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Trends and Effects of Organochlorine Residues on Oregon and Nevada Wading Birds, 1979-83

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Abstract.—The incidence of DDT (parent compound) declined significantly in the eggs of Black-crowned Night-Herons (*Nycticorax nycticorax*), White-faced Ibis (*Plegadis chihi*), and Black-necked Stilts (*Himantopus mexicanus*), and showed a downward trend in Snowy Egrets (*Egretta thula*). Mean DDE residues (breakdown product of DDT) in eggs declined significantly in Black-crowned Night-Herons and showed a downward trend in Black-necked Stilts and Snowy Egrets; however, no trend was apparent for White-faced Ibis. Some night-herons, egrets, and ibis laid thin-shelled eggs that cracked; eggshell thickness was negatively correlated with DDE residues in the egg contents. Ibis were the most sensitive species to DDE-induced shell thinning. Generally, reduced reproductive success for ibis started at lower DDE egg residues (3 ppm) than for either Snowy Egrets (5 ppm) or night-herons (8 ppm). Egg residue profiles, band recoveries, biotelemetry studies, and residues in fish and other prey items implicate the southwestern United States (a wintering area) as an important source of DDT-DDE that caused the most serious reproductive problem encountered during the study (in night-herons nesting at Ruby Lake, Nevada). Available evidence indicates that the three other species, together with night-herons from Oregon and Idaho, winter in Latin America.

Key words: Nycticorax nycticorax, Egretta thula, Plegadis chihi, Himantopus mexicanus, Organochlorine residues, DDE, PCB, Eggshell thinning, Productivity.

Organochlorine and polychlorinated biphenyl (PCB) residues decreased in most of the nation during the last decade; however, concentrations remained sufficiently high in some areas to reduce recruitment and survival in certain wildlife populations (Fleming et al. 1983). Eight years after DDT was banned, Black-crowned Night-Herons (*Nycticorax nycticorax*) nesting in Washington, Oregon, and Nevada were showing DDE-related reproductive problems (Henny et al. 1984). The most serious reproductive problems occurred in Nevada; however, DDE residues in night-heron eggs declined significantly between 1979 and 1980. In this study, we evaluated residue trends at Oregon and Nevada night-heron colonies through 1983. The study was also broadened to include the Black-necked Stilt (*Himantopus mexicanus*), Snowy Egret (*Egretta thula*), and White-faced Ibis (*Plegadis chihi*). We evaluated (1) trends over time in egg residues (the primary objective), (2) effects of organochlorine residues on nesting success, and (3) wintering localities of the four species and organochlorine residues there.

METHODS

Sampling procedures

During this 5-year study, a "sample egg" was collected at random from 250 Black-crowned Night-Heron nests, 40 Black-necked Stilt nests, 68 Snowy Egret nests, and 90 White-faced Ibis nests. The nesting colonies were located in Oregon at Malheur National Wildlife Refuge (NWR) and in Nevada at Ruby Lake and Stillwater NWRs, at Franklin Lake (near Ruby Lake), at Carson Lake (near Stillwater), and at Halleck (Fig. 1).

For night-herons at each colony, the percentage of eggs sampled with > 8 ppm DDE wet weight (the amount associated with impaired productivity, including egg breakage, [Henny et al. 1984]) was used to evaluate the impact of DDE on that colony. We obtained some data on reproductive success for the other species from marked nests where a sample egg was collected. The success or failure of marked stilt nests was difficult to determine because the precocial young left soon after hatching. A special effort was made to monitor six

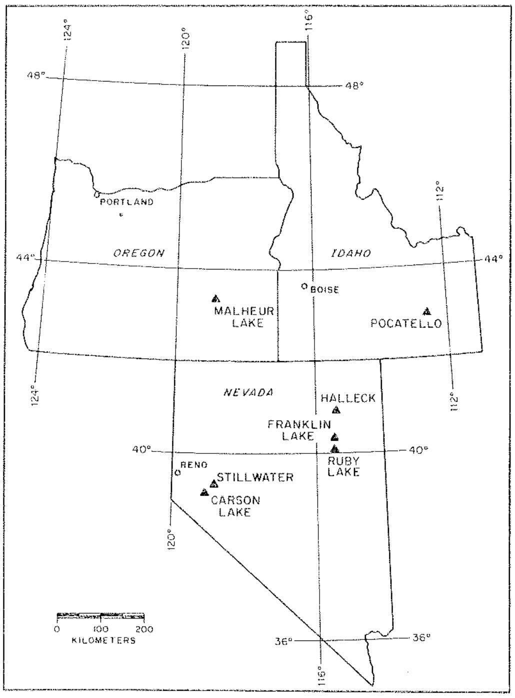

Fig. 1. Location of wading bird colonies studied in Oregon and Nevada, 1979-83.

marked nests in 1981. Nests were marked on 5 May and checked again on 21 May. The Black-necked Stilt incubation period is 25-26 days (Harrison 1978); based on the embryonic development of eggs collected, we estimated that eggs from either five or six nests would hatch about 21 May. We also report on 36 Snowy Egret nests (from different years and colonies) that had a sample egg collected very early in incubation and that were revisited when young were expected to be 7 to 10 days old. These timing constraints limited the number of suitable nest records for determining an index to reproductive success. The Snowy Egret reproductive analysis included a stratification at 5 ppm DDE to allow a direct comparison with Findholt's (1984) findings.

