POLYCHLORINATED BIPHENYLS IN THE GLOBAL ECOSYSTEM

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ABSTRACT

Compounds identified as polychlorinated biphenyls, pollutants of industrial and agricultural origin, are now widely dispersed in the global ecosystem. Tissues of peregrine falcons have contained the highest concentrations so far measured. Significant amounts are also present in several species of pelagic sea birds. The geographical distribution patterns indicate that the polychlorinated biphenyls, DDT, and the other chlorinated hydrocarbon biocides, are dispersed predominately by air transport. The polychlorinated biphenyls are powerful inducers of hepatic enzymes which degrade oestradiol. Their enzyme inducing activity in pigeons is approximately four times as great as that of technical DDT and six times that of p,p'-DDE. Both the polychlorinated biphenyls and p,p'-DDE could account for a significant portion of the environmental deterioration which has caused the aberrant calcium metabolism observed in raptors and other species of birds since the Second World War.

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Deterioration of the environment has proceeded at a rapid pace and it is universally accepted that it has caused the extinction of some species and has profoundly influenced the relative abundance of others. Whether chemical changes in the global ecosystem have been sufficient to cause widespread harmful effects is still a matter of controversy, yet the interpretation of Ratcliffe's findings that the calcium metabolism of British peregrine falcons (Falco peregrinus) changed adversely just after the Second World War is unambiguous (1). A widespread change in the chemical environment has occurred which has affected not only the calcium metabolism of the peregrine falcon but also of other raptors and terminal avian carnivores in both Britain and North America. In every case thin eggshells have been associated with populations which were declining and which were also contaminated with the synthetic chlorinated hydrocarbons which have come into general use since the war. Moreover, geographic variations in eggshell thicknesses have been correlated with the amounts of chlorinated hydrocarbon residues in populations of peregrine falcons, bald eagles Haliaeetus leucocephalus, ospreys Pandion haliaetus, double-crested cormorants Phalacrocorax auritus, and herring gulls Larus argentatus (1,2). No other environmental change, such as radioactive fallout, has shown comparable variation over a wide geographical area.

Calcium physiology is intimately related to reproductive physiology and is to a large extent regulated by steroids such as estrogen and vitamin D (3). All or most of the synthetic chlorinated hydrocarbon biocides so far tested induce hepatic enzymes which degrade steroids

by hydroxylating them, thereby increasing the rate at which they are excreted (4, 5, 6, 7, 8, 9). The relatively small amounts required to produce this effect (6,10,11,12,13) and the discovery that small amounts of DDT appear to have estrogenic effects (4) have made irrelevant much of the parts per million approach to pollutant ecology based only upon toxicity data.

In both Great Britain and North America it was the decline of the peregrine falcon which has initiated concern about the possible harmful effects of environmental contamination. In the distinguished tradition of British field ornithology, the population collapse in Great Britain was well documented (14,15,16,17) but in the United States the eastern population was extinct before competent observers were aware of a general, widespread decline (18). Breeding peregrines persist in apparently normal numbers in the Pacific northwest (19) and in the Arctic (20,21). A small remnant population remains in southwestern North America.

In 1967 we collected an unhatched, abandoned egg in Baja California, Mexico. Analysis of this egg (Table I) showed that it contained almost 5 milligrams of p,p'-DDE, indicating a high level of contamination in both the adult female and the local peregrine population. Considerable effort was made to identify the unknown peaks present in the chromatograms but these attempts were unsuccessful until the reports appeared from Sweden (22,23) and Great Britain (24) identifying polychlorinated biphenyls in European wildlife. The published chromatograms of the commercial mixture of polychlorinated biphenyls (PCB) and of an extract of a European kestrel (Falco tinnunculus) (24) were very similar to those

times of the unknown peaks in these extracts proved to be identical with those of several PCB compounds on DC-200 and QF-1 columns (25) and on a mixed SE-30:QF-1 column. The chlorine content of several extracts and standards was determined with a Dohrman microcoulometric detector and a method of quantification of the PCB peaks was devised based upon peak heights produced in the electron capture detector related to standard p,p'-DDE (25). Toxaphene, a mixture of polychlorinated camphors, has been reported to be resistant to nitration, whereas DDT is destroyed (26). PCB is also not destroyed by this procedure.

