCDDs, and PCDFs were analyzed by GC/MS; the detection limit varied from 0.06 to 2.8 ng kg^{-1} ww. 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 ran for co-planar PCBs, PCDDs, and PCDFs (GLIER 1995). 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. Eggs were analysed for total mercury by atomic absorption spectrophotometry with a dry weight (dw) detection limit of 0.07-0.10 $\mu g\ g^{-1}$. 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).

Residue concentrations were summarized as geometric means and log-transformed for statistical analyses. 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 < 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 ($\alpha = 0.05$) was used to separate means. Unless otherwise noted, differences were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Osprey Population Numbers and Productivity

We believe our survey of nests on overwater structures and along the immediate shoreline was complete, and special efforts were made to locate tree nests in the Columbia Gorge. Elsewhere, any nests out of sight from the shoreline were probably missed. In 1997, we monitored 80 nests adequately with early and late visits (68 occupied, 12 active with an egg collected), but another 10 successful nests were not identified until toward the end of the breeding season. The success of all nests adequately monitored in 1997 was 69.6% (Table 1); the additional 10 successful nests (assuming the same percent nest success) imply that another 4.4 nests were probably missed during first visits and failed, thus no birds were present to observe on later visits. Our best population estimate for the study area in 1997 was 94 occupied nests (68 + 12 + 10 + 4.4). Following the same logic in 1998 when 78.0% of the nests were successful (Table 2), the population estimate was 103 occupied nests (76 + 15 + 10 + 2.8). Thus, the nesting population increased an estimated 9.6% from 1997 to 1998. Only a few nests were monitored in 1995, and although the 1996 study effort was fairly complete for the lower three reaches of the river, all nests were probably not located, thus the percent population change from 1996 to 1997 was not calculated.

Perhaps the best comparison of productivity among reaches is the combined data (at nests without an egg collected) for 1997 and 1998 as presented at the bottom of Table 2. The number of young produced per occupied and per active nest (1.47 and 1.56) in Reach I was nearly identical to Reach III (1.46 and 1.54) with Reach II (below Bonneville Dam) somewhat lower (1.23 and 1.35) and Reach IV (the lower river reach) the highest (1.79 and 1.91). The combined productivity for all river reaches was 1.54 and 1.64. Production rates were all higher than the 0.80 young/active nest that is generally recognized necessary to maintain a stable population (Spitzer 1980, Spitzer *et al.* 1983). The production rates for Osprey on the Willamette River in 1993 were also 1.54 and 1.64 for occupied and active nests, respectively (Henny & Kaiser 1996).

Factors Potentially Confounding Spatial Residue Patterns in Osprey Eggs

Several issues may confound the interpretation of spatial Osprey egg residue patterns (see Henny *et al.* 2003). Briefly, they are: (1) migratory Osprey may accumulate some contaminants while at wintering grounds, though they spend ~1 month on the breeding grounds accumulating local contaminants prior to egg laying, (2) fish species eaten by Ospreys could travel substantial distances up or down the river and confound spatial patterns of egg residues, (3) some Osprey may not consistently fish in the Columbia River, but seek other sources of fish in ponds or lakes adjacent to the river which have different contaminant profiles, and (4) some individual Osprey may opportunistically capture fish of different trophic levels (higher or lower contaminant loads) that are abundant or especially vulnerable to capture near their nests.

Table 1. A summary of nesting success for Ospreys nesting along the Columbia River in 1997.

	Reach I			Reach II			Reach III			Reach IV			Combined		
	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early
Category	No	Yes	Visit[a]	No	Yes	Vist	No	Yes	Visit	No	Yes	Visit	No	Yes	Vist
Occupied Nests	15	NA	NA	12[b]	NA	NA	19	NA	NA	21	NA	NA	67[b]	NA	NA
Active Nests	15	5	NA	11	1	NA	18	3	NA	20	3	NA	64	12	NA
Successful Nests	12	3	1	5	1	2	11	2	5	19	2	2	47	8	10
Adv. Young	22	6	1	9	2	3	24	2	10	42	4	6	97	14	20
Young/Occupied Nest	1.47	NA	NA	0.75	NA	NA	1.26	NA	NA	2.00	NA	NA	1.45	NA	NA
Young/Active Nest	1.47	1.20	NA	0.82	2.00	NA	1.33	0.67	NA	2.10	1.33	NA	1.52	1.17	NA
Young/Successful Nest	1.83	2.00	1.00	1.80	2.00	1.50	2.18	1.00	2.00	2.21	2.00	3.00	2.06	1.75	2.00

Note: Columbia River study area divisions by river mile (RM): Reach I (149-286), Reach II (124-143), Reach III (86-122), Reach IV (31-82). NA = Not Applicable (either an egg was collected or advanced young were observed [all active nests]) or no visit was made early with only successful nests recorded late in season, or no evidence of occupied nest (incubating bird, or 2 birds present) on early visit(s).

