SATELLITE TELEMETRY AND PREY SAMPLING REVEAL CONTAMINANT SOURCES TO PACIFIC NORTHWEST OSPREYS

John E. Elliott,[1,5] Christy A. Morrissey,[1] Charles J. Henny,[2] Ernesto Ruelas Inzunza,[3] and Patrick Shaw[4]

[1]*Environment Canada, Science and Technology Branch, Pacific Wildlife Research Centre,*
5421 Robertson Road RR# 1, Delta, British Columbia V4K 3N2 Canada
[2]*United Sates Geological Survey, Forest and Rangeland Ecosystem Science Center,*
3200 SW Jefferson Way, Corvallis, Oregon 97331 USA
[3]*Pronatura Veracruz, Antonio Ma. de Rivera 12-2, Xalapa, Veracruz 91000 Mexico*
[4]*Environment Canada, Science and Technology Branch, 201–401 Burrard Street, Vancouver, British Columbia V6C 3S5 Canada*

Abstract. Migratory behavior can be an important factor in determining contaminant exposure in avian populations. Accumulation of organochlorine (OC) pesticides while birds are wintering in tropical regions has been cited often as the reason for high concentrations in migrant populations. To explore this issue, we satellite tracked 16 Ospreys (*Pandion haliaetus*) over the period 1996–2003 from breeding sites in British Columbia, Canada, and integrated the results into a database on 15 Ospreys that were satellite tracked over the period 1995–1999, from breeding locations in Washington and Oregon, USA. Data on wintering sites of 31 Ospreys in Mexico and Central America were used for spatially targeted sampling of prey fish. Concentrations of the main organochlorine contaminant, p,p'-dichloro-diphenyl-dichloroethylene (DDE), in fish composites from Mexico ranged from 0.005 to 0.115 µg/g wet mass. Significant differences existed among fish families in p,p'-DDE, total dichloro-diphenyl-trichloroethane (ΣDDT), Σchlordanes, and total polychlorinated biphenyls (ΣPCBs). Catfish (family *Ariidae*) generally had significantly higher levels of DDT metabolites and other organochlorine contaminants compared to other fish families collected. Differences in prey contaminant levels were detected among the collection sites around coastal Mexico, with fish from Veracruz State generally having higher levels of DDT metabolites, Σchlordanes, ΣPCBs, and hexachlorobenzene. Eggs collected from 16 nests throughout the Pacific Northwest (nine from British Columbia, seven from Oregon and Washington) where Ospreys had been satellite tagged, showed marked variation in levels of DDT metabolites (p,p'-DDE; range 0.02–10.14 µg/g). Wintering site had no significant effect on contaminant concentrations in sample eggs from those specific Ospreys; rather concentrations of p,p'-DDE, were predicted by breeding sites with highest levels in eggs of Ospreys breeding in the lower Columbia River, consistent with published reports of continued high concentrations of DDT and related compounds in that system.

Key words: DDT; Mexico; migration; Osprey; Pandion haliaetus; persistent organic pollutants; satellite telemetry.

INTRODUCTION

Since the 1970s, use of DDT (dichloro-diphenyl-trichloroethane) has been severely restricted, except in some tropical regions where DDT may still be applied for control of malaria and other insect born diseases (Walker et al. 2003). However, concerns continue over unsanctioned uses of DDT and residual contamination of food chains (Carvalho et al. 2002), including the associated impact of metabolites on wildlife (Lacher and Goldstein 1997). Among the biota most heavily impacted by early indiscriminate use of DDT and other persistent organic pollutants (POPs) were top avian predators, particularly birds of prey (Newton 1979). The Osprey (*Pandion*

haliaetus), an obligate piscivore, accumulated high concentrations of POPs from its aquatic food chain, and populations declined significantly during the 1950s to 1970s. Following restrictions on use of many POPs, contamination of Ospreys decreased and populations largely recovered (Houghton and Rymon 1997). However, 25% of individual Osprey eggs collected during the 1990s from widespread areas of the Pacific Northwest continued to have concentrations of the metabolite, DDE (dichloro-diphenyl-dichloroethylene), greater than the critical reproductive threshold of 4.2 mg/kg (Wiemeyer et al. 1988, Elliott et al. 2000). Henny et al. (2004) reported that DDE continued to thin eggshells and affect productivity of Pacific Northwest Ospreys. In the case of the Osprey and many other North American migrants which winter in Latin America, ongoing exposure to significant DDT-related compounds (r-DDT) has often been attributed to exposure on wintering sites, either from historic or continued use of organochlorine

insecticides in the south, especially in earlier years (Henny et al. 1982, Springer et al. 1984, DeWeese et al. 1986, Elliott and Shutt 1993, Elliott et al. 2000).

During the last decade, satellite transmitters have enhanced the capability to define avian migration routes for several large bird species, including Ospreys (Hake et al. 2001, Kjellen et al. 2001, Martell et al. 2001, Meyburg et al. 2001). Satellite telemetry provides detailed records of departure and arrival dates, as well as breeding and wintering locations over large geographic areas. Data on specific wintering locations and contaminant residues for individual migratory birds is potentially useful for discriminating among relative contaminant sources and detailing spatial variation.

In this study, we report on autumn migration routes, breeding and wintering sites of western North American Ospreys, and residue levels in common fish prey on the wintering grounds in Mexico. Furthermore, using a subset of satellite tagged birds for which we had a sample egg and knew its winter location, we attempted to relate ratios of DDE:DDT in eggs to their known breeding and wintering locations to try and isolate the principal source of contaminant exposure from either the northern breeding or southern wintering areas.

Methods

Sampling design for Osprey

From 1996 to 1999, six breeding Ospreys were selected opportunistically for satellite tagging, thus sampling was effectively random as regards contaminants exposure. From 2000 to 2003 we focused on sampling a single egg from two to 10 Osprey nests at several study sites located at higher altitudes or in drainages receiving mainly alpine runoff, to meet requirements of a companion study (J. E. Elliott, *unpublished data*). Those eggs were shipped immediately to the laboratory and analyzed for contaminants within a one month period. We theorized that determination of DDT hotspots on the wintering grounds would be done most effectively by targeting Ospreys for satellite tagging based on the degree of exposure. That design proved unsuccessful, however, as (1) unlike data from the early 1990s (Elliott et al. 2000) only a few eggs ($N = 72$, years 2000–2003) had DDE > 5 μg/g wet mass, and (2) whether by chance or due to contaminant effects at the putative threshold, all nests with eggs containing relatively high DDE (3.5–5.0 μg/g wet mass) failed after egg laying. We resorted, therefore, to opportunistic selection of adults for capture and tagging, based primarily on trapping convenience. In total, we have data from 16 Osprey nests, where an egg was collected and an Osprey was satellite tracked, nine from nests in British Columbia and seven from Washington/Oregon. Egg collection methods were described previously (Elliott et al. 2000, Henny et al. 2004).