In Table I are presented the results of analyses of peregrine falcons, all of which were originally trapped for the purpose of falconry, which died shortly afterwards in captivity from a variety of causes and were then donated to us for analysis. Significant amounts of PCB were present in Arctic peregrines only a few months old (Nos. 5 and 6), but higher residues were present in a second year Arctic bird (No. 2) and exceptionally high residues were present in an adult trapped in California (no. 4). In birds 2 and 4 the total lipid reserves were very low, and in both the brain levels of DDE and PCB were high, perhaps at toxic levels. Fat mobilization during reproduction or in times of starvation or stress could be expected to cause significant changes in the internal distribution of chlorinated hydrocarbons. Steroid hydroxylase activity in the liver might increase at this time. Dieldrin concentrations were lower than in the peregrines analyzed in Britain, but DDE concentrations were approximately comparable (28).

In Table II are presented the results of analyses of peregrine prey species, remains of which were collected at eyries in Baja California, Mexico. With the exception of the remains of one mourning dove (Zenaidura macroura) and of three fish bats (Pizonyx vivesi), prey material found at four eyries consisted of sea birds. Of these, the eared grebe (Podiceps caspicus) and the black petrel (Loomelania melania) constituted 32% and 25%, respectively, of the remains. Black petrels, like other petrels and shearwaters (29,30, Table III) contained especially high concentrations of both DDT and PCB, a fact which appears to result from their feeding upon organisms at the sea surface, which would receive the components of aerial fallout. Reproductive success in this population of peregrines appears to be subnormal. In 1968, each of two pairs hatched only one young, both of which were fledged. Two other pairs apparently fledged only one young per eyrie and none was observed to hatch or to fledge more than a single young. In the past, two to four young, the number normally produced by healthy peregrines (20), were raised by each pair (31). The region is wilderness, with little or no human interference, and is remote from sources of pollutant application.

In California, numbers of breeding peregrines have been reduced by at least 80% in recent years. Despite minimal human interference, peregrines have disappeared from the nearby Islas Coronados in Mexico, where it can be inferred that they preyed upon seabirds. The remaining few pairs in California, however, appear to be reproducing normally and rear, when undisturbed, 2 to 4 young each year. They are found, like most of the surviving peregrines in Great Britain (17), in a relatively

low levels of chlorinated hydrocarbons. Twenty seven remains of 16 prey species collected at a coastal eyrie which produced three young birds in 1968 included 8 mourning doves, one rock dove (Columba livia), 2 woodpeckers, 8 passerine species, one grebe and 6 shorebirds (Scolopacidae). No analyses of the prey species from that region have yet been made, but mourning doves from San Diego (Table III) contained very low residues. On the basis of the residue data available on land and water birds in California (29,32), it is a reasonable hypothesis that the food species of this pair and of other successful pairs at inland eyries are less contaminated than water birds preyed upon by peregrines elsewhere. A clutch of eggs collected in this region contained the normal, prewar, amount of calcium, whereas other peregrine eggs from California collected since the Second World War have contained significantly smaller amounts (2). Despite official protection, the surviving birds are still subjected to shooting by sportsmen and to harrassment of the eyries. If these could be effectively reduced, the populatinn might yet survive.

In Table III are presented the results of analyses of marine and terrestrial birds and of three species of fresh water fishes for PCB and DDT content and concentration. From the ratio of total DDT to PCB, it is apparent that regional fallout patterns for the two compounds exist. In almost all of the fishes (25) and the birds from San Francisco Bay which have been analyzed, this ratio is between one and two. Among the birds this was true for the peregrine falcons (Table I), the western gull eggs, the Caspian tern eggs and one of two black-crowned night heron eggs (Table II). The other black-crowned night heron egg had a typically "ocean" profile, suggesting that the adult female had spent the winter

along the coast. In most of the birds from the Farallon Islands, which are 27 miles west of the Golden Gate Bridge, this ratio is between 2 and 5. In Panama, where PCB contamination might come from the Canal Zone and industrial areas in Panama City, the ratio is between 1 and 2 (Table III).

In the Gulf of California, a region relatively remote from the sources of either DDT or PCB contamination, this ratio is in most cases approximately 9 or 10. This was true in the egg of the peregrine falcon (Table I) in all of the black petrels and least petrels analyzed, in the Craveri's Murrelets (Table II), in five of six osprey eggs, and in six of seven western gull eggs (Table III). Among the exceptions, the fish bat, with relatively more DDT, but with low concentrations of both DDT and PCB, was the most divergent, with a ratio of 43 (Table II). It is not clear whether this reflects differences between avian and mammalian physiology or a fundamental difference in feeding habits. The exceptions among the osprey and western gull eggs had relatively more PCB; the profiles of the chromatograms resembled those of the Caspian tern from San Diego. The adult females might, therefore, have come from the other side of the peninsula of Baja California. In the eggs of both the elegant terns and the Heermann's gulls, this ratio is lower, reflecting higher amounts of PCB relative to DDT. Both species migrate out of the region following the nesting season and most likely acquire their PCB residues elsewhere.