Eggs were refrigerated until opened. Individual contents were placed in chemically cleaned jars and then frozen for later analysis. Fish netted in Mexico near night-heron wintering locations were preserved in 10% formalin until chemical analyses were performed. Shell thickness was measured at three sites on the equator with a micrometer graduated in units of 0.01 mm and then averaged.

Chemical analyses

The analyses of eggs for organochlorine pesticides and their metabolites (p,p'-DDE, p,p'-DDD, p,p'-DDT, dieldrin, heptachlor epoxide, oxychlordane, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, endrin, toxaphene, mirex, hexachlorobenzene [HCB] and beta-hexachorocyclohexane [beta-HCH]), and polychlorinated biphenyls (PCBs) were conducted at the Patuxent Wildlife Research Center, Laurel, Maryland. Sample preparation, extraction, cleanup and separation of pesticides from PCBs have been described in detail by Cromartie et al. (1975). Sep-Pak (Clark et al. 1983) was substituted for the Florisil described in Cromartie et al. (1975) for samples collected in 1981 having an aliquot lipid weight of less than 1.0 g. For samples collected in 1981, 1982, and 1983, Silica gel (100-200 mesh, grade 923, Davison Chemical Division, W. R. Grace & Co.)[1] was substituted for SilicAR described in Cromartie et al. (1975). For all samples except those collected in 1981, the SilicAR or silica gel separation was collected into four fractions rather than three in order to separate dieldrin or endrin into a discrete fraction (Kaiser et al. 1980). Samples collected in 1982 and 1983 were not analyzed for mirex, therefore fractions I and II of the silica gel separation were combined. The samples were not analyzed for HCB in 1982 or for beta-HCH in 1980-83.

Fish collected in Mexico were analyzed in a similar manner. Three formalin samples used for preserving the fish were each wet extracted with 2x20 ml of 85:15 hexane:methylene chloride and 1x20 ml of hexane. The extracts of each sample were combined then concentrated to 10 ml for direct GC analysis. None contained organochlorine pollutants.

All fractions were quantified by electron-capture, gas-liquid chromatography using a 1.83-m x 4-mm i.d. glass column packed with 1.5/1.95% SP-2250/2401 on 100/120 mesh Supelcoport. Residues in 10% of the samples were confirmed with a Finnigan model 4000 gas-liquid chromatograph/mass spectrometer.

Recoveries of pesticides and PCBs from fortified chicken eggs averaged 94%;

[1]Use of trade names does not constitute endorsement by the U.S. government.

results were not corrected for percent recovery. The lower limits of reportable residues were 0.1 ppm for pesticides (except 0.01 ppm for Nayarit fish samples) and 0.5 ppm for PCBs (except 0.05 ppm for Nayarit fish samples). We corrected residues of eggs to an approximate fresh wet weight using egg volume (Stickel et al. 1973); residue concentrations are expressed on a wet weight basis.

Statistical analyses

Residue data were transformed ($\log_{10}$) for statistical testing. The lower limit of quantification was halved for samples in which a contaminant was not detected; this value was used to calculate geometric means when at least one-half of the samples contained detectable residues. If ANOVA was significant ($P \leq 0.05$), Duncan's New Multiple Range Test (Duncan 1955) was used to determine significance among means.

The frequency of occurrence was presented for most organochlorines that were detected in < 50% of the eggs. No statistical tests were conducted unless a contaminant occurred in more than 10% of the eggs at a location. We used the log-likelihood ratio with a G statistic for testing goodness of fit (Zar 1974). Cell values were used to identify the colonies or years that were different. If a zero value occurred, that cell was pooled with an adjacent cell. Generally, colony comparisons were done separately for each year to avoid confounding colony differences with time. The level of significance was $P \leq 0.05$.

Banding analyses

A listing of all band recoveries for Black-crowned Night-Herons, Black-

TABLE 1. Organochlorine pollutants (ppm, wet weight) in eggs (geometric mean or frequency of occurrence) of Black-crowned Night-Heron from southern Oregon and northern Nevada, 1979-83. The 1979-80 data are from Henny et al. (1984).