[a] Only successful nests found late in the season.

[b] One additional occupied nest was excluded from this summary because productivity was not determined.

Table 2. A summary of nesting success for Ospreys nesting along the Columbia River in 1998, and combined 1997-1998.

	Reach I			Reach II			Reach III			Reach IV			Combined		
	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early	Egg Collected		No Early
Category	**No**	**Yes**	Visit[a]	**No**	**Yes**	Visit	**No**	**Yes**	Visit	**No**	**Yes**	Visit	**No**	**Yes**	Visit
Occupied Nests	19	NA	NA	10	NA	NA	20	NA	NA	26	NA	NA	75	NA	NA
Active Nests	17	3	NA	9	5	NA	19	4	NA	24	4	NA	69	16	NA
Successful Nests	14	3	2	7	4	3	15	4	4	21	4	1	57	15	10
Adv. Young	28	5	4	18	6	8	33	6	9	42	7	3	121	24	24
Young/Occupied Nest	1.47	NA	NA	1.80	NA	NA	1.65	NA	NA	1.62	NA	NA	1.61	NA	NA
Young/Active Nest	1.65	1.67	NA	2.00	1.20	NA	1.74	1.50	NA	1.75	1.75	NA	1.75	1.50	NA
Young/Successful Nest	2.00	1.67	2.00	2.57	1.50	2.67	2.20	1.50	2.25	2.00	1.75	3.00	2.12	1.60	2.40
1997-1998 Combined[b]															
Young/Occupied Nest	1.47	NA	NA	1.23	NA	NA	1.46	NA	NA	1.79	NA	NA	1.54	NA	NA
Young/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
Young/Successful 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

Note: Columbia River study area divisions by river mile (RM): Reach I (149-286), Reach II (124-143), Reach III (86-122), Reach IV (31-82).
NA = Not Applicable (either an egg was collected or advanced young were observed [all active nests]) or no visit was made early with only successful nests recorded late in the season, or no evidence of occupied nest (incubating bird, or 2 birds present) on early visits.

[a] Only successful nests found late in the season.

[b] Includes data presented in Table 1 (1997) and the top of Table 2 (1998) combined.

Columbia River Ospreys migrate quickly (mean of 13 days with minimal opportunity for contaminant loading *en route*) to their wintering grounds in southern Mexico and northern Central America (Martell *et al.* 2001) where industrial contamination is generally low, although DDE and some other pesticides may be present (Henny *et al.* 2003). Osprey tend to remain in the same locale throughout the *ca.* 6-months on their wintering grounds. Four adult females from the study area were trapped and equipped with satellite transmitters and an egg was collected from each nest. They nested at RM 91 (2386 µg kg^{-1} DDE, wintered at Acaponeta, Mexico), RM 124A (10139 µg kg^{-1} DDE, wintered Colima, Mexico), RM 125A (5807 µg kg^{-1} DDE, wintered Tampico, Mexico), and RM 277 (5210 µg kg^{-1} DDE, wintered San Miquel, El Salvador). This limited data may be useful, with additional data from other females, to evaluate the importance of DDE/DDT sources on the wintering grounds.

Concerning the second issue of seasonal movements of fish species predominant in the diet of nesting Osprey on the Columbia River, we have limited our discussion to movements of Largescale Suckers *Catostomus macrocheilus* which are distributed widely and are generally abundant throughout the Columbia River system (Reimers & Bond 1967, Gray & Dauble 1977) and were most frequently observed as prey remain items at Osprey nest sites in our study area (Largescale Suckers also comprised 82.8% of biomass in the diet of nesting Osprey on the nearby Willamette River [Henny *et al.* 2003]). Based on a limited amount of tag-recapture data, Dauble (1986) reported Largescale Sucker movement as far as 14km upstream and 60km downstream from original capture sites. However, Osprey return from wintering grounds to Columbia River nests in late March through early April and most lay eggs in late April and early May, prior to peak upstream movements of suckers in June and the average peak spawning period (mid-May to mid-June) reported by Dauble (1986). Therefore, the fish eaten prior to Osprey egg laying most likely reflect local contaminant conditions.

The fish movement issue, the likelihood that some Osprey pairs forage away from the main river at times, and that some Osprey pairs opportunistically select fish species occupying different trophic levels depending on species abundance and susceptibility to capture may influence the variability observed in individual Osprey egg residue concentrations. Other Osprey egg-contaminant studies have shown patterns of PCDDs and PCDFs associated with breeding ground point sources; i.e., higher concentrations downstream of pulp mills than upstream (Elliott *et al.* 1998). Though some egg-residue data from individual nests are spatially presented, our emphasis is on mean contaminant concentrations among river reaches (Table 3), which tends to minimize individual egg/nest site variability.