Osprey capture and telemetry

From 1996 to 2003, we trapped 18 (17 female, one male) adult Osprey at their nests in British Columbia,

Canada. Body mass is a reliable method for sexing Ospreys as females are known to be larger than males (Poole 1989). Birds were captured using previously published methods with either a domed noose carpet (bal-chatri) placed over the active nest or modified dho-ghaza mist nets, with a tethered Great-horned Owl (*Bubo virginianus*) as a lure (Bloom 1987). Each bird was weighed, measured, and banded with a U.S. Fish and Wildlife Service band on one leg and a red alphanumeric band on the other leg. A small satellite transmitter (platform transmitter terminal; Microwave Telemetry, Columbia, Maryland, USA) weighing 30–35 g was fitted between the scapulas using a standard backpack style with a Teflon ribbon harness (Kenward 1987). Satellite locations of Ospreys were received using NOAA satellites operated by Service Argos, Inc. (Landover, Maryland, USA). Latitude and longitude locations were reported by Argos along with date, time, and location accuracy intervals. Transmitters were programmed to turn on and off for varying periods during the annual cycle to conserve power. Typical cycles for battery-powered units were programmed to transmit for six to eight hours and turn off for 24 to 98 hours during migration or remain off for longer (eight to 11 days) during the breeding and wintering period. Solar powered units were programmed to turn on for 10 hours and turn off for 24–26 hours. Additional data on satellite-tagged Ospreys ($n = 7$) trapped by the U.S. Geological Survey at nest sites along the Willamette and Columbia Rivers in Oregon and Washington State were also included in the analysis of wintering locations and egg DDE:DDT residues to improve the sample size. We assumed that the Washington and Oregon birds are part of the meta-population of Ospreys breeding throughout the Pacific Northwest region that likely share similar migratory routes and wintering locations.

Fish collection

Fish samples were collected opportunistically during 2000–2002 in five different Mexican states: eight sites in southeastern Gulf of Mexico states of Veracruz and Tabasco, two sites in southeastern Oaxaca, and five sites in northwestern states of Jalisco and Nayarit (Fig. 1). We collected qualitative data on Osprey prey choice during opportunistic feeding observations at a number of those sites. By working with local biologists, subsistence fisherman, and small commercial fishing operations, we collected several fish species that are potential prey of Osprey, including mojarra (*Gerridae* spp.), catfish (*Arius* spp., *Rhamdia* spp.), guavina (*Gobiomurus dormitor*), mackerel (*Scomberomorus sierra*), mullet (*Mugil* spp.), snook (*Centropomidae* spp.), surgeonfish (*Acanthuridae* spp.), and tilapia (*Cichlasoma uropthalmus*, *Oreochromis niloticus*). Every attempt was made to collect fish from areas where satellite-tagged Ospreys were wintering or from known Osprey winter-ing sites in Mexico including the Laguna de Alvarado in Veracruz State, Villahermosa in Tabasco State, Barra de
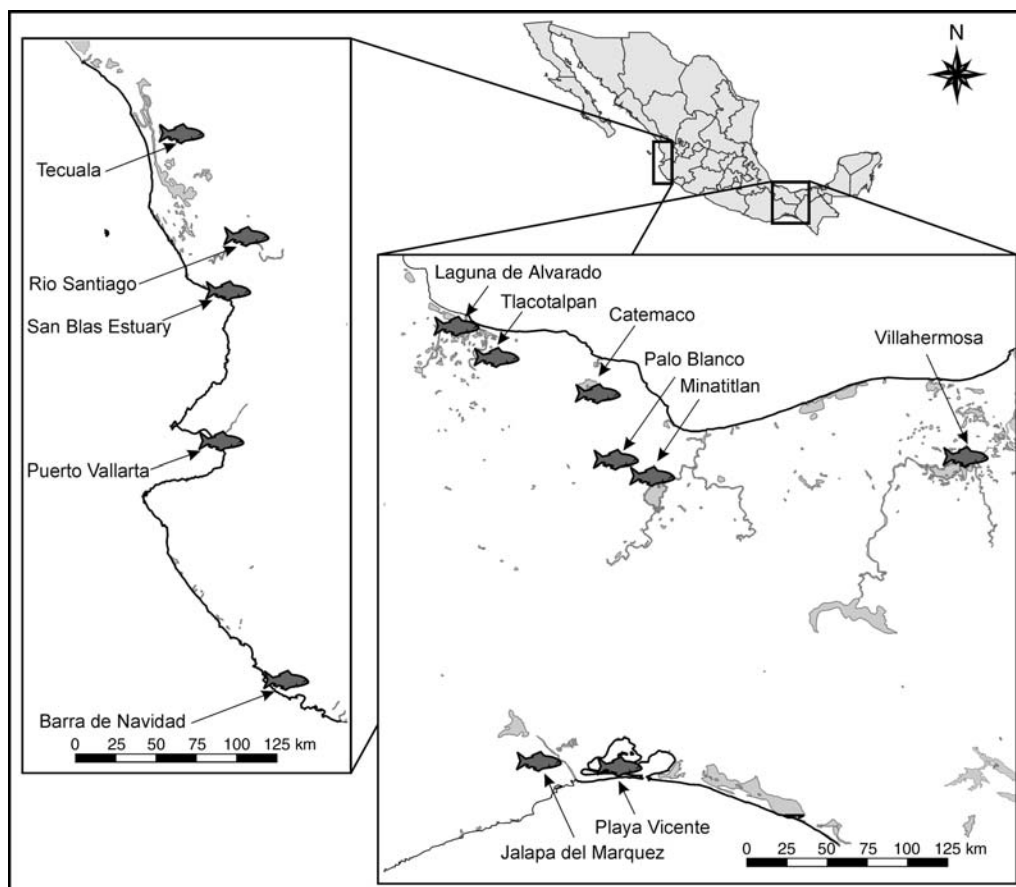
Fɪɢ. 1. Map of Mexico showing collection areas for fish samples on the Pacific and the southeastern coasts of Mexico. Samples were collected in 2000–2002.

Navidad in Jalisco State, and the San Blas estuary in Nayarit State. In order to obtain a sample over a larger geographic area, several other samples were collected from small commercial fisherman at dockside or in local markets in other Mexican states. A minimum of three to five individual fish of the same species at each site was used to make up a single composite pool. All samples were labeled and stored in polyethylene bags on ice until frozen locally. Frozen samples were shipped by air back to Canada and stored at −20°C at the Pacific Wildlife Research Centre, Delta, British Columbia, Canada.

Fish sample preparation and chemical analysis

Fish samples were each partially thawed, weighed, measured, and dissected at the Pacific Environmental Science Centre (PESC) in North Vancouver, British Columbia, Canada to separate the muscle fillets from the remaining carcass. Otoliths were removed for age determination. Muscle fillets and composite samples of the remaining carcasses were weighed and analyzed separately according to previously established protocols in order to assess risk to human consumers of only muscle tissue as well as wildlife that consume whole carcasses. Since Ospreys are generally consuming whole

fish, we report only the contaminant concentrations for calculated composites of whole body fish. Dissected fish samples were refrozen at −25°C until shipping on dry ice to the National Wildlife Research Centre (Ottawa, Ontario), where they were homogenized in a stainless steel blender, and refrozen at −40°C until shipment to the Great Lakes Institute for Environmental Research (GLIER), Windsor, Ontario, Canada.

Organochlorine pesticides and PCBs were analyzed at GLIER using gas chromatography with a mass specific detector (GC-MSD). Tissue samples were first homogenized, and then an aliquot of 2–5 g of the homogenate was further ground with anhydrous sodium sulfate to a free-flowing powder. This was layered on a column stopped with glass wool, a 50-mL solution of 50:50 dichloromethane (DCM):hexane, and a surrogate standard. After one hour, the sample was eluted with another 250-mL solution of 50:50 DCM:hexane. The eluate was rotoevaporated to a final volume of 2 mL, transferred to hexane, and the total volume made up to 25 mL. For lipid determination, 2 mL of this extract was removed to a pre-weighed beaker, and dried at 105°C. The remaining extract was concentrated to 2 mL by rotoevaporation. Moisture content was determined by

loss of weight on drying a 1 g aliquot at 125°C for 24 hours.