Location Year (N)	Geometric mean DDE ppm	High DDE ppm	Occurrence: DDE ≥ 8 ppm	DDT	DDD	Dieldrin	Chlordanes[a]	PCB's
Ruby Lake								
1979 (27)	8.21 A[b]	130	16 (59%)[c]	14 (52%)[c]	10	7	11	19 (1.70)[d] A
1980 (25)	4.13 B	21	5 (20%)	4 (16%)	5	4	8	18 (1.45) A
1982 (15)	3.43 B	16	4 (27%)	4 (27%)	4	3	1	11 (1.25) A
1983 (15)	2.79 B	12	2 (13%)	2 (13%)	0	0	0	8 (0.82) A
Malheur Lake								
1979 (20)	4.70 A	22	9 (45%)	9 (45%)	8	6	7	6
1980 (21)	2.73 A	14	4 (19%)	5 (24%)	4	5	1	4
1982 (15)	1.23 B	8	1 (7%)	1 (7%)	0	1	0	0
1983 (15)	1.06 B	12	1 (7%)	0	0	1	0	1
Stillwater								
1980 (7)	5.08 A	26	4 (57%)	2 (29%)	3	0	1	2
1981 (14)	2.50 A	14	3 (21%)	2 (14%)	3	5	5	6
1982 (16)	3.06 A	12	2 (13%)	3 (19%)	2	3	0	4
1983 (15)	2.03 A	13	2 (13%)	2 (13%)	1	2	1	1
Halleck								
1981 (15)	4.63 A	56	7 (47%)	4 (27%)	3	3	3	11 (1.37)
1982 (15)	2.21 A	11	2 (13%)	1 (7%)	0	0	0	1
1983 (15)	2.65 A	28	4 (27%)	3 (20%)	2	0	1	2

Note: PCB's = polychlorinated biphenyls. Beta-BHC found in 15 eggs—11 Ruby Lake, 4 Malheur Lake (not analyzed in 1980-83); hexachlorobenzene in 1 egg at Stillwater (not analyzed in 1982); endrin found in 3 eggs—2 Ruby Lake, 1 Halleck; toxaphene found in 11 eggs— 3 Ruby Lake, 4 Malheur Lake, 3 Stillwater, 1 Halleck.

[a]Includes heptachlor epoxide, oxychlordane, *trans*-nonachlor, *cis*-nonachlor, and *cis*-chlordane.

[b]Columns sharing a letter or an unbroken line are not significantly different, P > 0.05. Brackets show years pooled when a "0" value occurs.

[c]Occurrence (percent occurrence).

[d]Value in parenthesis is geometric mean, ppm (only calculated when residues detected in ≥ 50% of samples.

necked Stilts, Snowy Egrets, and White-faced Ibis banded in Idaho, Oregon, Nevada, and Utah was obtained from the Bird Banding Laboratory, Laurel, Marylan, on 23 May 1984. Some recoveries were from birds banded in this study. Band recoveries during the winter (November through February) were evaluated to determine wintering localities of night-herons, egrets, and ibis from Oregon, Nevada, and Idaho. No band recoveries existed for stilts. Many of the band recoveries from Mexico had inexact dates of recovery. In this analysis, all band recoveries south of the United States were considered winter records.

RESULTS AND DISCUSSION

Residues in eggs and reproductive success

Black-crowned Night-Heron—DDE was detected in 249 of 250 eggs. DDE residues in eggs declined significantly between 1979 and 1980 (Henny et al. 1984) and continued to decline during the early 1980s (Table 1). DDE residues declined 77% at Malheur Lake and 66% at Ruby Lake between 1979 and 1983. The percentage of eggs sampled with > 8 ppm DDE (the effect level, see METHODS) decreased significantly during the study at Malheur Lake (45 to 7%) and at Ruby Lake (59 to 13%); DDT, the parent compound, similarly decreased at both locations. DDE residues and the incidence of DDE > 8 ppm also decreased over time at Stillwater and Halleck, although changes were not statistically significant in these shorter series of data.

The incidence of chlordane and related compounds (heptachlor epoxide, oxychlordane, *trans*-nonachlor, *cis*-chlordane), decreased significantly at Ruby Lake, Malheur Lake, and Stillwater. These compounds were seldom detected during 1982 and 1983 at any of the study locations. We believe technical chlordane was the most important source of the chlordane compound detected rather than heptachlor because heptachlor epoxide was almost always found in eggs at lower concentrations than oxychlordane (HE:OXY usually 0.35 to 1.0:1) (see Stickel et al. 1979, Blus et al. 1983). The incidence of dieldrin decreased significantly at Malheur Lake.

PCBs were detected in 68% of the eggs at Ruby Lake and showed a gradual but not significant decrease over time. The incidence of PCBs at Malheur Lake decreased significantly from 1979-80 to 1982-83. PCBs were detected in only 31% of the eggs at Halleck, 25% at Stillwater, and 15% at Malheur Lake with a trend toward lower incidence in later years. No significant difference in overall PCB occurrence (years pooled) was detected at Malheur Lake, Stillwater, and Halleck, but the Ruby Lake colony was significantly higher than were the other three.

Black-necked Stilt—DDE ranged from 0.31-15.6 ppm in 40 eggs collected at Carson Lake; geometric means declined 58% ($P >$ 0.05) from 1980 to 1983 (Table 2). No significant correlation was evident between DDE and eggshell thickness ($r = -0.096$), and shell thickness was similar to that of the pre-DDT era. The occurrence of DDT decreased significantly during the study; 6

TABLE 2. Eggshell thickness and organochlorine pollutants (ppm, wet weight) in eggs (geometric mean or frequency of occurrence) of Black-necked Stilts from Carson Lake, Nevada, 1980-83.