Organochlorine Pesticides and Mercury in Osprey Eggs

Mean concentrations of DDE in Osprey eggs collected in 1997-1998 from the lower Columbia River were the highest among OCs (Table 3), and significantly higher than mean DDE concentrations reported in 10 Osprey eggs collected from the Willamette River in 1993 (Henny *et al.* 2003) (4872 vs. 2350 µg kg^{-1}, $P = 0.015$). However, no significant difference was found in mean DDE concentrations among the four Columbia River reaches. Mean concentrations of DDD (198.6 µg kg^{-1}) and (DDT) (19.77 µg kg^{-1}) showed no significant difference among river reaches in the Columbia River (Table 3), and were both only small percentages of the sum of DDT and its metabolites (3.9% and 0.4%, respectively).

Total chlordanes, heptachlor epoxide, dieldrin, mirex, ß-HCH and HCB were found at low concentrations with no significant differences among river reaches (Table 3). No particular reach consistently showed the highest or lowest geometric mean concentrations for pesticides. The two highest HCB concentrations recorded along the river (17.1 and 16.2 µg kg^{-1}) were from Osprey eggs collected in 1997 at RM 120 and RM 118 within Reach III immediately downstream from an aluminum smelter at RM 120 (Figs. 1, 2). The other egg collected at RM 118 (with only 2.3 µg kg^{-1} of HCB) was taken two miles downstream of the smelter on the opposite side (Washington) of the river. HCB is an interesting contaminant as it is no longer used as a fungicide in North America (cancelled in the United States in 1985) or Europe, but occurs as a minor contaminant in many commonly used modern pesticides and has several industrial sources including use as a wood preservative and in aluminum casting (Bailey 2001). Eggs were not collected immediately adjacent (within two miles) to the other aluminum smelters, which were located at RM 216, 188, 103 and 63 within our study area (Figs. 1, 2), except at RM 101. The nest at RM 101 was located near the mouth of the Willamette River at Kelly Point, about two miles downstream on the opposite side of the river from the smelter and contained average HCB residues (3.5 µg kg^{-1}). An extremely high concentration of HCB (1888 µg kg^{-1}) was also reported in an Osprey egg collected in 1991 (Elliott *et al.* 2000). The egg was collected along the upper Columbia River much further upstream from our study area in eastern Washington near Matney Mill at Kettle Falls. Elliott *et al.* (2000) noted that the elevated HCB in the egg from Matney Mill suggests a local point source of industrial activity or possibly a leaching waste dump. No further corroborative data have been found.

Mercury concentrations in Osprey eggs were generally low (geo. mean 0.29 µg g^{-1} dw) and were not significantly different among river reaches (Table 3); the highest egg concentration (0.94 µg g^{-1}) was from RM 137 (Fig. 3).

PCBs, PCDDs and PCDFs in Osprey Eggs

In contrast to the OCs and Hg egg residue concentrations which showed no significant difference in residue patterns among the river reaches, the mean concentration for PCB 105 was significantly higher in eggs (79.05 µg kg^{-1}) from Reach II (in the gorge immediately downstream from Bonneville Dam) than in Reach I upstream (25.04) or Reach III further downstream of the dam (28.74) (Table 3). The residue concentrations for almost all other PCB congeners showed a similar pattern, though differences among reaches were not statistically significant. PCB TEQs followed the same pattern with values twice as high in Reach II (75.91 ng kg^{-1}) as in Reach I (36.27) with intermediate values in Reach III (41.30) and Reach IV (53.10) (Table 3). The observed egg residue pattern implied that there was a significant point source of PCBs entering the river somewhere near Bonneville Dam that was surprisingly different from the PCB patterns associated with the other three hydroelectric dams in the study area. A Press Release on 20 November 2000 (two years after our field data were collected) corroborated our findings when a previously undisclosed landfill (in use from 1942 to 1982) containing electrical equipment heavily contaminated with PCBs was reported on an island at Bonneville Dam (US Army Corps Engineers 2000).

Table 3. A comparison of organochlorine contaminants, PCBs and mercury concentrations in Osprey eggs by river reach from the Columbia River in 1997 and 1998.