Samples having lipid content >10% were cleaned up on a BioBeads, S-X3 (Biorad) column eluted with a 50:50 solution of DCM:hexane. The sample extract was further cleaned up on a florisil column eluted first with 50 mL hexane (fraction 1, containing CBs, some Ocs, and PCBs), then with a 50-mL solution of 15:85 DCM:hexane (fraction 2, containing OCs and non-ortho PCBs) followed by a 100-mL solution of 60:40 DCM:hexane (fraction 3; containing heptachlor epoxide and dieldrin). To each fraction was added 5 mL isooctane before rotoevaporation to 2 mL final volume.

Analyses were conducted in batches containing one method blank (isooctane), one control sample (reference material), and five unknown samples. The three florisil fractions were run on a Hewlett Packard model 5890 Series II Plus gas chromatograph with 63Ni-ECD detector, HP-3396 integrator, HP-7673A autosampler with separation on a 60 m × 0.25 mm inner diameter × 0.25 μm DB-5 film thickness (Hewlett Packard, Palo Alto, California, USA). Samples were identified if peaks matched calibration standard times with a retention window of ±0.04 minutes. Compounds were quantified by comparing sample peak areas against matching calibration standard solutions. The complete suite of analytes included 40 non-ortho PCB congeners, aro-chlors, and a total of 26 organochlorine pesticides and metabolites. Total PCB (ΣPCB) concentrations are reported as the sum of all 40 congener peaks. Instrument detection limits for all compounds were approximately 0.05 ng/g wet mass.

Data analysis

Data on bird locations were reviewed and entered into databases then plotted on maps using the ArcView GIS System (Environmental Systems Research Institute, Inc., Redlands, California, USA). If multiple locations for a single individual were reported in one day, we used the most accurate reading for that transmission period (as given by Argos) to plot migration routes. The departure and arrival dates were calculated from the best median estimates for transmission periods of the last day on the breeding site and the first date of migration or the last day of migration and the first day on a consistent winter site. Total migration time was then estimated as the number of days between departure and arrival.

Concentrations of contaminants in whole body fish composites were calculated as ([muscle mass × muscle concentration] + [composite carcass mass × composite carcass concentration])/(sum of fish masses). For samples collected in 2002 ($n = 8$ pools), individual muscle fillets were not analyzed with the remaining carcasses. Therefore, we used linear regression equations for each contaminant to predict the whole body composite concentrations given only data from the carcasses. Levels of several OCs were often at or below detection

limits, so we only report total chlordanes (Σchlordanes) (sum of trans- and cis- nonachlor, trans- and cis-chlordane and oxychlordane), total hexachlorocyclohexanes (ΣHCH; sum of α-HCH, β-HCH, γ-HCH), and total mirex (Σmirex; sum of mirex and photomirex). In order to permit statistical comparisons, a value of one-half the detection limit (0.025 ng/g) was assigned to the totals that were still below detection. If less than 50% of samples contained no detectable residues, no statistical tests were performed. Contaminant concentrations (fish and Osprey eggs) were log-transformed to improve normality (Shapiro Wilk W test). A two-way ANOVA was used to analyze for differences in contaminant concentrations among fish samples collected by location (state) and by family (common name). An interaction term could not be entered into the model since sampling of fish families and locations were related and sample sizes were small thus biasing the statistical scope of the test. We report back transformed least-square (LS) means and standard errors (SE) for contaminant residues in fish to account for interactive effect of location on fish families and vice versa. Geometric means are also provided for fish by family and by location. Pearson product moment correlations (r) were also used to test for correlations between contaminant residues in fish and latitude of collection location (degrees and minutes). A two-way ANOVA, incorporating breeding (British Columbia sites, Willamette basin, and Columbia basin) and wintering (Mexico, United States, Central/South America) locations of individual Ospreys, was used to identify the best predictor of DDT residues in eggs. Reasonably low contaminant variability existed among the British Columbia egg samples collected from a large geographic region (coefficient of variation = 0.25), prompting us to group them as one area. Again, an interaction term could not be entered into the model since sample sizes were small thus biasing the statistical scope of the ANOVA. A Tukey multiple comparison procedure was used to separate means, and differences were considered significant when $P < 0.05$. All egg values are reported as back transformed LS means and SE to account for the interactive effects in addition to geometric means (in μg/g wet mass).

RESULTS

Osprey migration and wintering locations

Of the 18 transmitters deployed, 16 Ospreys were successfully tracked throughout the first fall migration to their wintering site. The remaining two transmitters failed prior to the initiation of migration. Satellite-tagged Ospreys breeding in British Columbia typically departed for migration in late August or early September in all years of the study 1996–1997, 1999–2001, and 2003 (Table 1). The migration period lasted from 12–39 days (21.7 ± 8.5 days [mean ± SD]). In total, nine (56%) of the satellite-tagged Osprey wintered in Mexico, four (25%) wintered in Central and South America (Nicara-

TABLE 1. Summary of satellite-telemetry information for 16 Ospreys tagged in British Columbia, Canada, on their breeding grounds and successfully tracked through the southward migration to their wintering sites.

Satellite ID	Sex	Year	Breeding dates	Breeding location	Migration dates	Migration time (d)	Wintering location Nearest city	Wintering location State and country
96-22909	F	1996	27 Jun–23 Aug	Creston	23 Aug–8 Sep	17	Tampico	Tamaulipas, Mexico
96-22910	F	1996	27 Jun–10 Sep	Creston	10 Sep–10 Oct	31	Cosammaloapan	Veracruz, Mexico
96-24549	F	1996	27 Jun–21 Aug	Creston	21 Aug–18 Sep	29	Corpus Christi	Texas, USA
97-24549	F	1997	10 Jul–31 Aug	Nelson	31 Aug–11 Sep	12	Alvarado	Veracruz, Mexico
99-22909	F	1999	13 Jul–21 Aug	Penticton	21 Aug–28 Sep	39	David	Chiriqui, Panama
99-22910	F	1999	14 Jul–2 Sep	Oliver	2 Sep–13 Sep	12	Corpus Christi	Texas, USA
00-24486†	F	2000	10 Jul–9 Sep	Golden	9 Sep–20 Sep	12	Culiacan	Sinaloa, Mexico
00-24488†	F	2000	19 Jul–15 Sep	Nakusp	15 Sep–11 Oct	27	Maracaibo	Zulia, Venezuela
00-24549	F	2000	30 Jun–6 Sep	Pitt River	6 Sep–29 Sep	24	Mazatlan	Durango, Mexico
01-04008	F	2001	16 Jul–3 Sep	Atlin Lake	3 Sep–29 Oct‡	57‡	San Andres Tuxtla	Veracruz, Mexico
01-22910	M	2001	15 Jul–26 Sep	Atlin Lake	26 Sep–25 Oct	30	Acapulco	Oaxaca, Mexico
01-24487	F	2001	5 Jul–4 Sep	Upper Arrow Lake	4 Sep–25 Sep	22	Murciélago	Guanacaste, Costa Rica
01-24489	F	2001	21 Jul–12 Sep	Ootsa Lake	12 Sep–6 Oct	25	Chinanadega	Chinandega, Nicaragua
03-24486†	F	2003	15 Jul–11 Sep	Ashcroft	12 Sep–24 Sep	13	Culiacan	Sinaloa, Mexico
03-06234†	F	2003	24 Jun–31 Aug	Nicola Lake	31 Aug–13 Sep	14	Houston	Texas, USA
03-06235	F	2003	24 Jun–26 Aug	Nicola Lake	28 Aug–15 Sep	19	San Blas	Nayarit, Mexico

† Individual Ospreys tracked for two consecutive years to the same breeding and wintering location.

