DDE IN A RESIDENT ALEUTIAN ISLAND PEREGRINE POPULATION

CLAYTON M. WHITE

Department of Zoology
Brigham Young University
Provo, Utah 84601

WILLIAM B. EMISON[1]

AND

FRANCIS S. L. WILLIAMSON

Chesapeake Bay Center for Environmental Studies
Smithsonian Institution
Edgewater, Maryland 21037

The chlorinated hydrocarbons, especially DDT and its derivatives, are responsible for some of the perturbations we are witnessing today in bird populations (Anderson et al. 1969; Porter and Wiemeyer 1969; Heath et al. 1969; Enderson and Berger 1970). In an effort to record the cosmopolitan occurrence of these chemical compounds in the world's ecosystems, biologists have sampled in many remote areas. Continued sampling from specific localities suggests that the chlorinated hydrocarbons are indeed accumulating at top trophic levels in food webs, but that concentrations vary greatly from region to region depending on remoteness from areas of major application of these chemicals and on their patterns of dispersal.

The scope of the global contamination by the DDT compounds is indicated by the fact that small amounts are found in the Adélie Penguin (*Pygoscelis adeliae*) and the Skua (*Catharacta skua*) in Antarctica (Tatton and Ruzicka 1967), and by the small amounts in resident Gyrfalcons (*Falco rusticolus*) and the dangerously high amounts in migratory Peregrine Falcons (*Falco peregrinus*) in arctic Alaska (Cade et al. 1971). Because Peregrines are top predators in food webs, preying primarily on birds, they readily accumulate persistent pesticides and are therefore particularly good indicators of the biological magnification of chemicals in an ecosystem. This report presents data on the accumulation of DDE (a major metabolite of DDT) in an essentially resident Peregrine population (White et al. 1971) and their prey, in a relatively remote habitat, Amchitka Island (approx. 51° N and 179° E) in the central North Pacific Ocean.

METHODS

Six eggs were collected in May 1969, four eggs in May 1970, three eggs in May 1971, and one (an unbroken egg found in an eyrie) in January 1970. Two of the eggs collected in 1969 contained live embryos, and one collected in 1971 was freshly abandoned. The remainder were either addled or contained dead embryos. The 14 eggs came from 8 different females and 11 different clutches. The eggs were immediately washed, measured, and weighed, and their contents placed in 10% formalin for later analysis.

Peregrine prey items were identified by examination of parts remaining at nesting sites or nearby plucking perches, and by observation of the killing or eating of identifiable prey on the tundra. Specimens of prey species also were collected for later analysis; body parts were preserved in formalin or the entire specimen was frozen. All specimens used in the pesticide analysis were collected between 1968 and 1970.

Extraction and clean-up of the samples followed standard procedures (USFDA 1963; Cade et al. 1971). Determination and quantification were made with a Varian Aerograph gas chromatograph, equipped with Ni^{63} electron capture detectors, a 2% QF-1, and either a 5% SE-30 or 1% SE-52 column. Because polychlorinated biphenyls may interfere with the determination of some DDT compounds (Anderson et al. 1969; Peakall and Lincer 1970), only DDE was studied. Further, DDE is the most abundant of the DDT compounds and appears to be primarily responsible for eggshell-thinning (Heath et al. 1969; Wiemeyer and Porter 1970).

The index of eggshell thickness was derived using the weight (mg)/length × width (mm) of the shell (Ratcliffe 1967, 1970). DDE values are in parts per million wet weight except where labeled otherwise in table 3.

RESULTS

Thirty-two species have been identified from Amchitka as prey of the Peregrine (table 1). Although some species are more frequently taken as prey in one season than in another, we have not indicated seasonal predominance; however, most of the data in table 1 were

[1] Present address: Department of Environment, Box 4036 G.P.O., Sydney, N.S.W. Australia 2001.

TABLE 1. Prey items found at Amchitka Island Peregrine Falcon eyries or plucking perches, 1968–72.