In sea birds from the Pacific, whether in the fulmars, red phalarope, ancient murrelet and rhinoceros auklet, species nesting in the Arctic and the North Pacific, or in the shearwaters which breed in Australia, New Zealand and Chile, this ratio was usually between 5 and 10. PCB was not

found in eggs of the Adélie Penguin, brought from Cape Crozier, Antarctica and kindly made available for analysis by Dr. R. E. Feeney. In these, however, the amount of DDT on a lipid weight basis was very low and the ratio of DDT to the lowest amount of PCB which could have been detected was only 18. A larger amount of fat material from Antarctic organisms, which would yield a sufficient amount of DDT would, therefore, have to be analyzed before concluding that PCB has not yet reached the Antarctic.

The presence of PCB in the few land birds analyzed shows that it is also distributed among terrestrial ecosystems in North America. The PCB concentrations in the three species of fresh water fish from Clear Lake, Lake County, California, were very low, lower than those in marine fish from San Francisco Bay and Puget Sound, and in several cases, lower than those in fish from the Pacific Ocean (25).

Individuals of species resident in industrial areas have, as expected, higher PCB levels than individuals of the same species from more remote regions. Analysis of 10 eggs from 10 clutches of the western gull from the Farallon Islands showed an average DDT concent of 412 micrograms with a standard error at the 95% confidence level of 102 and a PCB content of 136 $\pm$ 55. DDT and PCB content of 4 eggs from 3 clutches from an island in San Francisco Bay was significantly higher (Table III). Seven eggs from 7 clutches in the Gulf of California contained 385 $\pm$ 230 micrograms of DDT and 45 $\pm$ 30 micrograms of PCB. The DDT content is, therefore, not significantly different from that of the Farallon eggs, but the PCB content is much lower.

Birds from the Gulf of California also contain dieldrin and endrin (Tables II and III) but the number of analyses is as yet insufficient to

compare their relative abundance to that of DDT and PCB. Despite the inability of the Shell Chemical Company to find any chlorinated hydrocarbons at the mouth of the Colorado River which drains into the Gulf (34) it is likely that some do enter from that source. A significant fraction, however, must come from the atmosphere (35), and air transport best explains the presence of PCB in remote areas. They are poorly soluble in water and have very low but finite vapour pressures (36). Incineration of PCB-containing materials would greatly increase the rate of entry into the atmosphere. Since PCB is used in the manufacture of many industrial products, the high amounts found in San Francisco Bay, Puget Sound (25) and San Diego Bay presumably result from direct discharge of industrial wastes into these waters.

The PCB compound with retention time 1.25 on DC-200 columns and 1.33 on QF-1 columns, relative to p,p'-DDE, is one of the more prominent peaks in San Francisco Bay extracts and in the commercial mixtures, yet it is not present or is present in relatively lower amounts in extracts from Baja California and Panama. To test the possibility that PCB might be subject to degradation by ultraviolet light, standard PCB solutions in hexane were evaporated to dryness in petri dishes, or over layers of water and 3% NaCl solution, and irradiated at a distance of 4 inches with a 15-watt germicidal lamp emitting at 2537 A. In each case, the major change in the chromatograms of the irradiated PCB was a reduction in the relative height of this peak. The effect was more pronounced when PCB was irradiated on the aqueous surfaces.

Peregrines could, therefore, acquire PCB as well as the other chlorinated hydrocarbons, over all of their global range. No PCB

residue data are available for prey species from the Atlantic, but compounds which appear to be PCB have been isolated from seals (33). A second year male peregrine spent the winter of 1967-68 on Isla Pacheca, Panama, where the pelican, booby, and frigate bird eggs of Table III were collected. The high concentrations in all of the petrels analyzed suggest that the fork-tailed petrels (Oceanodroma furcata), a major prey species of the Peale's race of the peregrine falcon in British Columbia (19, might be similarly contaminated.

The white-tailed kite is becoming abundant in areas of California where insecticide use is intense, yet because it preys primarily upon the short-lived and herbivorous vole Microtus, the species accumulates very low residues of either DDT or PCB. The American kestrels and the barn owl eggs analyzed also contained very low residues. Both species are very common in California. In contrast, the single Cooper's Hawk, a species which elsewhere has shown thinning of eggshells (2) and which preys upon birds, contained high amounts of both DDT and PCB (Table III).

The percentage of p,p'-DDE in the total DDT residue has been given in the tables below. In almost all cases it is above 80 percent. It is most likely, therefore, the most ecologically relevant of the DDT compounds although the differences in estrogenic activity among the various DDT compounds (4) suggest that biological effect does not necessarily reflect parts per million concentrations.