‡ Poor estimate for arrival date on the winter grounds and migration time. The satellite transmitter did not transmit at regular intervals during fall migration.

gua, Costa Rica, Panama, and Venezuela), and three (19%) wintered in eastern Texas, USA (Table 1).

Southward migration to the winter sites typically followed two main routes, although there was no clear pattern with respect to specific breeding origin in British Columbia. Several Ospreys (seven out of 16) followed the continental divide passing through the western United States and wintered along the Gulf of Mexico including Texas and eastern Mexico. Others (five out of 16) followed similar paths south, but remained further west to winter along the Pacific Coast of Mexico. Following similar early migration routes, four Ospreys flew greater distances south, extending their migration to destinations in Central or South America. Four individuals retained their working transmitters over a second migration period and were found breeding and wintering in the same locations between years. Satellite-tagged Ospreys originating from Washington and Oregon similarly wintered primarily in Mexico (87%) and Central America (13%) (Martell et al. 2001).

Contaminants in fish from Mexican wintering areas

During 2000–2002, we collected and analyzed eight families of common prey fish from five states in Mexico. The most commonly detected organochlorine contaminants were p,p'-DDE (100%), p,p'-DDT (100%), p,p'-DDD (100%), PCBs (92%), trans-nonachor (83%), hexachlorobenzene (HCB; 67%), dieldrin (67%), lindane (g-HCH; 58%), cis-chlordane (58%), and cis-nonachlor (50%; see Appendix). Contaminant concentrations differed significantly by family for p,p'-DDE ($F_{7,23}$ = 7.61, P = 0.001), ΣDDT ($F_{7,23}$ = 6.05, P = 0.003), Σchlordanes ($F_{7,23}$ = 7.04, P = 0.002), and ΣPCBs ($F_{7,23}$ = 3.82, P = 0.02). Catfish had significantly higher ΣDDT and p,p'-DDE levels than several other fish species including guavina, mullet, and tilapia (Table 2). Average ratios of DDE:DDT were also higher for catfish over other fish including mullet, snook and surgeonfish ($F_{7,23}$ = 4.14, P = 0.02), suggesting that catfish may have higher ΣDDT residues as a result of higher bioaccumulation rates of the more persistent DDE metabolite. ΣChlordanes (primarily in the form trans-nonachlor and cis-chlordane) were significantly elevated in catfish and surgeonfish compared to guavina and tilapia composites ($F_{7,23}$ = 7.04, P < 0.002). Individual composite samples also ranged widely in total PCBs from below detection to 20.13 ng/g. Surgeonfish, catfish, mackerel, and snook contained the highest concentrations of PCBs (Table 2). Although contaminant concentrations were often correlated with lipid content (e.g., ΣDDT; r^2 = 0.20, P = 0.03), mean lipid content was not significantly different among family groups, and thus did not explain differences observed in contaminant levels. Differences in contaminant concentrations among fish pools were likely caused by interspecific differences such as feeding habits or sampling locations.

After controlling for family related effects, differences in fish residues among collection locations (Mexican states) were apparent for all the DDT metabolites (DDE, DDD, DDT), ΣDDT (P = 0.04), Σchlordanes (P = 0.002), ΣPCBs (P = 0.002), and HCB (P = 0.03; Table 3). A trend of lower contaminant concentrations at higher latitudes (northern states) was detected for most of the OCs measured but was not significant (e.g., ΣDDT: r = −0.23, P = 0.27). Consistent with this finding, fish collected from Veracruz had significantly higher contaminant levels than other Mexican states sampled (Table 3). Significant differences also existed in DDE:DDT ratios among collection sites ($F_{4,23}$ = 4.78, P = 0.02; Table 3). In particular, Nayarit and Tabasco had

JOHN E. ELLIOTT ET AL.

TABLE 2. Mean contaminant concentrations (LS means ± SE [geometric means in parentheses] in ng/g wet mass) detected in various groups of common Osprey prey fish families collected from all five states in Mexico during 2000–2002.

Common family name	No. composite samples	Lipid (%)	p,p'-DDE	p,p'-DDD	p,p'-DDT	Total DDT
Mojarra	1	5.6	8.15	3.10	0.46	11.59
Catfish	5	9.2 ± 1.0	75.82 ± 1.31 (64.54)	8.12 ± 1.40 (9.55)	1.18 ± 1.55 (1.09)	86.09 ± 1.31 (77.51)
Guavina	2	5.2 ± 0.4	6.57 ± 1.54 (6.76)	1.98 ± 1.70 (3.41)	0.40 ± 2.01 (0.38)	9.62 ± 1.54 (10.70)
Mackerel	1	6.2	20.69	2.84	1.59	28.09
Mullet	5	5.0 ± 1.4	11.48 ± 1.32 (10.83)	2.89 ± 1.41 (2.44)	0.86 ± 1.56 (0.80)	16.05 ± 1.32 (14.73)
Snook	3	7.0 ± 2.8	24.89 ± 1.43 (21.29)	4.06 ± 1.55 (4.47)	2.05 ± 1.78 (2.02)	31.87 ± 1.43 (28.35)
Surgeonfish	1	10.6	50.37	7.60	13.54	68.85
Tilapia	6	8.5 ± 2.3	10.70 ± 1.31 (11.25)	3.43 ± 1.40 (5.58)	0.53 ± 1.56 (0.79)	15.61 ± 1.32 (17.94)

significantly higher DDE:DDT ratios than Oaxaca and Veracruz states, indicating lower degradation rates or shorter weathering time of DDT, possibly from more recent use in the Veracruz and Oaxaca states. Levels of total hexachlorocyclohexanes (ΣHCH) and dieldrin were generally low and showed no significant differences among fish families or collection locations in Mexico (Table 3).

Sources of DDT in Osprey eggs

Differences existed among individual egg DDT profiles by breeding location with the Columbia River eggs having significantly higher ΣDDT ($F_{4,11} = 3.58$, $P = 0.01$), p,p'-DDE ($F_{4,11} = 3.27$, $P = 0.02$), and p,p'-DDD ($F_{4,11} = 3.29$, $P = 0.02$) residues than eggs from the Willamette basin and all the British Columbia sites combined (Fig. 2A, B). We could not detect any effect of winter location (by country or for Mexico, by state) on individual DDT profiles despite the differences observed among locations in prey contaminant levels (Fig. 2A, B). However, DDE:DDT ratios in eggs were significantly higher for Osprey that migrated to Central/South America compared to those that wintered in Mexico and the United States ($F_{2,14} = 5.13$, $P = 0.03$; Fig. 2B). Furthermore, the Willamette eggs had considerably higher DDE:DDT ratios than eggs from the Columbia River or British Columbia sites ($F_{2,14} = 5.14$, $P = 0.03$; Fig. 2A). In summary, Ospreys breeding in the Willamette basin and Ospreys that migrated to Central or South America had higher ratios of DDE:DDT, suggesting historic weathered sources rather than recent exposure to DDT compounds, whereas Ospreys breeding in the

Columbia basin were more likely exposed to the parent compound DDT.

