Bull. Environ. Contam. Toxicol. (1985) 35:767-775

Environmental Contamination and Toxicology

Organochlorine Residues and Eggshell Measurements for Tree Swallows *Tachycineta bicolor* in Colorado

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Tree swallows were more contaminated with p,p'-DDE (DDE) than 49 other species of prey-sized birds collected in the Rocky Mountains and adjacent regions during the nesting seasons 1977-80 (Enderson et al. 1982; L.R. DeWeese unpubl.). DDE in two pooled samples of 7 and 11 adult tree swallow carcasses from Montana and Oregon averaged 10.6 ppm (wet basis) and in three similar pools from Colorado it averaged 18.0 ppm (L.R. DeWeese unpubl.). In contrast, DDE concentrations in five pools of European starlings (Sturnus vulgaris) from the same three states averaged <0.1 ppm (Cain and Bunck 1983). We considered tree swallows at risk to contaminant effects because their DDE residues were 100 to 180 times the level in resident starlings and because 3% of the breeding females in a northcentral Colorado population died on their nests from no evident cause during egg-laying (R.R. Cohen unpubl.).

This paper reports organochlorine (OCL) concentrations in breeding female tree swallows, nestlings, and eggs, and measurements of egg size and eggshell thickness. Our objective was to determine if higher concentrations of OCL chemicals were associated with adult mortality or nesting failure.

MATERIALS AND METHODS

The study area is located 42 km WNW of Denver, Colorado in the Front Range of the Rocky Mountains, including the SW part of Boulder County and the greater part of Gilpin County at 2600 ± 150-m elevation. The mountainous terrain is rolling to steep and characterized by upper montane forest (Marr 1961). During early 1981, 21 nest boxes were erected on fence posts in the study area to attract nesting tree swallows; live females and their eggs were collected. These nest boxes were located near 400 other nest boxes that had been in place since 1975 for a long-term study of tree swallow breeding biology and population dynamics (Cohen 1976). Dead females, unattended eggs, and dead nestlings were obtained from some of the latter nest boxes in 1980 and 1981. All samples were collected in June and July and chemically analyzed for OCLs.

Female swallow carcasses and brains were analyzed individually. Carcasses were prepared by removing the beak, tarsi, feathers,

and gastrointestinal tract. All nestlings from a given nest were pooled intact for analysis. Eggs were measured to determine length, breadth, and volume (by water displacement), then cracked at the girth and contents removed. All eggs had little or no embryonic development. Egg contents from the same clutch were pooled; six clutches of five eggs and four clutches of four eggs were analyzed. Eggshells were washed, air-dried at room temperature for several weeks, and weighed. We measured tree swallow eggshells at the Denver Museum of Natural History and the University of Colorado, Boulder for comparisons with eggshells collected in this study.

Each sample was analyzed for OCL contaminants including p,p'-DDT, p,p'-DDD, p,p'-DDE, dieldrin, endrin, toxaphene, heptachlor epoxide, cis-chlordane, oxychlordane, cis-nonachlor, trans-nonachlor, and polychlorinated biphenyls (PCBs). Samples were homogenized, mixed with anhydrous sodium sulfate, and extracted with hexane in a soxhlet apparatus. Extracts were cleaned by Florisil column chromatography, and pesticides separated from PCBs by silica gel column chromatography (Cromartie et al. 1975). Lipid weights were determined for egg and carcass samples. Residues were quantified by electron-capture gas-liquid chromatography using a 1.5/1.95% SP-2250/2401 column and residues in two samples were confirmed by gas chromatography-mass spectrometry (Kaiser et al. 1980).

The lower limit of reportable residues in egg and carcass samples was 0.1 ppm for pesticides and 0.5 ppm for PCBs. The lower limit in brain samples was 0.5 ppm for pesticides and 2.5 ppm for PCBs. Trial recoveries of pesticides and PCBs from fortified mallard tissue and chicken egg using these methods averaged 96% and 93% respectively. Residues were not adjusted for percent recovery.

Concentrations of OCL chemicals in carcasses (but not brains) were adjusted for moisture loss after death. Residues in eggs were adjusted for moisture loss as described by Stickel et al. (1973) and are reported on a wet-weight basis unless otherwise indicated. Geometric means are used to express chemical residues to avoid over emphasizing extreme high values. Arithmetic means are used for eggshell dimensions and lipid values because they are more normally distributed. Residues in birds and eggs were compared with nonparametric procedures, whereas, percentage lipids were compared with parametric procedures.