Previous work (13) has shown that both DDT and dieldrin induce hepatic enzymes in the pigeon which, in an in vitro preparation, increase the metabolism of progesterone and testosterone. This work has now been extended to study the metabolism of oestradiol by enzymes induced by

p,p'-DDE, technical DDT (Dupont) and PCB (Aroclor 1262). The experimental procedure previously described (13) was followed except that the chlorinated hydrocarbons were injected intramuscularly rather than given orally and in the separation of oestradiol and its metabolites, the solvent system used was the upper layer of a mixture of benzene:heptane:methanol:water 7:3:8:2. The strips were monitored with an autographic strip scanner. The profiles obtained for the various inducing agents are shown in figure 1. It will be noted that the profile of the metabolites obtained following enzyme induction using DDE and DDT are identical, but that a different metabolite is produced by the enzyme induced by PCB. The amount of metabolites formed was calculated from the radioactivity of the peaks. The results obtained are given in Table IV.

p,p'-DDE at body concentrations of 40 ppm in the pigeon significantly increases the rate of oestradiol degradation by the induced hepatic enzymes under the experimental conditions. It may be concluded, therefore, that DDE in nature increases the rate of metabolism of estrogen and other steroids as they pass through the liver. The metabolites produced are more polar and their biological activity is most likely altered. On a weight basis, the PCB preparation had an oestradiol degrading potential approximately 5.6 times that of p,p'-DDE and 4.1 times that of technical DDT. PCB and p,p'-DDE may, therefore, be the most ecologically significant pollutants now accumulated by organisms.

Studies on the activity of induced enzymes in the rat at various times after a single injection of DDT or dieldrin have been made by Ghazal (37). He found that it took 70 days for the activity to fall to half its maximum value in the case of DDT and 15 days in the case of

dieldrin. Experiments with dieldrin on pigeons show that only a quarter of maximum activity remains after a month. Thus, there is evidence that the effects of these induced enzymes can persist over a long period of time although more studies are needed to determine the steroid degrading potentials of livers of those species contaminated with chlorinated hydrocarbons. The profile of the metabolites should be some indication of the history of exposure to chlorinated hydrocarbons.

Decreases in eggshell thickness and eggshell weight have amounted to as much as 19% in both Britain and America (1,2). Chances of eggshell breakage are thereby greatly increased (1,14). Humidity may significantly affect the hatching success of duck eggs (38,39) and decreased eggshell thickness in poultry has been shown to cause decreased hatching success through increased water loss from eggs (40,41). The environment in which birds now exist is no longer the same as that in which they evolved; it is unlikely that any species has the genetic capacity to meet the selection pressures resulting from the abrupt environmental change which has produced the thin eggshells.

Several mechanisms may account for the aberrant calcium metabolism observed in peregrines and other birds. Vitamin D, a steroid, is essential for the absorption of calcium from the alimentary tract and increases the level of calcium available from bone resorption (42,43). Hens deficient in Vitamin D lay eggs with lower eggshell weights, less yolk calcium, and presumably, with lower Vitamin D contents. The developing embryos of such eggs utilize less calcium from the eggshell (44). Reduced levels of estrogen and androgen could be expected to reduce the deposition of medullary bone, a major source of calcium during egg and eggshell formation

(3,45,46,47). Lowered estrogen levels could also affect both the amount of calcium normally excreted (48) and the concentration of serum calcium which normally increases under estrogen stimulation as a result of liver synthesis of yolk proteins which are bound to calcium (45). Induction of steroid metabolizing enzymes by chlorinated hydrocarbons could affect any of these processes.

Vitamin A mobilisation is also influenced by estrogen (49,50) indicating that eggs of contaminated birds might be deficient in vitamin A. Bumblefoot is a foot ailment that has showed an increased incidence in captive peregrine falcons in recent years. Both prophylaxis and treatment involve the administration of vitamin A.

Fortunately, all of these hypotheses are subject to experimental test: alienated molecular biologists are now in a position to perform an enormous and invaluable service to the world's wildlife and to those concerned with its preservation. The peregrine falcon is a species long highly revered and respected. G.H.Thayer (51) has described it as "the embodiment of noble rapacity and lonely freedom". A subtle irony therefore exists in the fact that the peregrine may be the first species to be extirpated by global contamination.

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Table 1: Chlorinated hydrocarbons in North American peregrine Falcons. Concentrations in parts per million, wet weight, dry weight, or lipid weight.