Discussion

The concept that migratory birds acquire OC pesticides from wintering areas of Latin America has been suggested for many years. Mexico and other Latin American countries continued to use DDT and other OC pesticides for public health and for agricultural purposes for some time after legislated restrictions were imposed in Canada and the United States. Based on pesticide sales and production estimates from the early 1990s, Mexico ranked only behind Brazil as a producer and consumer of OC pesticides among 11 Latin American countries (Albert 1996). By the late 1990s, widespread use of OC pesticides was reduced in Mexico, supported by temporal monitoring data (Waliszewski et al. 1998). Organophosphorus and carbamate insecticides have largely replaced OCs for agricultural pest control in the northern states of Mexico, but DDT was apparently applied for malaria control until at least the 1990s as far north as Sinaloa State (Mora 1997). Since 1978, DDT continued to be used legally for agricultural practices in Chiapas State in southern Mexico, but speculation of illegal use in other areas continues. Female Ospreys lay their first egg on average three weeks after returning to breeding grounds (Poole 1989), and are essentially income breeders producing eggs from locally acquired lipid and protein (Drent and Daan 1980). Much of the contaminant residues in eggs derive from breeding ground sources, as demonstrated, for example, by significant spatial differences in polychlorinated dioxins and furans in Osprey eggs collected

TABLE 3. Mean contaminant concentrations (LS means ± SE [geometric means in parentheses] in ng/g wet mass) detected in Osprey prey fish (all families) in five Mexican states during 2000–2002.

Location (Mexican state)	No. composite samples	p,p'-DDE	p,p'-DDD	p,p'-DDT	Total DDT
Jalisco	3	48.17 ± 1.59 (32.69)	3.07 ± 1.77 (2.38)	3.45 ± 2.11 (2.47)	54.21 ± 1.59 (37.76)
Nayarit	5	8.36 ± 1.36 (11.96)	1.53 ± 1.45 (1.86)	0.29 ± 1.64 (0.46)	10.59 ± 1.36 (14.66)
Oaxaca	3	14.53 ± 1.60 (22.53)	3.95 ± 1.78 (5.49)	1.93 ± 2.13 (1.26)	21.78 ± 1.60 (32.04)
Tabasco	2	16.59 ± 1.51 (15.78)	6.19 ± 1.66 (6.21)	0.54 ± 1.94 (0.28)	23.94 ± 1.51 (22.56)
Veracruz	11	21.52 ± 1.30 (20.23)	6.90 ± 1.38 (6.94)	2.39 ± 1.53 (1.66)	32.05 ± 1.30 (30.00)

TABLE 2. Extended.

DDE:DDT	Total PCBs	Total chlordanes	HCB	Dieldrin	Total HCH
17.66	0.12	0.14	0.11	0.04	0.04
64.53 ± 1.34 (59.12)	2.49 ± 1.69 (2.76)	0.43 ± 1.30 (0.38)	0.07 ± 1.86 (0.13)	0.13 ± 1.35 (0.10)	0.09 ± 1.57 (0.12)
16.49 ± 1.58 (18.01)	0.22 ± 2.31 (0.34)	0.04 ± 1.51 (0.05)	0.03 ± 2.69 (0.07)	0.05 ± 1.60 (0.04)	0.08 ± 2.06 (0.08)
13.03	1.24	0.29	0.58	0.05	0.19
13.30 ± 1.34 (13.56)	0.48 ± 1.71 (0.83)	0.16 ± 1.30 (0.19)	0.11 ± 1.88 (0.10)	0.04 ± 1.35 (0.03)	0.04 ± 1.59 (0.04)
12.16 ± 1.46 (10.52)	1.23 ± 2.00 (2.81)	0.13 ± 1.41 (0.15)	0.06 ± 2.26 (0.12)	0.10 ± 1.48 (0.07)	0.08 ± 1.81 (0.11)
3.72	3.95	0.87	0.32	0.29	0.33
20.29 ± 1.34 (14.25)	0.14 ± 1.70 (0.32)	0.07 ± 1.30 (0.09)	0.02 ± 1.87 (0.08)	0.06 ± 1.35 (0.04)	0.10 ± 1.58 (0.17)

up and down stream of pulp mills in British Columbia (Elliott et al. 1998). However, in the case of slowly metabolized compounds like DDE with half times as long as 418 days (Clark et al. 1986), the female bird would retain some of the contaminant burden acquired on the wintering grounds. Eggs are thus likely to contain a composite of DDE acquired locally and retained from wintering exposure. Other studies of migratory birds including peregrine falcons *Falco peregrinus* (Henny et al. 1982, Springer et al. 1984, DeWeese et al. 1986) sharp-shinned hawks *Accipiter striatus* (Elliott and Shutt 1993), black-crowned night herons *Nyticorax nycticorax* (Henny et al. 1984) and white-faced ibis *Plegadis chihi* (Henny and Herron 1989) have attributed high levels of DDE in blood, carcasses or eggs to consumption of contaminated prey on the wintering grounds. Those conclusions were derived from sampling birds on the breeding and wintering grounds or while on migration both southward and northward. A few studies have used prey samples collected in Latin America to identify sources of DDT and other OCs (Fyfe et al. 1990, Banasch et al. 1992). While many researchers have alluded to the possibility that Latin America is the major source of OC contamination to birds breeding further north, few have been able to detail migration and specific wintering grounds through telemetry or band recoveries. Studies of Black-crowned Night Heron colonies from the intermountain west showed high DDE residues in eggs of birds nesting at Ruby Lake, Nevada (Henny et al. 1984). The authors initially attributed that finding to sources away from the breeding grounds, but through radio telemetry methods they found few contaminated birds were wintering in

Mexico, and that most came from contaminated sites in the southwestern United States, not Mexico (Henny and Blus 1986). Therefore, studies that combine telemetry techniques with contaminant studies have the advantage of more accurately isolating breeding and wintering sources of contaminants. Satellite transmitters, as used in this study, offer greater insight into contaminant related issues in larger migratory species.

Nine British Columbia Ospreys and seven Oregon/ Washington birds had a sample egg analyzed from the breeding site and were successfully tracked to their wintering site in the same year. That provided a reasonable sample to assess DDT:DDE residues in eggs and relate it to breeding vs. wintering ground exposure, as we were able to discriminate contaminant exposure among sites on a statistically significant basis. Although DDE concentrations in Osprey eggs varied from 0.02 to 10.14 μg/g wet mass, wintering site (by state/country) had no influence on total DDT, DDD, or DDE concentrations. Instead, DDE levels were predicted by breeding site with the highest egg DDT metabolites in birds breeding on the Columbia River, consistent with data on contamination of fish prey in that system. For example, mean DDE concentrations in largescale sucker *Catastomus macrocheilus*, the most important Osprey prey species from the Columbia River, averaged 84 and 94 ng/g wet mass (Henny et al. 2004). Using the biomagnification factor (BMF) of 87 derived specifically for Ospreys (Henny et al. 2003) results in DDE concentrations that exceed the 4.2 μg/g wet mass effects level from Wiemeyer et al. (1988). That result is consistent with reports of elevated DDE and shell thinning, and depressed nest success of Osprey popula-

TABLE 3. Extended.