Year (N)	Shell Thickness (mm)	Geo. mean DDE ppm	High DDE ppm	DDT[a]
1980 (10)	0.217 A[b]	3.26 A	16	6 (60%)
1981 (10)	0.203 A	1.96 A	10	1 (10%)
1982 (10)	0.209 A	1.94 A	8	1 (10%)
1983 (10)	0.217 A	1.38 A	16	0

Note: Pre-DDT era eggshell thickness (mean ± SE) in Utah was 0.205±0.002 based on 1 egg measured from each of 40 clutches; heptachlor epoxide and oxychlordane in 1 egg (same), toxaphene in 1 egg, DDD in 1 egg, polychlorinated biphenyls in 1 egg, epoxide hexachlorobenzene in 1 egg (not analyzed for in 1982), and endrin in 4 eggs (2 in 1980, 2 in 1982), dieldrin in 5 eggs (3 in 1980, 2 in 1982).

[a]Occurrence (percent occurrence).

[b]Columns sharing a letter or an unbroken line are not significantly different, P > 0.05. Brackets show years pooled when a "0" value occurs.

TABLE 3. Eggshell thickness and organochlorine pollutants (ppm, wet weight) in eggs (geometric mean or frequency of occurrence) of Snowy egrets from southern Oregon and northern Nevada, 1981-83.

				Occurrence		
Location, Year (N)	Shell thickness (mm)	Geo. mean DDE ppm	High DDE ppm	DDE ≥ 5 ppm	DDT	Dieldrin
Stillwater						
1981 (12)	0.217 A[a]	1.43 A	34	4 (33%)[b]	4 (33%)[b]	3
1982 (15)	0.196 B	1.91 A	12	4 (27%)	4 (27%)	2
1983 (15)	0.216 A	0.62 A	15	1 (7%)	1 (7%)	0
Malheur Lake						
1981 (10)	0.211	1.70	15	3 (30%)	1 (10%)	0
Franklin Lake						
1981 (16)	0.215	0.73	7	1 (6%)	2 (13%)	1

Note: Toxaphene found in 2 eggs, heptachlor epoxide and oxychlordane in 1 egg (same), *trans*-nonachlor in 3 eggs, DDD in 5 eggs.

[a]Columns sharing a letter or an unbroken line are not significantly different, P > 0.05. Brackets show years pooled where a "0" value occurs.

[b]Occurrence (percent occurrence).

TABLE 4. Residues of DDE (ppm, wet weight) in Snowy Egret eggs relative to nesting success, clutch size, eggshell thickness, and egg breakage (all colonies and years pooled).

	Number of nests			Young/successful nest[b]		Clutch size[c]			Shell Thickness (mm)[d]			
DDE (ppm)	Total	Sucess-ful[a]	(%)	Mean	SE	Mean	SE	N	Mean	SE	N	Clutches with cracked eggs[e]
≤ 1.0	16	15	(94)	2.33	0.28	3.63	0.22	24	0.220	0.004	32	4/32 (12.5%)
1.01-5.0	14	11	(79)	3.09	0.28	3.74	0.21	19	0.208	0.005	23	3/23 (13.0%)
5.01-10.0	4	2	(50)	2.00	1.00	3.80	0.20	5	0.199	0.009	6	0/6 —
10.01-20.0	2	1	(50)	2.00	—	3.75	0.25	4	0.187	0.006	6	2/6 (33.3%)
> 20	—	—	—	—	—	5.00	—	1	0.184	—	1	1/1 (100%)

[a]At least one young attained the age of 7-10 days old.

[b]One egg was collected from each nest for residue analysis.

[c]Includes the sample egg collected (excludes nests with the sample egg fresh and no followup visits).

[d]Pre-DDT era eggshell thickness (mean ± SE) in Utah was 0.222±0.002 (Findholt 1984).

[e]The incidence of cracked eggs is minimal because all nests were not followed completely through the nesting cycle.

of 10 eggs contained DDT in 1980 but none did in 1983. Other organochlorine pesticides were detected in low concentrations (< 0.50 ppm), primarily during 1980. Only 1 of 40 eggs contained PCBs.

Six stilt nests were visited at about the time they were expected to hatch based on embryonic development of the sample egg. Eggs from five of the six nests hatched; the sample egg from the unhatched clutch contained 1.7 ppm DDE and showed the least development. The nest contained three warm eggs when last visited. Sample eggs from the five nests with eggs that hatched contained the following DDE residues: 0.31, 0.36, 2.5, 4.9, and 10.4 ppm.