	River Reach (geo. mean)				
Contaminant[a]	I	II	III	IV	Combined (Extremes)
N	9	6	7	7	29
HCB	3.99 A[b]	3.43 A	4.41 A	2.87 A	3.66 (1.0-17.1)
DDE	5144 A	7111 A	3766 A	4252 A	4872 (977-18377)
Mirex	6.13 A	5.99 A	3.48 A	4.75 A	5.00 (1.5-43.3)
ß-HCH	NC	0.74 A	0.50 A	0.76 A	0.43 (ND-15.9)
Chlordanes[c]	28.36 A	23.25 A	33.61 A	22.57 A	26.84 (6.2-188.8)
DDD	252.70 A	228.09 A	210.57 A	122.07 A	198.61 (38.7-1213.2)
DDT	28.93 A	15.39 A	9.46 A	31.35 A	19.77 (0.2-161.4)
HE	11.90 A	7.11 A	8.28 A	3.34 A	7.21 (ND-55.7)
Dieldrin	6.18 A	4.38 A	11.52 A	5.40 A	6.47 (1.5-120.9)
Mercury	0.26 A	0.42 A	0.25 A	0.30 A	0.29 (0.12-0.94)
∑ PCB Congeners[d]	1246 A	2317 A	1129 A	1449 A	1435 (389-11674)
PCB 77	150.42 A	242.44 A	198.52 A	241.66 A	199.05 (35.9-584.5)
PCB 81	15.58 A	12.09 A	28.01 A	11.00 A	15.80 (ND-132.0)
PCB 126	238.29 A	419.08 A	262.42 A	353.92 A	301.58 (51.4-1296.8)
PCB 169	12.66 A	30.94 A	19.09 A	26.58 A	20.12 (0.2-66.9)
PCB 99	37.78 A	101.39 A	45.00 A	56.58 A	53.29 (10.4-392.9)
PCB 118	92.38 A	247.74 A	112.80 A	132.19 A	129.64 (30.8-1049.6)
PCB 153	226.10 A	368.89 A	179.43 A	250.03 A	242.43 (71.1-1233.9)
PCB 105	25.04 B	79.05 A	28.74 B	39.08 AB	36.56 (9.2-162.3)
PCB 138	182.98 A	398.02 A	171.44 A	224.08 A	222.15 (58.2-1455.5)
PCB 182/187	76.26 A	112.90 A	57.52 A	84.78 A	79.27 (21.3-614.8)
PCB 183	28.76 A	46.84 A	21.84 A	31.82 A	30.50 (8.4-272.7)
PCB 180	116.14 A	183.57 A	85.62 A	122.74 A	120.22 (29.5-1314.2)
PCB TEQs	36.27 A	75.91 A	41.30 A	53.10 A	47.81 (14.81-244.84)

Note: [shaded box] Reach with highest concentration; NC = Not calculated, contaminant detected in < 50% of eggs, ND = Not Detected.

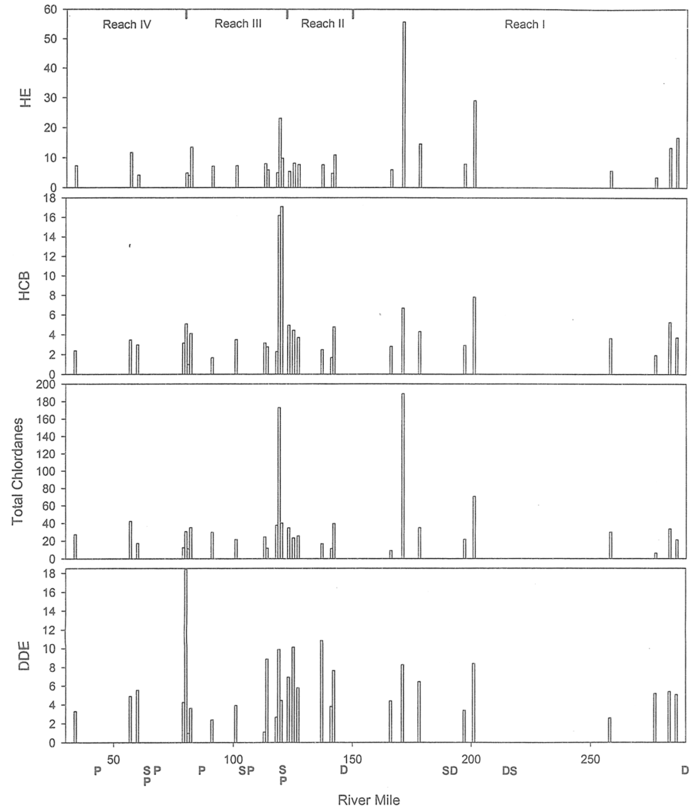
[a] Organochlorine contaminants (µg kg^{-1} wet weight), mercury (µg g^{-1} dry weight), PCBs (µg kg^{-1} wet weight, except 77, 81, 126 and 169 ng kg^{-1} wet weight) and TEQ (ng kg^{-1}).

[b] Values in rows sharing the same letter are not statistically significant. Pentachlorobenzene (0.3 to 2.0 µg kg^{-1}) detected in 9 eggs: 2 in Reach I, 1 in II, 4 in III and 2 in IV. Octachlorostyrene (0.6 to 1.0 µg kg^{-1}) detected in 3 eggs: 1 in Reach II and 2 in IV. Lindane (0.1 to 0.2 µg kg^{-1}) was detected in 4 eggs: 1 in Reach I, 1 in II and 2 in III.

[c] Total chlordanes = sum of *trans*-nonachlor, *cis*-nonachlor, oxychlordane, *trans*-chlordane, *cis*-chlordane.

[d] Sum 42 congeners.