DDE:DDT	Total PCBs	Total chlordanes	HCB	Dieldrin	Total HCH
13.94 ± 1.64 (13.24)	2.10 ± 2.45 (1.37)	0.64 ± 1.56 (0.67)	0.02 ± 2.89 (0.04)	0.20 ± 1.66 (0.11)	0.06 ± 2.17 (0.04)
28.53 ± 1.38 (25.91)	0.24 ± 1.81 (0.47)	0.08 ± 1.34 (0.12)	0.03 ± 2.01 (0.03)	0.05 ± 1.40 (0.07)	0.07 ± 1.67 (0.06)
7.53 ± 1.64 (17.83)	0.21 ± 2.48 (0.20)	0.08 ± 1.56 (0.08)	0.21 ± 2.92 (0.09)	0.06 ± 1.67 (0.08)	0.25 ± 2.18 (0.25)
30.98 ± 1.54 (56.42)	0.27 ± 2.21 (0.18)	0.13 ± 1.48 (0.08)	0.11 ± 2.55 (0.04)	0.07 ± 1.56 (0.07)	0.04 ± 1.98 (0.04)
9.00 ± 1.32 (12.21)	3.56 ± 1.66 (2.55)	0.33 ± 1.29 (0.23)	0.49 ± 1.83 (0.24)	0.04 ± 1.33 (0.04)	0.19 ± 1.55 (0.16)

tions along reaches of the Columbia River (Henny et al. 2004). Consistent with the egg data presented here, concentrations of DDE, average 32 ng/g wet mass, were much lower in largescale sucker from the Willamette River (Henny et al. 2003).

Generally, minor concentrations and low variability of DDT compounds were found in Osprey eggs from over a large geographic area in British Columbia. This is in contrast to higher egg residues (frequently >5 mg/kg wet mass) reported from previous collections of Osprey eggs in British Columbia during 1991–1997 (Elliott et al. 2000). Osprey prey species such as largescale sucker were sampled in 2002 from locations in British Columbia, such as Osoyoos Lake in the South Okanagan fruit growing region, an area with well documented r-DDT contamination of avian food chains (Morrissey et al. 2004, Elliott et al. 2005). Average concentrations of DDE in sucker samples were 300 ng/g wet mass, which using the BMF of 87 would result in egg DDE concentrations of 26 µg/g wet mass. Mean DDE concentrations in Osprey eggs from the South Okanagan were much lower, averaging 2.6 µg/g wet mass (Morrissey et al. 2004). The difference between predicted and measured concentrations of DDE in Osprey eggs may be the result of spatial and temporal variation in prey availability and foraging behaviour by Ospreys. Early in the breeding season, while eggs are being formed, Ospreys appear to feed more often in small farm ponds, and then move to forage in the larger and more contaminated river and lake later in the breeding season.

Willamette Ospreys and those birds which migrated to Central and South America also had considerably higher DDE:DDT ratios than the other groups. Osprey egg residues found in this study were probably influenced by low-level weathered DDE found in the Willamette basin and in Central America, whereas in Mexico and Texas there appears to have been more recent exposure to the parent compound DDT.

There is limited data on pesticide residues in fish and other aquatic biota from coastal areas of Mexico. Several studies have described the southern and eastern Mexican states of Veracruz, Tabasco, and Chiapas as the most heavily contaminated by DDT (Albert 1996, Mora 1997). In particular, Veracruz had been previously identified as an area of major concern for DDT pollution in Mexico (Kiff et al. 1980), and Chiapas is the only state that continued to use DDT legally for agricultural purposes after the 1978 ban (Mora 1997). Consistent with other studies measuring OC contaminants in fish tissues, DDE was the most prevalent OC detected in all our fish samples, and was generally higher in samples from the southern states. In general, fish collected from Veracruz had significantly higher contaminant levels than the northwestern state of Nayarit (ΣDDT, DDT metabolites, HCB). Additionally, DDE:DDT ratios in fish were also lower in the southern states of Veracruz and Oaxaca, possibly an indication of more recent DDT applications in southern Mexico.

In general, catfish were among the most contaminated family group even after correcting for differences in collection location. However, mean DDE residues in catfish were 75.8 ng/g wet mass and ranged up to 115 ng/g wet mass. Despite differences in species and reporting methods, those values are still within the range previously reported for other fish samples in Mexico (Rosales and Escalona 1983, Albert et al. 1988, Gutiérrez-Galindo et al. 1988). If we employ the BMF of 87 determined specifically for Ospreys by Henny et al. (2003), then consumption of catfish could result in significant accumulation of DDE. Although data are limited, based on our own observations and anecdotal reports, catfish are not important prey species for Ospreys wintering in the coastal lagoons of Mexico; mullet were observed as the most common prey type. At average DDE concentrations of 11.5 ng/g wet mass, and a maximum of 17 ng/g wet mass and using the BMF of 87, consumption of mullet would not result in toxicologically significant accumulation of DDE in Ospreys.

The low OC concentrations in fish tested suggest that Pacific Northwestern Ospreys are not exposed to particularly high concentrations of DDT metabolites or other OC pesticides while wintering in the sampled areas. It is nevertheless conceivable that pesticide hotspots exist even in the tested regions; they would likely be detected only by finer grained sampling. We were unable to locate any specific winter hotspots using a relatively unbiased approach of sampling fish from various lagoons and estuaries where Ospreys were known to winter, based on selecting birds for satellite tagging largely without prior knowledge of DDT burdens. Although we did not sample prey from the other wintering areas identified in Texas and Central America, birds that migrated to those locations had the lowest egg DDE residues. Mora et al. (2001) analyzed fish from the Texas and Tamaulipas, Mexico border region and found some samples contained relatively high concentrations of DDE (up to 9.6 µg/g wet mass) that were generally higher on the Texas side of the border, indicating that hotspots still occur in some agricultural drainage lagoons. Pesticides have also been heavily used in agricultural regions of Central America with consumption rates of 11.8 kg/ha of agricultural area during 1980–1989 (Castillo et al.1997). However, concentrations of OC pesticides in fish declined significantly in later years (1985–1991) compared to those sampled in 1970 (Castillo et al. 1997). Among recent Central America studies, greatest concentrations of total DDT were measured in fish (muscle tissue) sampled from Nicaragua (range <0.002–0.114 µg/g; Calero et al. 1993). High levels of DDT compounds, toxaphene, and other pesticide residues have also been reported in sediments and shellfish from lagoons on the Pacific coast of Nicaragua (Carvalho et al. 2002). In general, the concentrations reported in the literature are not significantly greater than those found in our fish samples from Mexico.
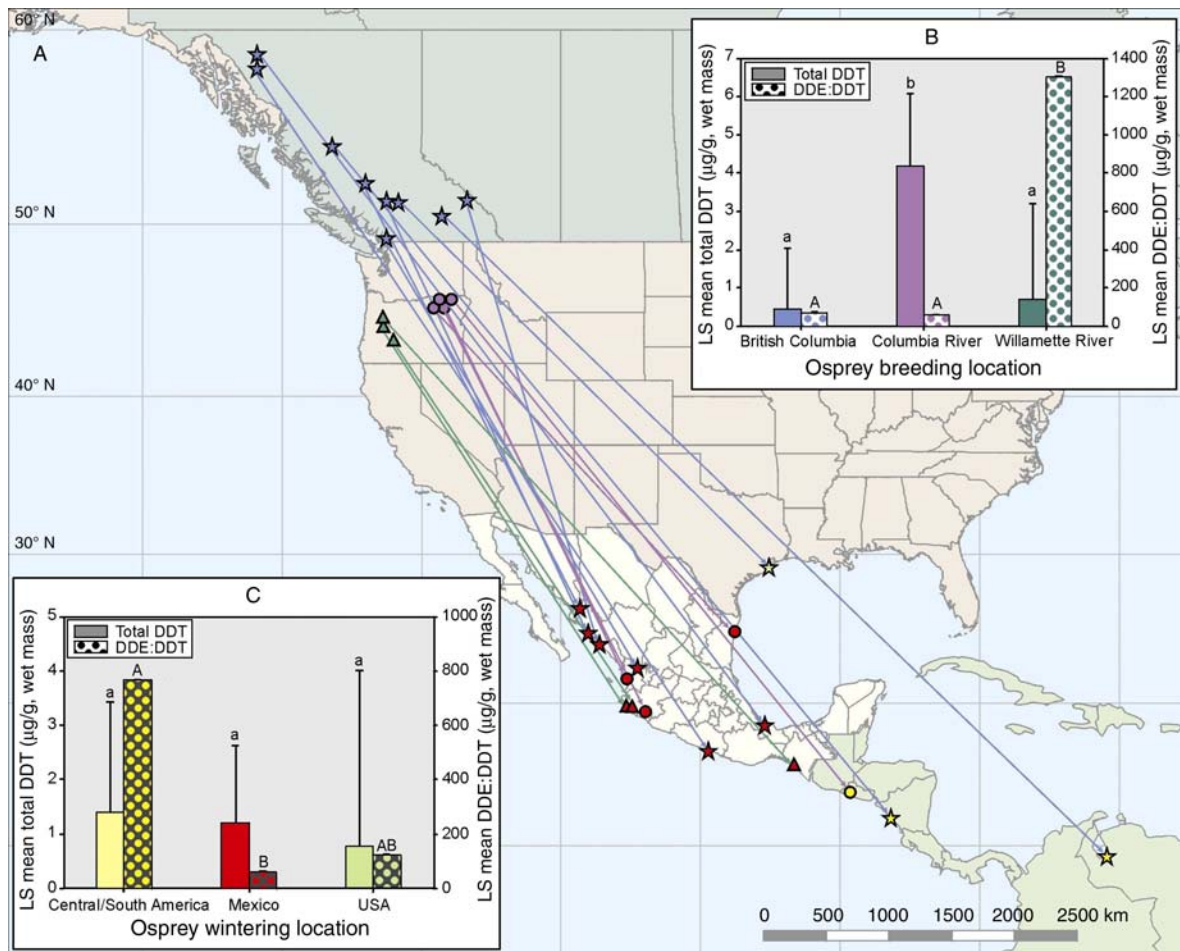
FIG. 2. (A) Map showing breeding and trapping locations for Ospreys in British Columbia, Washington, and Oregon and their fall migration routes and wintering destinations in Mexico and Central and South America. (B) Total DDT and DDE:DDT ratio in eggs from three breeding locations. (C) Total DDT and DDE:DDT ratio in eggs based on three wintering locations for female Ospreys that produced those eggs.