Sample	Dieldrin	Total DDT[a]	%DDE	PCB	DDD/PCB
1. Unhatched egg[b] Baja California (wet)	0.11	102	97	10.2	10
2. Second year[c] migrant from Arctic					
breast muscle (wet)	NM	99	94	28	3.5
breast muscle (dry)		296		84	
brain (wet)	NM	85	98	21	4.7
carcass (wet)	0.87	70	93	19.7	3.5
carcass (lipid)	62.5	5000		1420	
3. Immature, California[d]					
breast muscle (wet)	NM	14.4	90	9.4	1.5
liver (wet)	NM	7.7	92	4.5	1.7
brain (wet)	0.04	2.8	89	1.5	1.9
brain (lipid)	0.50	36		19.3	
carcass (wet)	0.11	20.2	92	10.8	1.9
carcass (lipid)	1.6	300		160	
4. Adult, California[c]					
breast muscle (wet)	NM	127	87	98	1.3
liver (wet)	NM	77	80	57	1.4
brain (wet)	0.31	49.5	86	34.6	1.4
brain (lipid)	3.7	595		415	
carcass (wet)	1.7	85	87	65	1.3
carcass (lipid)	50	2600		1980	
5. Immature[f] migrant from Arctic					
breast muscle (wet)	NM	2.3	81	0.16	14
breast muscle (dry)		7.8		0.54	
liver (wet)	NM	1.0	92	0.10	10

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Table 1, continued

brain (wet)	NM	0.43	83	0.03%	12
body fat (wet)	NM	50.3	82	3.2	16
carcass (wet)	0.07	9.3	82	0.80	12
carcass (lipid)	0.44	63.7		5.5	
6. Immature Arctic migrant (g)					
breast muscle (wet)	NM	1.9	89	0.6	3.4
breast muscle (dry)		6.0		1.9	

[a] DDT residues include: p,p'-DDT, p,p'-DDE, p,p'-DDD (p,p'-TDE), p,p'-DDMU, o,p'-DDT and o,p'-DDE. NM: not measured.

[b] Chlorinated hydrocarbon contents of the egg were: 4,700 micrograms p,p'DDE; 40 micrograms o,p'-DDE; 29 micrograms p,p'-DDT; 7.4 micrograms p,p'-DDD; 37 micrograms p,p'-DDMU; 5 micrograms dieldrin; 12 micrograms heptachlor epoxide. Concentrations were calculated by assuming a volume of 47.3 ml., the average value obtained by measuring 11 clutches of peregrine eggs from California in the Museum of Vertebrate Zoology, University of California, Berkeley, and by assuming a density of 1.0.

[c] Second year female, captured in October on the Texas coast during migration. Died in captivity shortly afterwards, no apparent cause of death. No body fat. Total body content of chlorinated hydrocarbons: 35 mg. DDT, 10 mg. PCB, 0.44 mg. dieldrin, 0.18 mg. heptachlor epoxide. Total body lipid, 7 gm.

[d] Plumage characteristics of both 3 and 4 were intermediate between those of typically resident California birds and the arctic race F.p. tundrius, as described by White (27). No. 3 was immature female of the year trapped in the southern San Francisco Bay area in the winter of 1966. Observed feeding in the area for a week prior to capture. Died suddenly after eating a dead gull. Moderate body fat. Total body chlorinated hydrocarbon content: 13 mg DDT,

6.8 mg. PCB, 0.07 mg. dieldrin, 0.09 mg. heptachlor epoxide. Total body lipid, 43 gm.

[e] Adult female. Trapped in the southern San Francisco Bay area in the winter of 1966. Observed feeding in the area for a month prior to capture. Died shortly afterwards with no apparent cause of death and no body fat. Total body chlorinated hydrocarbon content: 52 mg. DDT, 40 mg. PCB, 1.0 mg. dieldrin, 1.0 mg. heptachlor epoxide. Total body lipid, 20 gm.

[f] First year female trapped on the Texas coast in October. Lost at Pt. Mugu, California, the following January and was shot by a sportsman 3 weeks later. Abundant body fat. Total body content: 7 mg. DDT, 0.6 mg. PCB, 0.05 mg. dieldrin, 0.17 mg. heptachlor epoxide. Total body lipid, 110 gm.

[g] First year female trapped on the Texas coast in October. Died shortly afterwards of heat prostration.

Table II. PCB and DDT in prey species of Peregrine Falcons in the Gulf of California. Content in micrograms of whole bodies and eggs; concentrations in parts per million wet weight (W) or lipid weight (L).