Figure 2. DDE, total chlordanes, HCB, and HE concentrations in Osprey eggs collected along the Columbia River in 1997 and 1998. DDE expressed as µg g^{-1} wet weight, while other OCs expressed as µg kg^{-1} wet weight. The letters below the river mile scale represent dams (D), pulp and paper mills (P), and smelters (S).



Mean PCDD concentrations showed no consistent pattern among the four river reaches, though OCDD, which is not as toxic as other PCDDs, was significantly higher in Reach III near the Portland/Vancouver urban area than in Reach IV further downstream (Table 4). Of the 15 PCDD/PCDF congeners analysed, only 6 PCDDs/PCDFs were detected in ≥ 50% of the eggs in Reach I (calculated egg means shown in Table 4), whereas the incidence was higher in Reach II (14 of 15), Reach III (9 of 15) and Reach IV (11 of 15). PCDD TEQs (ng kg^{-1}) were similar among the four reaches (9.10, 9.48, 7.53 and 9.44). PCDF concentrations and TEQs were extremely low with no significant differences among reaches (Table 4).

DDE in Columbia River Largescale Suckers

No fish were collected during our studies in 1997-1998. However, with Osprey eggs from this study containing the highest DDE concentrations in North America in recent years, we were interested in examining recent existing data on DDE concentrations in whole-body samples of fish collected from the lower Columbia River. Furthermore, with DDE concentrations significantly higher in Osprey eggs from the Columbia River than from the nearby Willamette River, a comparison of DDE concentrations in adult Largescale

Suckers (a very important species in the Osprey diet from both rivers) would be particularly important. Three substantial series of Largescale Sucker data (1990-1993) with multiple sampling stations were found. One series from 1991 was not used because of matrix and coeluting peak interferences at the laboratory (Tetra Tech 1993). Sixteen composites (usually five fish) of Largescale Suckers (mean weight of individuals 639 g) collected in August 1993 from 14 backwater sites between RM 14 and RM 124 had a mean DDE concentration of 94 µg kg^{-1} ww (range for 14 sites, 37 to 160) (Tetra Tech 1996). Another series of 24 composites (usually three fish) from eight sites (mean weight 590 g) was collected in 1990-1991 (U.S. Fish & Wildlife Service 2002). They were collected between RM 20 and RM 120, except for one site at RM 286, and contained a mean DDE concentration of 84 µg kg^{-1} ww (range for 8 sites, 27 to 125). These means (84 and 94 µg kg^{-1}), as perhaps expected, were more than double the 32 µg kg^{-1} (geo.mean 22 µg kg^{-1}) reported for Largescale Suckers (mean weight 743 g) from the Willamette River in 1993 (Henny *et al.* 2003), and undoubtedly influenced DDE concentrations in Osprey eggs from the two rivers (4872 vs. 2350 µg kg^{-1}).

Figure 3. Mercury and OCDD concentrations, and PCB and Dioxin TEQs in Osprey eggs collected along the Columbia River in 1997 and 1998. Mercury expressed as µg g^{-1} dry weight, OCDD expressed as µg kg^{-1} wet weight, while the TEQs expressed as ng kg^{-1}. Letters below the river mile scale represents dams (D), pulp and paper mills (P), and smelters (S).

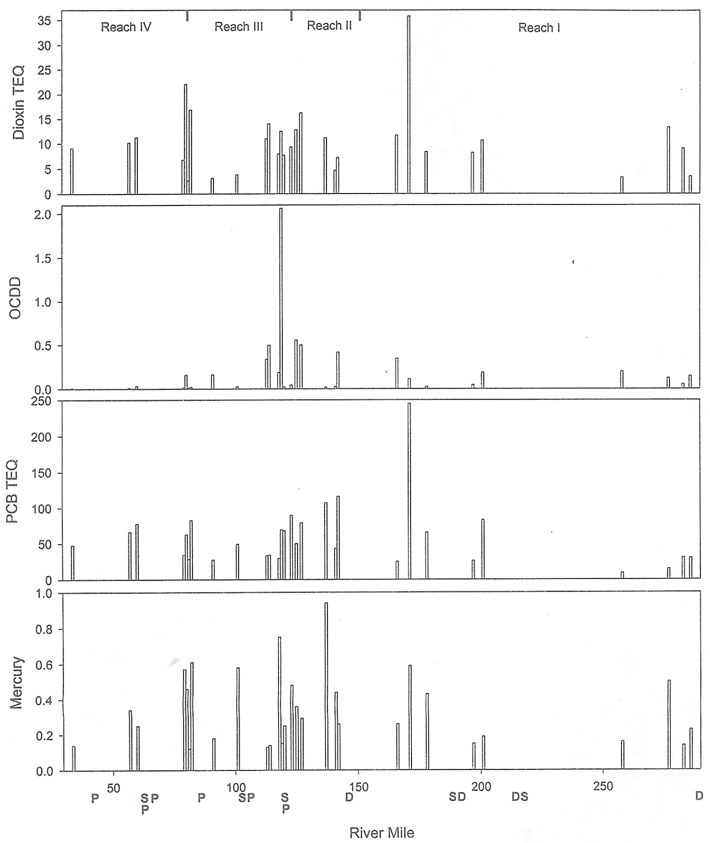


Table 4. A comparison of PCDD and PCDF concentrations in Osprey eggs by river reach from the Columbia River in 1997 and 1998.