Ospreys also may acquire contaminants while on migration, as birds pass through areas of southwestern United States with relatively high residual contamination of food chains from past use of OC pesticides (Mora 1997). Henny and Blus (1986) reported that migrant Black-crowned Night Herons wintering in the southwestern United States accumulated higher contaminant loads than birds wintering in Mexico. Songbirds and waterfowl collected in the southwestern United States especially New Mexico and Arizona had the highest DDE residue concentrations across the United States. (Cain 1981, Cain and Bunck 1983, Fleming and Cain 1985). Several Ospreys which were satellite tagged in British Columbia passed through the southwestern United States during migration. However, total migration time of our Ospreys was relatively short (mean = 22 days), and birds made only a few brief stopovers. Martell et al. (2001) described northwestern Ospreys as employing a "sprint" strategy during autumn

migration, traveling longer distances each day and having quicker overall transit times (13 ± 4 days [mean ± SD]) compared to either midwestern or eastern populations. Therefore, acquisition of contaminants is more likely to occur on the breeding and wintering grounds where Ospreys spend the majority of the annual cycle.

Conclusions

While OC pesticides were used in Mexico for some time after restrictions in Canada and the United States, we detected relatively small concentrations in fish across Mexican sampling locations. DDT compounds and especially DDE were the most prevalent OCs detected in all fish samples, and concentrations were related to the fish species and the collection location. Greater contaminant concentrations were noted in fish from the southern state of Veracruz, consistent with previous reports. However, concentrations of DDE and ratios of

DDE:DDT in Osprey eggs were most closely related to breeding ground exposure, not to specific winter sites. Therefore, our data suggest that Pacific northwestern Ospreys wintering in several states around Mexico currently are not exposed to elevated r-DDT compounds or other OC pesticides while on the wintering grounds. However, we caution that because of limitations of fish sampling sites and numbers of satellite-tagged birds, the results do not preclude the possibility that Osprey could be contaminated if they wintered in hotspots not detected in the present sampling.

LITERATURE CITED

Albert, L. A. 1996. Persistent pesticides in Mexico. Reviews of Environmental Contamination and Toxicology 147:1–45.

Albert, L. A, A. Figueroa, A. D. Viveros, R. Loera, and G. Mascarenas. 1988. Persistent pollutants in sediment and organisms of the Rio Blanco, Veracruz, Mexico. Third Chemical Congress of North America 28:18–23.

Banasch, U., J. P. Goossen, A. Einstein Riez, C. Casler, and R. Dominguez Barradas. 1992. Organochlorine contaminants in migrant and resident prey of Peregrine Falcons, *Falco peregrinus*, in Panama, Venezuela, and Mexico. Canadian Field Naturalist 106:493–498.

Bloom, P. H. 1987. Capture and handling raptors. Pages 99–124 *in* B. A. Giron Pendleton, B. A. Millsap, K. W. Cline, and D. M. Bird, editors. Raptor management techniques manual. National Wildlife Federation, Washington, D.C., USA.

Cain, B. W. 1981. Nationwide residues of organochlorine compounds in wings of adult Mallards and Black Ducks, 1979–1980. Pesticide Monitoring Journal 15:128–134.

Cain, B. W., and C. M. Bunck. 1983. Residues of organochlorine compounds in Starlings (*Sturnus vulgaris*), 1979. Environmental Monitoring and Assessment 3:161–172.

Calero, S., I. Fomsgaard, M. Lacayo, V. Martinez, and R. Rugama. 1993. Toxaphene and other organochlorine pesticides in fish and sediment from Lake Xolotlan, Nicaragua. International Journal of Environmental Analytical Chemistry 53:297–305.

Carvalho, F. P., J. P. Villeneuve, C. Cattini, I. Tolosa, S. Montenegro-Guillen, M. Lacayo, and A. Cruz. 2002. Ecological risk assessment of pesticide residues in coastal lagoons of Nicaragua. Journal of Environmental Monitoring 4:778–787.

Castillo, L. E., E. de la Cruz, and C. Ruepert. 1997. Ecotoxicology and pesticides in tropical aquatic ecosystems of Central America. Environmental Toxicology and Chemistry 16:41–51.

Clark, R. P., R. J. Norstrom, G. A. Fox, and H. T. Won. 1986. Dynamics of organochlorine compounds in Herring gulls (*Larus argentatus*): II. A two-compartment model and data for ten compounds. Environmental Toxicology and Chemistry 6:547–559.

DeWeese, L. R., L. C. McEwen, G. L. Hensler, and B. E. Peterson. 1986. Organochlorine contaminants in passeriformes and other avian prey of the Peregrine Falcon in the western United States. Environmental Toxicology and Chemistry 5:675–693.

Drent, R. H., and S. Daan. 1980. The prudent parent: energetic adjustments in avian breeding. Ardea 68:225–252.