RESULTS AND DISCUSSION

Table 1 summarizes OCL concentrations and lipids recovered in the 32 samples. Residues of six OCLs were detected in adult carcasses, four in eggs, two in brains, and one in nestlings. DDE accounted for 91% of total OCL (ppm DDE/ppm total OCL) residue ranging from 0 to 100% in each of the four sample types. DDE was detected in 30 samples (94%) and DDT in 2 samples (6%). Carcasses of breeding females and egg clutches had residues of six OCL chemicals not found in nestling samples. These were: DDT, PCBs,

Table 1. Organochlorine residues in carcasses and brains of breeding female tree swallows, eggs, and nestlings.

Sample type	(n)	% Lipids[b]	Residues (ppm, wet weight)[a] p,p'-DDE	PCBs	Other OCLs[c]	Total OCLs
Carcasses						
Alive[d]	(5)	12.9±0.7	4.4(5) 18	0.30(2) 0.60	0.11(2) 0.90	5.3(5) 18
Dead[e]	(6)	8.3±1.9	7.9(6) 44	0.37(3) 0.84	0.57(5) 2	9.3(6) 47
Brains						
Alive[d]	(5)	-	0.76(3) 1	ND	0.11(1) 3	1.3(4) 3
Dead[e]	(3)	-	1.3(3) 2	ND	ND	1.3(3) 2
Eggs						
Attended[d]	(5)	2.9±0.2	1.3(5) 6	0.25(1) 0.25	0.06(1) 0.18	1.8(5) 7
Unattended[e]	(5)	5.2±0.4	2.8(5) 7	0.33(3) 0.51	0.07(1) 0.17	3.3(5) 8
Nestlings						
Dead[e]	(3)	5.1±2.1	0.36(3) 0.83	ND	ND	0.36(3) 0.83

[a] Geometric mean, (number of positive samples), and maximum; one-half detection limit substituted for zero values; see text for chemical abbreviations (ND = not detected).

[b] Arithmetic means ± standard error of mean; - means no data obtained.

[c] Other OCLs include - frequency, ppm extremes: heptachlor epoxide - 9, 0.11-1.3; oxychlordane - 7, 0.05-0.55; DDT - 2, 0.18-2.8; dieldrin - 1, 0.11, and trans-nonachlor - 1, 0.09.

[d] Females, their brains and eggs.

[e] Carcasses and brains, but not eggs or nestlings, from the same females.

heptachlor epoxide, oxychlordane, dieldrin, and trans-nonachlor. The latter two were found only in female carcasses. Only residues of DDE were found in nestlings. DDT and DDE were the only OCLs recovered in brain samples, but higher sensitivity could account for the absence of other OCLs.

Only the DDE residue values and the total of all detectable OCLs were adequate for quantitative statistical comparison. By using these two variables, there were no significant ($P>0.05$) within-group (alive vs. dead; attended vs. unattended) or among-group (carcasses vs. brains vs. eggs vs. nestlings) differences (Wilcox-on-Mann-Whitney two-sample test, Steel and Torrie 1980). Of 11 females, five had carcass levels of DDE below 5 ppm. The other six birds had 6, 7, 7, 15, 18, and 44 ppm DDE; those with 15 and 44 ppm DDE were two birds found dead. Carcass lipids in dead females were lower than in live birds, but not significantly ($t=2.10$, $df=9$, $P=0.09$).

In an earlier study, several migrant passerines (including tree swallows) breeding in Colorado had mean DDE concentrations two to four-fold higher than resident species with similar food habits (Enderson et al. 1982). This suggests higher DDE contamination existing in some migrants is obtained away from their Colorado nesting habitat. Low DDE residues in nestling tree swallows relative to adults also suggest that nesting habitat is not the primary source of DDE. Relatively high DDE residues found in birds in Arizona, New Mexico, and Texas indicate the possibility that those areas are a significant U.S. source of DDE for wintering migratory birds (Clark and Krynitsky 1983). Other sources of DDE are suspected in areas south of the U.S. border. Whitethroats (Sylvia communis) breeding in Sweden (Persson 1971) and American robins (Turdus migratorius) breeding in parts of Maine (Knupp et al. 1966) also received their major exposure to OCL chemicals during migration.