	River Reach (geo. mean)				
Contaminant[a]	I	II	III	IV	Combined(Extremes)
N	9	6	7	7	29
2378 TCDD	5.35 A[b]	5.47 A	2.15 A	4.29 A	4.09 (ND-22.2)
Total TCDD	6.26 A	6.38 A	2.56 A	5.50 A	4.91 (ND-23.5)
12378 P_5CDD	0.59 A	1.07 A	1.96 A	2.84 A	1.30 (ND-11.1)
123478H_6CDD	NC	0.51	NC	NC	NC (ND-14.8)[c]
123678H_6CDD	NC	5.99 A	6.55 A	6.87 A	3.04 (ND-40.6)
123789H_6CDD	NC	0.73 A	1.03 A	NC	0.49 (ND-10.4)
Total H_6CDD	6.01 A	7.71 A	9.81 A	7.53 A	7.52 (ND-55.1)
1234678H_7CDD	26.44 A	14.37 A	25.01 A	6.43 A	16.35 (1.9-150.6)
Total H_7CDD	34.66 A	14.59 A	25.95 A	6.46 A	18.01 (1.9-150.6)
OCDD	104.30 AB	112.23 AB	178.11 A	17.86 B	78.70 (5.6-2062.6)
PCDD TEQs	9.10 A	9.48 A	7.53 A	9.44 A	8.85 (2.59-35.82)
2378 TCDF	0.80 A	1.62 A	1.36 A	0.56 A	0.96 (ND-10.3)
Total TCDF	1.86 A	2.73 A	1.86 A	0.70 A	1.59 (ND-18.0)
23478P_5CDF	NC	NC	NC	0.92	NC (ND-6.1)[c]
Total P_5CDF	7.21 A	1.83 A	0.46 A	1.30 A	1.85 (ND-131.1)
123478H_6CDF	NC	0.34 A	NC	0.34 A	0.20 (ND-3.8)
234678H_6CDF	NC	0.18	NC	0.18	NC (ND-1.7)[c]
123678H_6CDF	NC	0.23	NC	0.24	NC (ND-2.5)[c]
Total H_6CDF	1.27 A	1.82 A	0.43 A	1.49 A	1.09 (ND-30.6)
1234678H_7CDF	NC	0.89 A	0.53 A	NC	0.36 (ND-16.0)
1234789H_7CDF	NC	0.15	NC	NC	NC (ND-0.9)[c]
Total H_7CDF	0.31 A	1.42 A	0.91 A	0.48 A	0.61 (ND-17.0)
OCDF	0.17 A	0.26 A	0.31 A	0.26 A	0.24 (ND-13.0)
PCDF TEQs	0.18 A	0.60 A	0.25 A	0.36 A	0.29 (0.0-1.19)
Combined TEQs[d]	45.55 A	85.99 A	49.08 A	62.90 A	56.95 (12.47-281.53)

Note: [shaded box] Reach with highest concentration; NC = Not calculated, contaminant detected in < 50% of eggs, ND = Not Detected.
[a] Concentrations ng kg^{-1} wet weight.
[b] Values in rows sharing the same letter are not statistically significant.
[c] No statistical tests conducted when combined concentration was NC.
[d] Includes PCBs, PCDDs and PCDFs.

Contaminant Effects on Osprey Productivity

Of particular interest are our DDE findings in relation to its well-documented effects on avian reproduction and egg-shell thinning. Wiemeyer *et al.* (1988)