Elliott, J. E., M. M. Machmer, C. J. Henny, L. K. Wilson, and R. J. Norstrom. 1998. Contaminants in Ospreys from the Pacific Northwest: I. Trends and patterns in polychlorinated dibenzo-*p*-dioxins and -dibenzofurans in eggs and plasma. Archives of Environmental Contamination and Toxicology 35:620–631.

Elliott, J. E., M. M. Machmer, L. K. Wilson, and C. J. Henny. 2000. Contaminants in Ospreys from the Pacific Northwest: II. Organochlorine pesticides, polychlorinated biphenyls, and mercury, 1991–1997. Archives of Environmental Contamination and Toxicology 38:93–106.

Elliott, J. E., M. J. Miller, and L. K. Wilson. 2005. Assessing breeding potential of peregrine falcons based on chlorinated hydrocarbon concentrations in prey. Environmental Pollution 134:353–361.

Elliott, J. E., and L. Shutt. 1993. Monitoring organochlorines in blood of Sharp-shinned Hawks (*Accipiter striatus*) migrating through the Great Lakes. Environmental Toxicology and Chemistry 12:241–250.

Fleming, W. J., and B. W. Cain. 1985. Areas of localized organochlorine contamination in Arizona and New Mexico. Southwestern Naturalist 30:269–277.

Fyfe, R. W., U. Banasch, V. Benavides, N. Hilgert de Benavides, A. Luscombe, and J. Sanchez. 1990. Organochlorine residues in potential prey of peregrine falcons, *Falco peregrinus*, in Latin America. Canadian Field Naturalist 104: 285–292.

Gutiérrez-Galindo, E. A., G. Flores-Munoz, M. F. Villa-Andrade, and J. Villaescusa-Celaya. 1988. Hidrocarburos clorados en peces del Valle de Mexicali y Alto Golfo de California. Ciencias Marinas 14:1–22.

Hake, M., N. Kjellen, and T. Alerstam. 2001. Satellite tracking of Swedish Ospreys *Pandion haliatus*: autumn migration routes and orientation. Journal of Avian Biology 32:47–56.

Henny, C. J., and L. J. Blus. 1986. Radiotelemetry locates wintering grounds of DDE-contaminated Black-crowned Night Herons. Wildlife Society Bulletin 14:236–241.

Henny, C. J., L. J. Blus, A. J. Krynitsky, and C. M. Bunck. 1984. Current impact of DDE on Black-crowned Night-herons in the intermountain west. Journal of Wildlife Management 48:1–13.

Henny, C. J., R. A. Grove, J. L. Kaiser, and V. Raymond Bentley. 2004. An evaluation of Osprey eggs to determine spatial residue patterns and effect of contaminants along the Lower Columbia River, U.S.A. Pages 369–388 *in* R. D. Chancellor and B.-U. Meyburg, editors. Raptors worldwide. World Working Group on Birds of Prey and Owls, Budapest, Hungary.

Henny, C. J., and G. B. Herron. 1989. DDE, selenium, mercury, and white-faced ibis reproduction at Carson Lake, Nevada. Journal of Wildlife Management 53:1032–1045.

Henny, C. J., J. L. Kaiser, R. A. Grove, V. R. Bentley, and J. E. Elliott. 2003. Biomagnification factors (fish to Osprey eggs from Willamette River, Oregon, U.S.A.) for PCDDs, PCDFs, PCBs and OC pesticides. Environmental Monitoring and Assessment 84:275–315.

Henny, C. J., F. P. Ward, K. F. Riddle, and R. M. Prouty. 1982. Migratory Peregrine falcons, *Falco peregrinus*, accumulate pesticides in Latin America during winter. Canadian Field Naturalist 96:333–338.

Houghton, L. M., and L. R. Rymon. 1997. Nesting distribution and population status of US Ospreys 1994. Journal of Raptor Research 31:44–53.

Kenward, R. 1987. Wildlife radio tagging: equipment, field techniques and data analysis. Biological Techniques Series. Academic Press, London, UK.

Kiff, L. F., D. B. Peakall, and D. P. Hector. 1980. Eggshell thinning and organochlorine residues in the bat and Aplomado Falcons in Mexico. International Ornithological Congress 17:949–952.

Kjellen, N., M. Hake, and T. Alerstam. 2001. Timing and speed of migration in male, female and juvenile Ospreys *Pandion haliatus* between Sweden and Africa as revealed by field observations, radar and satellite tracking. Journal of Avian Biology 32:57–67.

Lacher, T. E., and M. I. Goldstein. 1997. Tropical ecotoxicology: status and needs. Environmental Toxicology and Chemistry 16:100–111.

Martell, M. S., C. J. Henny, P. E. Nye, and M. J. Solensky. 2001. Fall migration routes, timing, and wintering sites of North American Ospreys as determined by satellite telemetry. Condor 103:715–724.

Meyburg, B. U., D. H. Ellis, C. Meyburg, J. M. Mendelsoh, and W. Scheller. 2001. Satellite tracking of two Lesser Spotted Eagles, *Aquila pomarina*, migrating from Namibia. Ostrich, 72:35–40.

Mora, M. A. 1997. Transboundary pollution: persistent organochlorine pesticides in migrant birds of the southwestern United States and Mexico. Environmental Toxicology and Chemistry 16:3–11.

Mora, M. A., D. Papoulias, I. Nava, and D. R. Buckler. 2001. A comparative assessment of contaminants in fish from four resacas of the Texas, USA–Tamaulipas, Mexico border region. Environment International 27:15–20.

Morrissey, C. A., G. Kardosi, L. K. Wilson, and J. E. Elliott. 2004. Effect of food supply and contaminants on Osprey productivity in southern British Columbia, Canada. Pages 353–368 *in* R. D. Chancellor and B.-U. Meyburg, editors. Raptors worldwide. World Working Group on Birds of Prey and Owls, Budapest, Hungary.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, South Dakota, USA.

Poole, A. F. 1989. Ospreys: a natural and unnatural history. Cambridge University Press, Cambridge, UK.

Rosales, M. T. L., and R. L. Escalona. 1983. Organochlorine residues in two different lagoons of northwest Mexico. Bulletin of Environmental Contamination and Toxicology 30:456–463.

Springer, A. M., W. Walker II, R. W. Risebrough, D. Benfield, D. H. Ellis, W. G. Mattox, D. P. Mindell, and D. G. Roseneau. 1984. Origins of organochlorines accumulated by Peregrine Falcons, *Falco peregrinus*, breeding in Alaska and Greenland. Canadian Field Naturalist 98:159–166.

Waliszewski, S. M., A. A. Auguirre, R. M. Infazon, J. Rivera, and R. Infazon. 1998. Time trend of organochlorine pesticide residues in human adipose tissue in Veracruz, Mexico: 1988–1997 survey. Science of the Total Environment 221:201–204.

Walker, K. R., J. Ricciardone, and J. Jensen. 2003. Developing and international consensus on DDT: a balance of environmental health and disease. International Journal of Hygiene and Environmental Health 206:423–435.

Wiemeyer, S. N., C. M. Bunck, and A. J. Krynitsky. 1988. Organochlorine pesticides, polychlorinated biphenyls, and mercury in Osprey eggs 1970–79 and their relationships to shell thinning and productivity. Archives of Environmental Contamination and Toxicology 17:767–787.

APPENDIX

A summary of composite concentrations of organochlorine pesticides and total PCBs detected in fish collected from five locations on the north Pacific coast of Mexico and eight locations along the southeastern Gulf of Mexico, 2000–2002 (*Ecological Archives* A017-045-A1).