DDE residues in three banded females were higher in older birds. Their approximate ages (based on known or estimated age at banding) and carcass concentrations were: one year (alive), 1.4 ppm DDE; two to three years (dead), 2.4 ppm DDE; and six to seven years (dead), 44.1 ppm DDE. Seven different OCL compounds were detected in the oldest female, while only four OCLs were detected in the two younger birds. There are few examples for birds of increasing DDE residues with age, however, this was reported for herring gulls (Larus argentatus) (Faber 1978). In addition, the following-year recapture rates of female tree swallows banded in the study area 1975-82 are roughly 50% for two-year-olds, 45% for three-year-olds, 36% for four-year-olds, and 30% for five-year-olds (R.R. Cohen unpubl.). This decline is significant for four and five-year olds ($\chi^2=5.01$, $df=1$, $P=0.025$). Survival rates of Passeriforms are not known to decline naturally after the first year of life (Henny 1972). This evidence suggests reduced survival of females in this tree swallow population and a possible relationship with DDE.

Concentrations of DDT and its metabolites in avian brain tissue

can indicate cause of death (Stickel et al. 1966; Stickel et al. 1970). Maximum residues of brains of our tree swallows were 5.1 ppm DDE and 2.8 ppm DDT, both in live birds; DDD was not detected. These levels are far below the ≥314 ppm DDE, or ≥65 ppm DDD found in 95% of brown-headed cowbirds (Molothrus ater) that died after dietary exposure (Stickel et al. 1970) and the 30 ppm DDT plus DDD considered the lower limits representing danger and possible death in cowbirds (Stickel et al. 1966). It appears birds collected in this study were not threatened by the amounts of DDT/DDE present in their brains. DDE residues averaged 7.4 ppm (wet basis) in the brains of cliff swallows (Petrochelidon pyrrhonota) that died in Oregon following unusually cold spring weather (Henny et al. 1982). Exposure and starvation, and not DDE, were considered important to the cause of death.

DDE stored in the body fat of tree swallows could become lethal if enough µg of chemical became mobilized to the brain during periods of rapid fat utilization (Van Velzen et al. 1972). Birds fed DDT or DDE eventually mobilized a variable percentage of total carcass residue burden to their brains. This percentage ranged from 0.5 to 2% in survivors (Porter and Wiemeyer 1972; calculations by the present authors from data in Van Velzen et al. 1972; Stickel et al. 1970) and 10 to 20% in birds that died (Porter and Wiemeyer 1972). Corresponding values for dieldrin were 0.3 to 1% in the brains of survivors (Jefferies and Davis 1968) and 0.6 to 10% in the brains of those that died (ibid., Stickel et al. 1969). The brain weights of our tree swallows averaged 0.27 g and two birds had 279 and 537 µg of DDE in their carcasses. Therefore, a 15 to 30% mobilization rate could yield a lethal brain residue in these birds. About 10% of our female tree swallow samples fell into this category. Male tree swallows in NW Colorado had nearly twice the DDE residue burden of females collected at the same time (L.R. DeWeese unpubl.). Therefore, individuals of either sex, if forced to rely heavily on fat reserves, could receive immediate toxic effects of stored DDE (Van Velzen et al. 1972).

The carcasses of four female tree swallows were examined for evidence of gross pathology. A bird collected alive and one found dead appeared normal; one dead bird had an enlarged spleen; another a deep bruise on the breast. Uric acid crystal deposits on the heart of the latter bird suggested a protein deficiency. Of six dead females, four had carcass lipids below the lowest level of any collected alive. Lipids in two birds were nearly as low in tree swallows that died during unseasonably cold weather in Utah (Whitmore et al. 1977). It appeared that starvation, injury, and disease may have contributed to the deaths of some tree swallows we examined.

DDE concentrations were 1.4 and 3.9 ppm in clutches of eggs from nests with dead females; 1.4, 2.9, and 7.4 ppm in unattended eggs; and 0.3, 0.9, 1.4, 1.5, and 6.3 ppm in attended eggs. Although unattended eggs and those with dead females combined had nearly two times the average DDE and total OCL levels of attended eggs, these concentrations were not significantly different ($P>0.05$,

Wilcoxon-Mann-Whitney two-sample test). A review of several studies of passerines indicates that perhaps 8 to 9 ppm or perhaps higher total DDT residues in eggs is needed before reduced reproduction becomes evident (Persson 1971; Dyck et al. 1972; Johnson et al. 1976; Wilson 1980).