Snowy Egret—DDE was detected in 41 of 42 eggs collected at Stillwater between 1981 and 1983 (Table 3). No significant residue trends over time were detected and DDE residues (geometric means) at three colonies studied in 1981 (Stillwater, Malheur Lake, and Franklin Lake) were not significantly different. Eggs of egrets in Idaho with > 5 ppm DDE had a high frequency of breakage or disappearance, lower hatchability, and significantly thinner eggshells compared to eggs with ≤ 5 ppm (Findholt 1984). Our findings based on only 36 nests were similar to Findholt's (Table 4). Nests with eggs containing < 5 ppm DDE yielded 2.3 young (7 to 10 days old)/nest attempt (n = 30), while Findholt reported 2.1 (n = 10). Nests with sample eggs containing > 5 ppm DDE produced 1.0 young/nest attempt (n = 6) compared to Findholt's 1.3 (n = 9). The percentage of eggs containing DDE residues > 5 ppm at Stillwater decreased, though not significantly, from 33% to 7% during the study (Table 3). Other organochlorine pesticides were sometimes detected at low levels (< 1 ppm) but PCBs were never detected.

We found a significant relationship between DDE in eggs and eggshell thickness ($\hat{Y} = 0.212 - 0.017 \log_{10}X$, $r = -0.492$, $N = 69$, $P < 0.001$). Findholt (1984) reported similar findings.

White-faced Ibis—DDE was detected in 59 of 61 eggs collected at Carson Lake between 1980 and 1983 (Table 5). DDE residues were significantly lower in 1982 than in other years, but increased in 1983 to a level similar to 1980 and 1981. Thus, DDE residues in ibis eggs at Carson Lake were unique in not showing the decline found in other species. However, the occurrence of DDT decreased significantly. Each year the same location within the large colony was sampled and all eggs were collected on one day. Different segments of the large population (ca. 2000 pairs in 1980; ca. 3100 pairs in 1983) at Carson Lake laid eggs over a several week period. Capen (1977) and Steele (1984) apparently obtained a random sample of eggs from a Utah population, and showed that ibis eggshell thickness, which was correlated with DDE residues (see below), fluctuated from year to year (eggs not analyzed for residues each year). DDE residues (geometric means) during their studies (1.50 ppm in 1975 and 1.25 ppm in 1979) were within the range we found (Table 5).

Other organochlorine pesticides tended to parallel the occurrence of DDE, but none showed significant changes. PCBs in eggs were detected only twice, both times in 1980 (0.61 and 0.63 ppm). In contrast to the night-heron residues, the source of chlordane and related compounds in ibis was probably heptachlor. Heptachlor epoxide residues generally were higher than oxychlordane in the same egg (HE:OXY usually 3.0 to 5.0:1). The occurrence of pesticides at the other colonies was within the range reported during the four years at Carson Lake except in a small series of eggs at the Stillwater colony (about 45 km from Carson Lake) in 1981 when DDE residues were low and DDT and other pesticides were not present.

Eggshell thickness was significantly correlated with DDE (all eggs including non-random samples) ($\hat{Y} = 0.298 - 0.029 \log_{10}X$, $r = -0.628$, $N = 96$, $P < 0.001$); this relationship is similar to that reported previously (Capen 1977, King et al. 1980, Steele 1984). Random samples of eggs from Texas in 1970 and 1976 contained 0.94 and 0.25 ppm DDE (arithmetic means) with 3.2% and 4.5% shell thinning, respectively (King et al. 1980). Our annual estimates of shell thinning ranged from 5.2% to 12.8%. The eggs with the highest DDE residues (4-8 ppm, 8-16 ppm, and 16-20 ppm in Table 6) resulted in 15.0%, 17.4%, and 27.8% shell thinning, respectively.

Capen (1978) discussed problems associated with estimating ibis fledging success when the young leave the nest as early as 7 days of age. Many nests were not revisited at the proper time to determine the number of week-old young; therefore, our series of nests with complete records was small and will be reported after additional field work in 1985 and 1986. In Utah, Steele (1984) reported that nests with sample eggs containing ≤ 3 ppm DDE produced 1.72 young, while those with > 3 ppm produced only 1.25 young. The percentage of nests with a sample egg containing > 3 ppm DDE ranged from 6% to 40% during the 4-year study at Carson Lake (Table 5).

Wintering localities and DDT-DDE contamination

Earlier work with night-herons (Henny et al. 1984) showed no local DDE contamination in prey at colony sites included in this investigation. Therefore, band recoveries were evaluated to determine wintering localities for the species of interest breeding in Idaho, Oregon, and Nevada.

Black-crowned Night-Heron—Cooke (1913) listed a record of a night-heron wintering near Fallon, Nevada (Stillwater area), and a bird was occasionally observed at the Ruby Lake fish hatchery well into winter, but these records were exceptions. Banding and biotelemetry studies (Henny &

TABLE 5. Eggshell thickness and organochlorine pollutants (ppm, wet weight) in eggs (geometric mean or frequency of occurrence) of White-faced Ibis from northern Nevada and southern Oregon, 1979-83.