Species [a]	N	DDT µg	DDT ppm	%DDE	PCB µg	PCB ppm	DDT/PCB
Eared Grebe (13) Whole body	3	...	0.28,0.26, 12.1	97	NM [b]		...
Black Petrel (10) Whole body	8	810 (685-1344)	9.2(W)	81	...	1.0(W) (0.90-1.14)	9.2
Least Petrel (6) Whole body	3	99	3.2(W)	83	...	0.35(W)	9.3
Eggs	2	30 (23-37)	...	84	3.1 (1.2-5.0)	...	10
Fish Bat (3) Whole body	7	25 (15-31)	0.71(W)	62	0.58 (0.45-1.06)	0.02(W)	43
Craveri's Murrelet (2) eggs (one clutch)	2	230 [c] (223-238)	39(L)	80	...	4.5(L)	8.7
Whole body, adult	1	37.1	0.31(W)	85	...	0.039(W)	7.9
Whole body, adult	1	295	2.4(W)	85	...	0.26(W)	9.2
Elegant Tern (1) Eggs	8	15.5 (9.6-24.3)	5.0(L)	90	...	1.5(L) (0.8-3.6)	3.9
Heermann's Gull (1) Eggs	3	195 (94-278)	48(L)	95		8.1(L) (3.5-11.3)	5.9

[a] All specimens were collected in the vicinity of four peregrine eyries in Baja California. Numbers in parentheses are the number of remains of each prey species which were found at the eyries. Also found were remains of one cormorant. (Phalacrocorax sp.), one Red Phalarope (Phalaropus fulicarius), one Northern Phalarope (Lobipes lobatus), and one Mourning Dove (Zenaidura macroura), but local specimens of these species were not analyzed. Eggs of least petrels, elegant terns and Heermann's gulls were from different clutches. Eared grebe: Podiceps caspicus; black petrel Loomelania melania; least petrel: Halocyptena microsoma; fish bat: Pisonyx vivesi; Craveri's Murrelet: Endomychura craveri; elegant tern: Thalasseus elegans; Heermann's gull: Larus heermanni.

[b] not measured. Interfering peaks on chromatograms.

[c] both eggs also contained 0.08 ppm dieldrin (lipid weight) and 0.17 ppm endrin (lipid weight).

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Table III. PCB and DDT in the global ecosystem. Content in micrograms and concentrations in parts per million wet weight (W) or lipid weight (L).

Species	N	Total DDT µg	Total DDT ppm	%DDE	PCB µg	PCB ppm	DDT/PCB
White crappie[1]	1	--	1.83 (W)	6	--	0.004 (W)	475
Black crappie[2]	1	--	2.10 (W)	6	--	0.003	660
Bluegill[3]	1	--	5.5 (W)	6	--	0.005	1200
Adélie penguin,[4] eggs	5	0.78 (0.59-1.04)	0.128 (L)	74	<0.044 µg/egg		>18
Western grebe,[5] breast muscle	1	--	26.4 (W)	5	--	0.098 (W)	270
Fulmar[6]							
A	1	--	0.41 (W)	76	--	0.08 (W)	5
B	1	--	3.4 (W)	89	--	0.34 (W)	10
C	1	10,475	17.5 (W)	96	3900	6.5(W)	2.7
Pink-footed[7] shearwater	1	2,000	3.0 (W)	93	277	0.42(W)	7.2
Sooty shearwater[8]							
A	1	--	12.3 (W)	94	--	1.2(W)	10
B	1	--	10.3 (W)	86	--	0.9(W)	12
C	1	1,265	2.3 (W)	85	NM		
Slender-billed[9] shearwater	1	--	32.0 (W)	92	--	2.1(W)	15
Ashy Petrel[10]	3	2,158 (1644-2826)	59.3 (W)	95	389 (298-482)	9.8(W)	5.5
Brown Pelican,[11] eggs, Panama	6	59 (18-183)	11.5 (L)	61 (47-78)	23.1 (18-30)	--	1.55 (0.97-3.2)
eggs, Baja Calif.	2	53 (47-59)	10.0 (L)	81	10.4 (9.0-11.7)	--	6.5, 4.0