Levels of DDE <1.0 ppm were detected in a single nestling and two pools of nestlings, all found dead in three different unattended nests. Combined DDE and DDT residues below 9 ppm are probably not directly lethal to passerine nestlings (Dyck et al. 1972). Dead or killed nestlings of great tits (Parus major) and dead nestlings of American robins in orchards treated with DDT had up to 25 and 80 times higher total-DDT residues than our dead tree swallow nestlings (Bejer-Petersen et al. 1972; Johnson et al. 1976).

Measurements of tree swallow eggshells collected in North America prior to 1915 and for this study are given in Table 2. Wide overlap of 95% confidence intervals for each variable indicate that measurements of unattended eggs (1980 and 1981) were not significantly ($P>0.05$) different from those of attended eggs (1981) or historical eggs.

Although shell thinning was not demonstrated for Colorado tree swallows, studies of passerine eggshells collected before and after the use of DDT have found 7 to 18% eggshell thinning (Alsop 1972; Rothstein 1972; Anderson and Duzan 1978). In the present study, the tree swallow eggs with higher residue levels had heavier shells, perhaps because those eggs were larger. American robin eggs with 4.4 ppm average total-DDT residues also had heavier eggshells than those collected prior to DDT use (Knupp et al. 1976).

DDE concentrations in Colorado tree swallows could have a serious impact on sensitive bird-eating avian predators, including peregrine falcons (Falco peregrinus). Over three-fourths of adult female tree swallows contained carcass concentrations >2.8 ppm DDE. Studies with penned populations of raptor species fed 2.8 to 3.0 ppm (wet basis) DDE demonstrated 10 to 28% eggshell thinning and 11 to 41 ppm DDE egg residues (see Mendenhall et al. 1983). Peakall (1976) concluded that 15 to 20 ppm DDE in peregrine falcon eggs seriously reduced hatching success.

Results of our study fail to demonstrate a strong relationship between DDE contamination and survival or reproduction of tree swallows in northcentral Colorado. However, higher DDE residues in dead females and unattended eggs suggests possible DDE interference with essential biological processes. The cause of reduced survival with increasing age is unknown at present and could have negative effects on the population if it continues. A second study is needed in which a single egg per clutch of known-age banded females would be taken for analysis and the success of the remaining eggs in each nest followed through fledging of the young. This would permit examination of the approximate chemical burden in known-age breeding females (expressed in the egg residue) in relation to their survival and reproductive success. The mechanism

Table 2. Eggshell data for tree swallows collected in Colorado and other states pre-DDT use (1887 to 1914) and in Colorado post-DDT (1980 and 1981)[1].

Category, years and location	No. clutches sampled	Egg size (cm) Length	Egg size (cm) Breadth	weight (g)	Shell index[2] (g/cm^2)
Pre-DDT era					
Colorado	5	1.874±0.093	1.324±0.031	0.096±0.007	0.039±0.001
California, Washington and Wisconsin	7	1.863±0.084	1.331±0.062	0.099±0.018	0.040±0.004
All states combined	12	1.867±0.051	1.328±0.033	0.097±0.009	0.039±0.002
Post-DDT era, Colorado					
1980 unattended nests					
Group A[3]	5	1.928±0.194	1.334±0.056	0.099±0.015	0.039±0.009
Group B[4]	4	1.820±0.186	1.332±0.035	0.100±0.013	0.041±0.003
Groups A + B	9	1.889±0.111	1.333±0.027	0.099±0.009	0.040±0.005
1980 attended nests[3]	5	1.796±0.060	1.302±0.067	0.091±0.009	0.039±0.004
1981 unattended nests	12	1.882±0.082	1.337±0.021	0.100±0.004	0.040±0.002

[1] One egg was taken randomly from each clutch; data are mean ± 95% confidence limits.
[2] After Ratcliffe 1967 (weight/(length x breadth).
[3] Corresponds to eggs in Table 1 that were analyzed for pesticides.
[4] Eggs not analyzed for pesticides.

by which DDE may be influencing the population will remain unknown without further study.

Acknowledgements. We thank B.E. Petersen and M. Earlene Swann for preparing samples and measuring eggshells; L.F. Blus, Martha L. Gay, L.C. McEwen, and B.K. Williams for improving earlier drafts of the manuscript; and Lu Watkins for typing the manuscript.

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Received January 12, 1985; accepted January 28, 1985.