Location Year (N)	Shell thickness (mm)	Gen. mean DDE ppm	High DDE ppm	Occurrence						
				DDE ≥ 3 ppm	DDT	Dieldrin	Chlordanes[a]	Toxaphene	HCB	Endrin
Carson Lake										
1980 (15)	0.295 AB[b]	1.62 A	15	6 (40%)[c]	8 (53%)[c]	6	4	2	1	3
1981 (15)	0.288 B	2.23 A	19	5 (33%)	9 (60%)	5	4	1	5	2
1982 (16)	0.310 A	0.54 B	3	1 (6%)	2 (13%)	2	[0	1	na	1
1983 (15)	0.285 B	1.71 A	20	6 (40%)	3 (20%)	2	3]	2	1	1
Ruby Lake										
1979 (15)	0.301	1.09	7	2 (13%)	5 (33%)	4	4	0	0	2
Malheur Lake										
1980 (8)	0.308	1.27	8	1 (13%)	1 (13%)	3	0	1	3	0
Stillwater										
1981 (6)	0.305	0.52	3	1 (17%)	0	0	0	0	0	0

Note: HCB = hexachlorobenzene, NA = not analyzed; beta BHC found in 5 eggs in 1979 at Ruby Lake (not analyzed in 1980-83); DDD in 1 egg; polychlorinated biphenyls in 3 eggs.

[a]Includes heptachlor epoxide, oxychlordane, *trans*-nonachlor.

[b]Columns sharing a letter or an unbroken line are not significantly different, $P > 0.05$. Brackets show years pooled when a "0" value occurs.

[c]Occurrence (percent occurrence).

TABLE 6. Residues of DDE (ppm, wet weight) in White-faced Ibis eggs relative to clutch size, eggshell thickness, and egg breakage (all colonies and years pooled).

DDE (ppm)	Clutch size[a] Mean	Clutch size[a] SE	Clutch size[a] N	Shell thickness (mm)[b] Mean	Shell thickness (mm)[b] SE	Shell thickness (mm)[b] N	Clutches with cracked eggs[c]
≤ 1.0	3.94	0.15	31	0.313	0.003	37	1/37 (2.7%)
1.01-4.0	3.91	0.20	33	0.296	0.003	38	2/38 (5.3%)
4.01-8.0	4.00	—	6	0.278	0.007	8	2/8 (25.0%)
8.01-16.0	4.00	—	3	0.270	0.015	4	2/4 (50.0%)
16.01-20.0	4.00	—	1	0.236	0.005	4	3/4 (75.0%)

[a]Includes the sample egg collected (excludes nests with the sample egg fresh and no followup visits).
[b]Pre-DDT era eggshell thickness (mean ± SE) in Utah and California was 0.327±0.001, N=374 (Capen 1977).
[c]Note: An additional six non-random dented eggs were collected from six different nests and contained the following DDE residues (ppm): 4.3, 5.4, 5.4, 7.2, 7.4, and 8.3. The incidence of cracked eggs was minimal because all nests were not followed completely through the nesting cycle.

TABLE 7. The wintering localities of Black-crowned Night-Herons, Snowy Egrets, and White-faced Ibis.

Wintering location	Black-crowned Night-Heron: Oregon-Idaho	Black-crowned Night-Heron: Ruby Lake, Nevada	Snowy Egret: Nevada	Snowy Egret: Idaho	White-faced Ibis: Nevada	White-faced Ibis: Idaho
United States						
California-Arizona-Texas	0 (0)[a]	2 (3)[a]	0	0	0	0
Western States of Mexico						
Sonora	0 (1)	1 (0)	0	0	0	0
Sinaloa-Nayarit	8 (5)	0 (1)	2	1	3	4
Jalisco-Michoacan-Colema	2 (0)	0 (0)	0	1	3	5
Guerrero	0 (0)	0 (0)	0	0	0	1
Eastern States of Mexico						
Tamaulipas	0 (1)	0 (0)	0	0	0	0
Vera Cruz	2 (1)	0 (0)	0	0	0	2
Interior States of Mexico	0 (0)	1 (0)	0	0	0	1
Guatemala	0 (0)	0 (0)	0	1	0	0

[a]First value = band recovery, value in parenthesis = radio encounter for Black-crowned Night-Herons (Henny and Blus, in press).

Blus in press), showed that most night-herons from Ruby Lake (the most DDE-contaminated species and colony) wintered in the southwestern United States (southern California, Imperial Valley; Arizona, Gila River; southern Texas) and the interior of northern Mexico, while less contaminated night-herons from Idaho and Oregon leap-frogged those from Ruby Lake and wintered farther south in coastal Mexico (Table 7).

DDT-DDE residues from fish collected in coastal Mexico near locations where Oregon-Idaho birds wintered were generally low (Table 8). Rosales & Escalona (1983) also reported low DDT-DDE residues in the muscle of fish, crustaceans, decapods, and mollusks collected at two lagoons in northwestern Mexico (Yavaros, Sonora and Huizache-Caimanera, Sinaloa). However, high DDT-DDE ratios in some fish (up to 5.6:1) we collected in Mexico (Table 8) suggests that DDT is still used in portions of the country.