Species	Seasonal status on Amchitka	No.	Approx. weight class in grams	% of total	% of biomass
Scaled Petrel (*Pterodroma inexpectata*)	M[a]	1	100	0.18	0.08
Fork-tailed Petrel (*Oceanodroma furcata*)	RU	19	45	3.46	0.76
Leach's Petrel (*Oceanodroma leucorhoa*)	RU	20	40	3.64	0.70
Unidentified Petrel (*Oceanodroma* sp.)	RU	2	40[c]	0.36	0.07
Procellarid subtotal	—	42	—	7.64	1.61
Mallard (*Anas platyrhynchos*)	RM	2	1100	0.36	1.93
Mallard duckling	RM	1	30	0.18	0.02
Pintail (*Anas acuta*)	RM	1	900	0.18	0.79
Common Teal (*Anas crecca*)	R	28	400	5.12	9.85
Common Goldeneye (*Bucephala clangula*)	RM	1	1000	0.18	0.87
Harlequin Duck (*Histrionicus histrionicus*)	RM	1	650	0.18	0.57
Red-breasted Merganser (*Mergus serrator*)	RM	1	900	0.18	0.79
Water fowl subtotal	—	35	—	6.38	14.82
Rock Ptarmigan (*Lagopus mutus*)	R	22	600[b]	4.01	11.59
Upland game bird subtotal	—	22	—	4.01	11.59
American Golden Plover (*Pluvialis dominica*)	M	2	150	0.36	0.27
Ruddy Turnstone (*Arenaria interpres*)	M	1	110	0.18	0.09
Wandering Tattler (*Heteroscelus incanus*)	M	1	100	0.18	0.08
Wood Sandpiper (*Tringa glareola*)	M	1	55	0.18	0.05
Rock Sandpiper (*Calidris ptilocnemis*)	R	8	80[b]	1.45	0.57
Red Phalarope (*Phalaropus fulicarius*)	M	4	50	0.73	0.17
Black-headed Gull (*Larus ridibundus*)	M	1	290	0.18	0.26
Black-legged Kittiwake (*Rissa tridactyla*)	RU	2	400	0.36	0.70
Arctic Tern (*Sterna paradisaea*)	M	12	110	2.18	1.16
Aleutian Tern (*Sterna aleutica*)	M	7	130	1.27	0.80
Shorebird and gull subtotal	—	39	—	7.06	4.15
Pigeon Guillemot (*Cepphus columba*)	R	2	460	0.36	0.80
Horned Puffin (*Fratercula corniculata*)	RU	2	550	0.36	0.96
Tufted Puffin (*Lunda cirrhata*)	RU	2	800	0.36	1.40
Ancient Murrelet (*Synthliboramphus antiquus*)	RU	85	230[b]	15.51	17.18
Parakeet Auklet (*Cyclorrhynchus psittacula*)	RU	17	240	3.10	3.58
Crested Auklet (*Aethia cristatella*)	RU	131	230	23.90	26.48
Least Auklet (*Aethia pusilla*)	RU	105	85	19.16	7.85
Whiskered Auklet (*Aethia pygmaea*)	RU	7	110	1.27	0.67
Unidentified Auklets (Parakeet or Crested)	RU	32	235[c]	5.83	6.60
Alcid subtotal	—	383	—	69.85	65.52
Gray-crowned Rosy Finch (*Leucosticte tephrocotis*)	R	7	52[d]	1.27	0.31
Lapland Longspur (*Calcarius lapponicus*)	M	13	30	2.37	0.33
Snow Bunting (*Plectrophenax nivalis*)	R	7	50[d]	1.27	0.30
Passerine subtotal	—	27	—	4.91	0.96
Norway Rat (*Rattus norvegicus*)	R	5	300[e]	0.91	1.31
Grand Total	—	548	—	100	100