reported that 15 and 20% shell thinning of Osprey eggs was associated with 4200 and 8700 µg kg^{-1} DDE, respectively. However, no direct information was available on Osprey productivity related to the DDE concentrations, although Lincer (1975) noted that not one North American raptor population exhibiting ≥18% eggshell thinning has been able to maintain a stable self-perpetuating population. Therefore, mean DDE concentrations in eggs somewhere between 4200 and 8700 µg kg^{-1} would be expected to result in a declining Osprey population. Mean DDE concentrations in Osprey eggs from the Columbia River study area were within, but at the lower end of, this range (geo. mean 4872 µg kg^{-1}) (Table 3). We chose 8000 µg kg^{-1} as a DDE concentration of special concern to evaluate Osprey nest success along the Columbia River in 1997-1998 and the Willamette River in 1993. Only one of 10 (10%) eggs from the Willamette River contained > 8000 µg kg^{-1} DDE and the nest failed (Henny *et al.* 2003). Two eggs of nine in the Columbia River in Reach I, 2 of 6 in Reach II, 2 of 7 in Reach III, and 1 of 7 in Reach IV were above 8000 µg kg^{-1} (7 of 29; 24%). The seven nests from the Columbia River that contained eggs with > 8000 µg kg^{-1} DDE produced only eight young (1.14 young/active nest); one nest that failed contained a smashed egg. In contrast, the 10 nests with < 4200 µg kg^{-1} DDE in eggs produced 17 young (1.70 young/active nest), which is excellent for Ospreys. The 11 nests with intermediate concentrations of DDE in eggs (4200-8000 µg kg^{-1}) produced at a rate (1.18 young/active nest) similar to those with high DDE concentrations. We repeated this analysis with the addition of the 10 nests with an egg collected in 1993 from the Willamette River (Henny & Kaiser 1996) to better understand the relationship between DDE and productivity. The productivity values did not change appreciably with the addition of these 10 nests (Table 5), but recognize that one egg was collected and analysed from each of these nests. Eggshell thinning associated with the three DDE categories was 3.4%, 12.7% and 17.0%. Furthermore, eggshell thickness followed the classic semi-logarithmic DDE response (Fig. 4). Eggshell thickness for the 29 eggs from the Columbia River in 1997-1998 was 0.446 mm (-11.7%), compared to 0.494 mm (-2.2%) for the 10 eggs collected from the Willamette River in 1993.

Limited Osprey information was collected prior to this study from the lower Columbia River. One of three Osprey eggs (33%) collected in 1983 (Henny & Anthony 1989) and two of six eggs (33%) collected in 1995 and 1996 (Elliott *et al.* 2000) contained > 8000 µg kg^{-1} ww DDE with the highest concentration at 22,900 µg kg^{-1}. The highest DDE concentration found during this study (1997-1998) was slightly lower (18,377 µg kg^{-1}) and 24 % of the eggs sampled contained DDE > 8000 µg kg^{-1}. Lower production rates than in 1997 (1.45 young/occupied nest) and 1998 (1.61 young/occupied nest) (Tables 1 and 2) were recorded from a small series of nests (without an egg collected) studied in 1995 (Reaches II, III and IV only) (1.25 young/occupied nest, N = 12) and in 1996 (the same reaches) (1.20 young/occupied nest, N = 45 or 1.32 young/active nest N = 41). Farther upstream, on the Columbia River in southern Canada and northeastern Washington in more recent years, DDE concentrations in Osprey eggs collected in 1991, 1992, 1993 and 1997 were lower than found during our study with annual geometric means (N = 4 to 9 eggs) of 1820, 1780, 3770 and 1100 µg kg^{-1}, respectively (Elliott *et al.* 2000). Eleven eggs randomly collected in 1972 and 1973 in nearby Idaho contained much more DDE (geo. mean 7400 µg kg^{-1}) with six eggs (55%) containing > 8000 µg kg^{-1} (Johnson *et al.* 1975). Four of the six nests in Idaho failed, including the three nests with the highest DDE concentrations (12,000, 14,000 and 15,000 µg kg^{-1}); only 0.73 young/active nest were produced.

Table 5. Number of young Ospreys produced per nest (with one egg collected) in relation to DDE concentrations in the sample egg collected, and eggshell thickness.

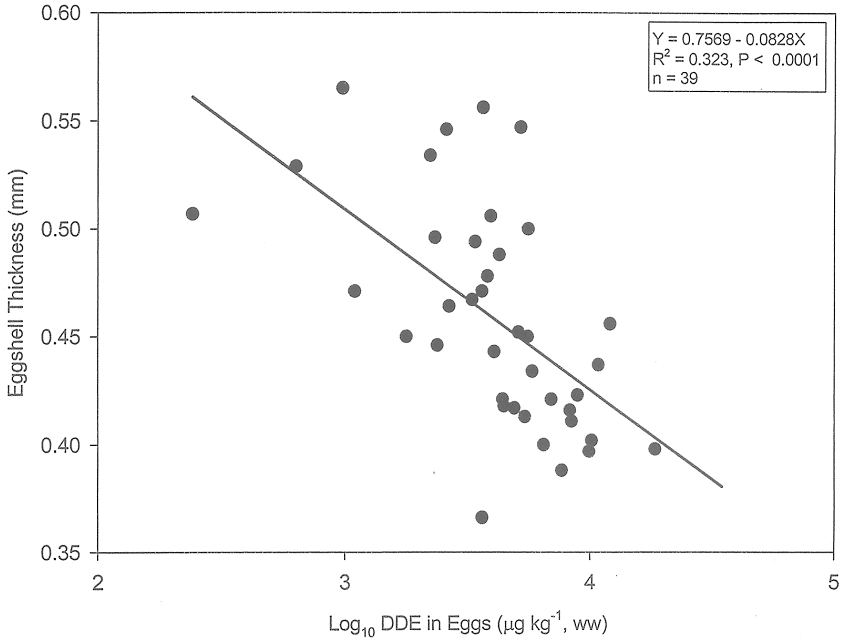
	Number of Nests with DDE (µg kg^{-1})		
Number of Young	< 4200	4200-8000	> 8000
0	1	3	3
1	6	3	2
2	10	6	3
3	1	0	0
Active Nests	18	12	8
Successful Nests	17	9	5
Adv. Young	29	15	8
Young/Successful Nest	1.71	1.67	1.60
Young/Active Nest	1.61	1.25	1.00
Geo. Mean DDE (µg kg^{-1})	2131	5473	10510
Mean Shell Thickness (mm)	0.488	0.441	0.419
Shell Thinning[a]	-3.4%	-12.7%	-17.0%