Channel catfish (*Ictalurus punctatus*) and carp (*Cyprinus carpio*) from the Alamo River (which flows into the Salton Sea) in the Imperial Valley contained the highest

TABLE 8. Organochlorine residues (ppm, wet weight) in fish and shrimp collected in Mexico, 1983-84.

Location (Date)	Family	Length extremes (mm) and/or total weight (g)	N	DDE	DDD	DDT
El Palillo, 18 km ne San Blas, Nayarit[a] 3 June 1984	Ictaluridae	75-120mm/48g	5	0.19	nd	0.16
	Atherinidae	18-60mm/31g	34	0.14	0.10	0.78
	Poecilidae	36-72mm/279g	111	0.38	0.20	1.10
8 Km w Villa Hildalgo, Nayarit[b] 4 June 1984	Poecilidae	66-75mm/25g	5	0.23	0.09	0.17
	Cichlidae	50-96mm/179g	20	0.25	0.03	0.03
	Eleotridae	109-150mm/245g	7	0.05	nd	nd
8 km e Playa Novilleros, Nayarit[c] 7 June 1984	Poecilidae	47-59mm/6g	4	0.03	nd	nd
	Shrimp	42-63mm/6g	6	nd	nd	nd
	Clupeidae	40-71mm/15g	13	0.02	nd	nd
	Engraulidae	49-57mm/19g	2	0.03	nd	nd
	Mugilidae	38-60mm/2g	15	0.02	nd	nd
	Centropomidae	89-97mm/11g	2	0.04	nd	nd
Bahia de Altata, Sinaloa[d] 22 July 1983	Pleuronectidae	15g	1	nd	nd	nd
	Haemulidae	130g	1	nd	nd	nd
	Centropomidae	64g	1	nd	nd	nd
	Gerridae	134g	5	nd	nd	nd
	Arridae	37g	1	nd	nd	nd
7 km e El Potrero de Sataya, Sinaloa[e] 22 July 1983	Eleotridae, (*Dormitator* sp.)	191g	1	nd	nd	nd
12 km e Vergel, Sinaloa[e] 22 July 1983	Eleotridae, (*Dormitator* sp.)	343g	1	0.10	nd	nd
	Eleotridae, (*Dormitator* sp.)	567g	1	0.18	nd	nd
	Eleotridae, (*Dormitator* sp.)	426g	5	0.12	nd	nd

Note: Detection limit 0.10 ppm for Sinaloa samples, and 0.01 ppm for Nayarit samples (nd = none detected).
[a]Stream, agricultural area.
[b]Irrigation canal, agricultural area.
[c]Brackish water.
[d]Shallow bay.
[e]Agricultural drain.

total DDT levels (3.6 and 4.6 ppm wet weight) in fish recorded in a California monitoring program in 1981 (La Caro et al. 1982). Furthermore, European Starlings (*Sturnus vulgaris*) from the Imperial Valley and Maricopa County, Arizona (location of Gila River), contained elevated concentrations of DDE in 1979 (Fleming et al. 1983). In the same review paper, high DDE levels were noted in fish collected from Painted Rock Reservoir and the Gila River. Another area with elevated DDE residues in fish and birds was the lower Rio Grande Valley in Texas (White et al. 1983). Thus, all known Ruby Lake night-heron wintering localities in the United States contained elevated organochlorine pollutants. Direct residue comparisons with the same fish species or size category could not be made between the U.S. and Mexico. We have no contaminant data from the interior of northern Mexico where some Ruby Lake herons wintered.

Black-necked Stilt—Stilts are summer residents in Nevada from at least May to September (Linsdale 1936). At Malheur Lake, the average spring arrival date was 27 April (5 April to 25 May) (Littlefield & McLaury 1973) with the peak fall departure date from 1 to 10 August and the latest 9 October (Littlefield & Cornely 1984). In California, the stilt is a common summer visitor and arrives from late March to early April and generally departs by mid-October (Grinnell et al. 1918). Stilts winter from the extreme southern U.S. through Mexico to the northern half of South America (Blake 1977, Rappole et al. 1983, Unit 1984). Alden (1969) reported that 153, 631, 386, and 904 stilts were seen at Christmas in coastal Nayarit, Mexico (San Blas), from 1964 to 1967, respectively. Smith and Stiles (1979) showed an increase in stilts, apparently migrants, along coastal Costa Rica from September through April. Wetmore (1965) recorded only two sightings of the species away from the coast in Panama. The specific wintering locality for the Carson Lake population remains unknown, but it probably is in the coastal zone.

Snowy Egret—Snowy Egrets banded in Nevada and Idaho were reported during winter in western Mexico and Guatemala (Table 7). The four records with known recovery localities were from the coastal zone. Three Snowy Egrets banded in Utah were also found in the coastal zone of western Mexico. Although some egrets winter in southern California (Unit 1984), the birds from Nevada apparently winter farther south in western Mexico and Guatemala.