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Table III, continued

Frigatebird[12] eggs, Panama	3	9.6,8.7,30.0	...	86	8.4,5.7,84.0	...	1.1,1.5, 0.4
Brown Booby[13] eggs, Panama	4	20.8 (16.4-24.5)	8.2 (L)	89	12.2 (6.5-18.9)	4.8(L)	1.7
Brandt's Cormorant[14] eggs	17	326	—	91	113	--	2.9
Pelagic Cormorant[15] eggs	2	128 (125-130)	--	90	62 (48-75)	--	2.1
Cinnamon Teal[16]	1	4340	10.9 (W)	70	--	0.91	12
White-tailed Kite[17] eggs, clutch A	4	11.4 (9.8-12.9)	0.76 (W)	77	6.4 (5.5-7.8)	--	1.8
Unhatched egg B	1	5.1	0.34 (W)	82	0.84	--	6.0
Unhatched egg C	1	5.3	0.35 (W)	73	3.6	--	1.5
Clutch D	2	8.3/egg	...	82	4.3/egg	...	2.0
Clutch E	3	10.2/egg	9.0 (L)	57	4.0/egg	...	2.6
Clutch F	4	31.9/egg	...	80	3.8/egg	...	8.5
Cooper's Hawk[18]	1	8,500	25.2 (W)	90	--	6.3	4.0
Golden Eagle[19] egg	1	150	2.0 (W)	98	17.5	0.23(W)	8.5
Osprey, Baja Calif.[20]	6	127 (30-264)	55 (L)	85	(7.3,3.0, 103)(24, 7.0,19)	--	8.5,10.1 1.3,11.2 9.7,11.1
Merlin[21]	1	435	2.9 (W)	94	55.4	0.39 (W)	12.7
American Kestrel[22]							
Whole body, adult	1	5.1	0.044	39	3.7	0.031	1.4
eggs, 2 clutches	6	2.4/egg	0.20 (W)	93	1.0/egg	0.09(W)	2.3
Black-crowned night heron (23)							
egg	1	541	--	89	330	—	1.6
egg	1	869	--	99	23	--	36

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Table III, continued

Western Gull[24]							
eggs, San Francisco Bay, 3 clutches	4	803 (632-1123)	--	85	805 (580-1310)	--	1.0
eggs, Farallon Is. 10 clutches	10	412±102	--	89	136±55		3.0
eggs, Baja Calif. 7 clutches	7	385±230	--	97	45±30	...	9.1,10.5, 5.0,12.3, 10.6,10.7, 10.5
Forster's Tern[25]							
eggs	2	665 (598-732)	--	89	114 (91-137)	--	5.8
Caspian Tern[26]							
eggs, San Francisco Bay	2	1269 (1216-1322)	--	89	805 (660-950)	--	1.7
eggs, San Diego Bay	5	1430 (991-2430)	--	88	1010 (550-1600)	--	1.4
Red Phalarope[27]	1	--	0.78 (W)	79	--	0.10	8
Common Murre[28]							
eggs	6	1945 (932-3621)	151 (L)	90	558 (364-1010)	45 (L)	3.5
Cassin's Auklet[29]	1	--	5.8 (W)	98	--	0.16	36
Ancient Murrelet[30]	1	--	0.75	90	--	0.15	5
Rhinoceros Auklet[31]	1	--	2.7	97	--	0.36	8
Mourning Dove[32]	2	12.0,33.1	0.19(W)	77, 93	Not detected	...	...
Barn Owl[33]							
eggs, one clutch	3	27.7/egg	1.25(W)	95	10.4/egg	0.47(W)	2.7
eggs, one clutch	2	143/egg	6.6 (W)	96	14.4/egg	0.66(W)	10
Meadowlark[34]	2	21.2,448	0.18, 3.3 (W)	77, 93	2.5,28.1	...	8.4, 15.9

Unless otherwise specified, analyses were of whole bodies. Endrin and dieldrin were identified on the basis of retention times on both QF-1 and DC-200 columns.

1. Pomoxis annularis, 284 gm., Clear Lake, Lake Co., Calif. May 1968
2. Pomoxis nigromaculatus, 212 gm., Clear Lake, Lake Co., Calif., May 1968.
3. Lepomis macrochirus, 229 gm., Clear Lake, Lake Co., Calif., May 1968.