Note: One nest sampled did not have complete information for productivity (it was excluded), and 10 nests were included from the Willamette River in 1993 (Henny and Kaiser 1996).

[a] Compared to 0.505 mm for pre-DDT era eggshells from eastern U.S.A. (Anderson and Hickey 1972).

Other OCs in Osprey eggs from our study area were extremely low, and mercury (reported as dw) was considerably below the known effect concentration (0.80 µg g^{-1} ww: Heinz 1979; Newton & Haas 1988) in all eggs. TEQs for PCBs, PCDDs and PCDFs combined were below the no-observable-adverse-effect for the hatching of Osprey eggs (136 ng kg^{-1} ww) suggested by Woodward *et al.* (1998) and supported by Elliott *et al.* (2001), except for one egg at RM 171 in 1998 (282 ng kg^{-1}) which produced one young. However, this egg also contained 8283 µg kg^{-1} of DDE. The rate of population change (+9.6%) between 1997 and 1998 was not influenced by the production rates observed in 1997 and 1998, but by recruits produced in 1995 or earlier (most Ospreys begin breeding as three- year-olds [Poole *et al.* 2002]). The production rates in 1995 and 1996 were higher than the generally accepted 0.80 young/active nest required to maintain a stable population, but lower than reported in 1997 and 1998 (Tables 1 and 2). Thus, based upon the higher production rates in 1997 and 1998, the Osprey population increase along the Columbia River in the future may be more rapid, at least until nest sites or other factors become limiting.

Figure 4. Significant negative relationship between shell thickness and log DDE concentration in eggs of Ospreys collected from the Columbia River (1997-1998) and the Willamette River (1993).



CONCLUSIONS

Ospreys were chosen because contaminant concentrations from fish consumed are biomagnified in their eggs (Henny *et al.* 2003), thus, many contaminants found at low concentrations or not detected in water or fish were consistently detected in Osprey eggs. We anticipated that residue patterns may emerge in Osprey eggs in relation to RM (from upper to lower river) and known point sources of specific contaminants. The fairly uniform distribution of Ospreys nesting along the 410km study area of the lower Columbia River permitted an overall evaluation of contaminant concentrations in eggs and their effects, as well as an evaluation of spatial patterns that could be used for detecting unknown contaminant sources. Residue data were presented spatially for individual eggs and issues that may confound the interpretation of residues in individual Osprey eggs were discussed. Therefore, general spatial patterns or means for river reaches, as opposed to individual egg concentrations, were of most interest.

Eggs from the Osprey population nesting along the lower Columbia River in 1997-1998 still have the highest DDE concentrations reported in North America during the late 1980s or 1990s (see Steidl *et al.* 1991; Audet *et al.* 1992; Woodford *et al.* 1998; Ewins *et al.* 1999; Clark *et al.* 2001; Martin *et al.* 2003), and correspondingly high DDE concentrations were found in a key fish species in their diet, the Largescale Sucker. However, the observed productivity in 1997-1998 was above that believed necessary to maintain a stable population. An observed population increase between 1997 and 1998 supports this assumption. Yet data presented showed that DDE negatively influenced eggshell thickness and productivity at some nests. The parent-material (DDT) in the egg with 18777 µg kg^{-1} was extremely low (2.3 µg kg^{-1}), which strongly suggests that the DDE source was not recently applied DDT (Henny *et al.* 1982). The other contaminants found in the eggs, except for one egg with a high TEQ from PCBs and PCDDs, appear to be below any known effect levels for Ospreys.

Additional fish collections and Osprey egg collections, with the specific purpose of further studying fish--Osprey egg contaminant relationships, were conducted on the Willamette River in 2001 and will be the subject of a future report. In that Willamette study, 30 pools of fish (two species) were collected in five reaches of the river (at three sites within each reach) and 25 Osprey eggs (five eggs in each reach) were collected. A better understanding of the relationships between fish and Osprey egg contaminant concentrations via biomagnification should result. We will also evaluate the relationships between the biomarker H4IIE and selected egg residue concentrations, which could result in reducing analytical chemistry costs. However, we believe the basic Osprey population data, egg residue data and productivity data collected along the lower Columbia River in 1997 and 1998 provide a basis for evaluating future changes in contaminants and their effects, and future changes in Osprey population numbers.

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