[a] M = migrant; R = resident; RU = resident in Aleutians but undetermined for Amchitka; RM = found year around but some members migrate.
[b] Average of combined male-female weight.
[c] Approximate average weight of both species.
[d] Average between summer and winter weight.
[e] Approximate average adult weight.

collected during the breeding season, and reflect mainly prey remains found at nest sites. Of the prey species identified, 22 are year-round residents in the Aleutians, 5 of which apparently augment their populations by migrants, and 10 are migratory (table 1). Residents form the bulk of the prey, or about 70% of the total species identified. DDE levels of selected prey species are given in table 2. In selecting the prey items to be analyzed, we considered both the frequency with which they were taken by the falcons

TABLE 2. DDE residues in representative prey items of Amchitka Peregrines. Residue concentrations are on a ppm wet wt. basis. Prey items represent both resident and migrant species.

Species	Number	Tissue sampled	Tissue Mean	Tissue Range
Common Teal	1	Pectoral muscle	0.020	
Rock Ptarmigan	3	Whole body[a]	0.371	(0.218–0.645)
Wandering Tattler	1	Whole body	0.309	
Rock Sandpiper	3	Whole body[a]	1.530	(0.445–3.270)
Arctic Tern	1	Whole body	1.884	
Aleutian Tern	1	Whole body	0.321	
Ancient Murrelet	2	Whole body	0.051	(0.009–0.094)
Crested Auklet	3	Whole body	0.006	(0.001–0.014)
Least Auklet	2	Whole body	0.009	(0.001–0.017)
Whiskered Auklet	1	Whole body	0.021	
Gray-crowned Rosy Finch	3	Whole body	0.041	(0.009–0.084)
Lapland Longspur	3	Whole body	0.112	(0.021–0.204)
Snow Bunting	1	Whole body	0.031	

[a] Data from Bell (1969) and represent the mean of the combined values of brain, liver, fat, and pectoral muscle as determined by WARF Institute Inc., Madison, Wisconsin.

and whether or not they were resident or migrant. We have tried to achieve a balance in the latter. On the average, the migrant prey species show 2.8 times greater levels of DDE than do the resident species sampled.

The thickness of the eggshells from Amchitka Peregrines show a 7.5% decrease ($P < 0.02$) over the sample of pre-DDT eggshells from Forrester Island (table 3). Although the Amchitka Peregrine population is widely separated geographically from the one on Forrester Island, they are both considered as belonging to the same subspecies, and specimens from both populations are essentially the same size (White 1968). Likewise, the eggs are not significantly different in length ($t = 0.60$) although the Amchitka eggs are slightly wider ($t = 2.20$, $0.05 < P < 0.02$). The difference in indices between the Amchitka and Forrester samples is considered to reflect an actual decrease in thickness of the shells of Amchitka Peregrines over eggs from the pre-DDT periods (for the same size eggs) and not an artifact of sampling error. It may be important that the 1970 Peregrine egg with 13.37 ppm DDE (table 3) came from an eyrie where the female laid a single egg and immediately deserted. In 1969, the same female (presumably) had four viable eggs in that eyrie but deserted them also when the embryos were about one-half developed. Two of those eggs were collected and one contained 3.52 ppm and the other 4.63 ppm DDE. Desertion of eggs by Peregrines once incubation is well underway is, in our experience, unusual and may be abnormal behavior.

DISCUSSION

The residue levels in Amchitka Peregrines are relatively low when compared to levels in other North American Peregrine populations (discussed beyond). Therefore, their food habits merit more consideration. About 67% (by number and biomass) of the diet of the

TABLE 3. Comparison of DDE levels in Amchitka eggs and their eggshell thickness with pre-DDT Forrester Island, Alaska, eggshell thickness.