Table III, continued

4. Pygoscelis adeliae, Cape Crosier, Antarctica, October, 1967.
5. Aechmophorus occidentalis, Clear Lake, Lake Co., Calif., May, 1968.
6. Fulmarus glacialis. A and B: Monterey Bay, Calif., Nov. 1, 1966. C: Point Reyes, Calif., December, 1967. Fulmars breed in Alaska.
7. Puffinus creatopus. Breeds in Chile. Collected in May, 1968, in the Gulf of California.
8. Puffinus griseus. Breeds in New Zealand and Chile. A and B: Monterey Bay, November 1, 1966. C: Gulf of California, May, 1968. NM: not measured, interfering peaks.
9. Puffinus tenuirostris. Breeds in Australia. Monterey Bay, Dec., 1966.
10. Oceanodroma homochroa. Farallon Islands, Calif. May, 1968.
11. Pelecanus occidentalis. Panama eggs were collected on Isla Pacheca and Isla Pachequilla, Gulf of Panama, Feb. 1968. One egg contained 0.06 ppm dieldrin and 0.06 ppm endrin, another contained 0.16 ppm dieldrin and 0.07 ppm endrin (lipid weight). Baja California eggs were collected at Bahia de los Angeles, March, 1968. One egg contained 0.24 ppm dieldrin and 1.13 ppm endrin (lipid weight).
12. Fregata magnificans. Isla Pacheca, Panama, February, 1968.
13. Sula leucogaster. Isla Pacheca and Isla Pachequilla, Panama, February,1968. Two eggs were analyzed for dieldrin and endrin. Dieldrin: 0.08, 0.18; endrin: 0.06 and 0.011 ppm (lipid weight).
14. Phalacrocorax penicillatus. Farallon Islands, May, 1967
15. Phalacrocorax pelagicus. San Mateo Co., Calif.
16. Anas cyanoptera. San Diego, April, 1968. Adult male.
17. Elanus leucurus. A: Contra Costa Co., Calif. April, 1968. B and C: Contra Costa Co., May, 1968, 2 and 3 young raised, respectively. D: abandoned, Contra Costa Co., May, 1967. E and F: destroyed nests, Contra Costa Co., March, 1968.
18. Accipiter cooperii. Balboa Park, San Diego, Feb., 1968. First year female, died of trichomoniasis.
19. Aquila chrysaetos. San Luis Obispo Co., Calif. April, 1968. Unhatched egg in nest where one young was raised. Egg also contained 4.7 micrograms of dieldrin, 1.9 micrograms of heptachlor epoxide, but no endrin.
20. Pandion haliaetus. Gulf of California, March, 1968. One egg also contained 0.10 ppm dieldrin and 0.25 ppm endrin (L).
21. Falco columbarius. Immature, Utah. December, 1967.
22. Falco sparverius. Adult was road kill, Mendocino Co., Calif., December,1967. Eggs from Davis, California, 1968.
23. Nycticorax nycticorax. Eggs from different clutches, San Francisco Bay, May, 1967.
24. Larus occidentalis. Standard errors, 95% confidence limits.
25. Sterna forsteri. San Diego Bay, May, 1967.
26. Hydroprogne caspia. 1967.
27. Phalaropus fulicarius. Monterey Bay, November 1, 1966.

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Table III, continued

28. Uria aalge. Farallon Islands, May, 1967.
29. Ptychoramphus aleutica. Farallon Islands, April, 1966.
30. Synthliboramphus antiquum. Monterey Bay, Nov. 1, 1966.
31. Cerorhinca monocerata. Monterey Bay, Nov. 1, 1966.
32. Zenaidura macroura. San Diego, July, 1968.
33. Tyto alba. Clutch A from Contra Costa Co., Calif. March, 1968. Clutch B from Yolo Co., Calif., April, 1968.
34. Sturnella neglecta. Davis, Calif., December, 1967.

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Table IV

Increase of oestradiol metabolism by pigeon liver homogenates from birds treated with various chlorinated hydrocarbons

	Amount of polar metabolities formed in mμmoles
Control	29.3 ± 6.5
DDE (40 mg/kg)	76.2 ± 13.1
DDT (40 mg/kg)	93.1 ± 11.2
PCB (20 mg/kg)	160.0 ± 10.5

Each figure is the average with standard deviation of a group of four birds. In all cases 500 mμmoles of oestradiol-6,7-T (500 mc/mM) was present in the incubation mixture. Incubation time 30 mins, weight of microsomal fraction used was 300 mg. All chlorinated hydrocarbons were injected i.m. into the pectoral muscle 7 days before sacrifice.

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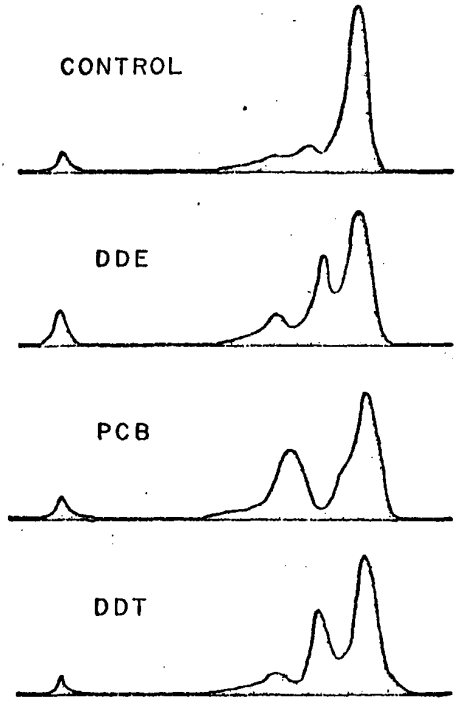


Figure 1. Chromatographic separation of oestradiol and its metabolites. The large peak is unaltered oestradiol.

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