White-faced Ibis—Ryder (1967) and Capen (1977) concluded that most ibis migrate from the Utah marshes to Mexico in late September and early October with a few stragglers remaining until December. Idaho and Nevada ibis also winter in Mexico (Table 7). Steele (1984) thought some ibis from Carson Lake relocated in northern Utah during the 1977 drought at Carson Lake. Generally, ibis are somewhat nomadic in response to local changes in conditions (Ryder 1967). The adjacent states of Michoacan, Jalisco, and Colema accounted for many of the Mexican recoveries of birds banded in Utah—56% (Ryder 1967), Nevada—50%, and Idaho—38%. Blake (1977) reported that ibis were observed chiefly in freshwater habitats. Many ibis winter inland in Mexico in the large agricultural states of Michoacan and Jalisco in contrast to night-herons, egrets, and probably stilts, which winter primarily in coastal areas.

CONCLUSIONS

Specific organochlorine pollutants in eggs decreased significantly in at least one colony for each of the following species: Black-crowned Night-Heron—DDE, DDD, DDT, chlordanes, dieldrin, and PCBs; Black-necked Stilt—DDT; and White-faced Ibis—DDT. Generally, residues also declined ($P > 0.05$) in eggs at the sites with more limited data. An exception was the large ibis colony at Carson Lake, which showed no apparent trend in DDE residues. Nomadic movement on the wintering grounds through areas with differing contaminant burdens may explain year-to-year egg residue fluctuations, but our egg sampling of the large Carson Lake nesting colony may have been inadequate. Steele (1984) noted higher DDE residues in eggs laid later in the season, and we sampled only one nesting segment each year. Additonal ibis research is underway to better understand residue trends and the magnitude of the DDT-DDE problem at Carson Lake related to time of nesting and possible amelioration of adverse effects through recycling.

DDE egg residues were highest in night-herons and were similar in stilts, ibis, and egrets. No significant relationship was detected between DDE and eggshell thickness for stilts. Morrison & Kiff (1979) noted little change in eggshell thickness of American shorebirds (Suborder Charadrii) during the DDT-era and reported only 1.9% thinning in stilts from Utah in 1959. They noted that shorebirds may have a lower sensitivity to DDE-induced eggshell thinning than many higher trophic-level species, in addition to usually possessing lower residue burdens. The lower sensitivity of stilts, compared to the egrets and ibis, which had similar DDE residues, was clear in this study. We estimated by regression analyses the percentage shell thinning resulting from 10 ppm DDE (i.e., a residue level well within the range encountered) in the three affected species; night-herons, egrets, and ibis had 12.0% 12.2%, and 17.7% shell thinning, respectively. Reproductive problems in egrets and night-herons appeared to begin above 5 and 8 ppm DDE, respectively. With the more DDE-sensitive ibis, our limited data suggest that egg cracking became a serious problem above 4 ppm and Steele (1984) showed reduced productivity above 3 ppm. The ibis nesting population at Carson Lake increased from about 2,000 pairs in 1980 to about 3,100 pairs in 1983, but immigration due to extremely high water levels in some breeding areas may have contributed to the increase.

The Ruby Lake night-heron population had (1) the highest DDE and DDT residues and the highest incidence of PCBs (an industrial pollutant; see Zinkl 1982); (2) no contaminant source near the breeding colonies; and (3) a unique wintering distribution that included the southwestern United States (California, Arizona, Texas). The other night-heron populations from Nevada (Stillwater and Halleck) possibly shared the same wintering area, e.g., Halleck had a high incidence of PCBs in 1981. Banding and telemetry data provided evidence that the egrets and ibis plus the night-herons that nested north of Nevada, wintered outside the United States. The PCBs in the Ruby Lake night-heron eggs were more likely obtained from the industrialized southwestern United States rather than from agricultural lands in the interior of Mexico. The Malheur Lake night-herons had the lowest incidence of PCBs (15.5% of eggs), while PCBs were rarely found in stilts (2.5%) and ibis (3.3%), and were absent in egrets. The unique winter localities and residue profiles from Ruby Lake night-herons intimated that DDT-DDE from the southwestern United States was involved in the most serious DDT-DDE problem encountered. Supporting the above conclusion, Northern Pintails (*Anas acuta*) accumulated more DDE and PCBs during fall-winter in the Imperial Valley of southern California than they did in three regions of southwestern Mexico (Mora 1984, Ohlendorf & Miller 1984). Egrets, stilts, and night-herons from Oregon and Idaho may now be benefitting from the generally low DDT-DDE residues in fish from coastal Mexico although fish with elevated DDT-DDE levels were found occasionally in agricultural areas in the coastal zone. Unfortunately, we know nothing about residues of DDT-DDE in the interior of Mexico where the ibis winter.

Clark & Krynitsky (1983) warned that DDT-migratory bird problems that appear at first glance to originate in Latin America may be of domestic origin. We believe a portion of the pollutant problems encountered by the species we studied resulted from wintering ground DDT-DDE accumulations in Latin America; however, the preponderance of evidence implicates the southwestern United States as the source of contamination of night-herons breeding at Ruby Lake Nevada.

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