Locality	N	ppm DDE (wet) Mean	ppm DDE (wet) Range	ppm DDE (wet) Standard error	ppm DDE (lipid) Mean	ppm DDE (lipid) Range	ppm DDE (lipid) Standard error	Shell thickness index Mean	Shell thickness index Range	Shell thickness index Standard error
Forrester[a] Island 1915–1920	30							1.88	(1.72–2.16)	± 0.026
Amchitka 1969	6	3.99	(3.03–5.55)	± 0.349	126.0	(97–151)	± 6.633	1.74	(1.60–1.91)	± 0.039
Amchitka 1970	5	6.96	(3.28–13.37)	± 1.637	236.0	(101–420)	± 56.097	1.73	(1.46–1.99)	± 0.094
Amchitka 1971	3	1.89	(1.27–2.43)		60.39	(40.71–77.81)		1.83	(1.64–2.09)	

[a] Data courtesy of D. W. Anderson and J. J. Hickey (unpubl.).

Amchitka Peregrines is composed of resident alcids (table 1). Small alcids may actually provide a greater percentage of the biomass consumed than is indicated in table 1. Because the alcids have relatively small wings (usually not eaten) and large bodies for their weight, a greater percentage of their body weight is eaten than is the case for other species of similar weight but possessing large wings. For example, as an index of the size of wings in several representative species, wings were cut off close to the body and weighed. The wings of an Ancient Murrelet (*Synthliboramphus antiquus*) were 4.6% of its total weight; those of a Snow Bunting (*Plectrophenax nivalis*) were 6.3%; a Rock Ptarmigan (*Lagopus mutus*), 6.5%; a Leach's Petrel (*Oceanodroma leucorhoa*), 11.5%; and the wings of a Glaucous-winged Gull (*Larus glaucescens*) (a rough approximation of kittiwakes and terns) were 12.9% of its body weight. Thus, for example, for each murrelet eaten, the falcon gets on the order of 6.9% more food, disregarding actual weight differential, than for each petrel it eats.

The following information on the foods of two of the more important species of alcids taken by the Peregrines on Amchitka is important. Stomachs and crops of Crested Auklets (*Aethia cristatella*) taken near Amchitka contained the mysid (*Stilomysis grandis*), the euphausid (*Thysanoessa longipes*), and beaks of small cephalopods. Stomachs of Ancient Murrelets taken in May and June contained principally the mysid (*Acanthomysis* sp.), a few euphausids (*Thysanoessa longipes*), and remains of small fishes (*Ammodytes hexapterus*). Bedard (1969) has shown that on St. Lawrence Island, Alaska, the major food items of auklets are also euphausids, mysids, amphipods, etc. Thus, there are few trophic levels (plankton—crustacean—alcid—Peregrine) in one of the major food chains on Amchitka. This is a relatively short food chain in comparison with other areas where Peregrines may be removed from the producer level by five or six trophic levels in the food chain (Cade et al. 1968). Within this important short food chain on Amchitka the biological accumulation of residues in the resident prey species is low (table 2).

The Rock Ptarmigan feeds entirely on parts of terrestrial plants; about 89% of its food is composed of crowberry (*Empetrum nigrum*) and horsetail (*Equisetum arvense*). Ptarmigan comprise almost 12% of the biomass of the Peregrine's food. The route of DDE into (or onto) the terrestrial vegetation, as shown by the DDE values in the ptarmigan (table 2), is difficult to explain in any way other than transport by air currents over vast distances.

Most of the data on Peregrine foods (table 1) were collected during the spring and summer. In winter, alcids move farther offshore or they have an irregular distribution around the island and are less frequently haunted by Peregrines. During this period, the falcons were often seen hunting passerine birds, Rock Ptarmigan, sandpipers, and Common Teal (*Anas crecca*) along the beaches, cliffs, and intertidal areas at low tide, as well as overland. Although fewer prey items are identified in winter, most were either Snow Buntings or Rock Ptarmigan. We also watched Peregrines use various tactics in hunting Gray-crowned Rosy Finches (*Leucosticte tephrocotis*) along bluffs in winter. The frequent hunting for passerines by falcons along the beaches in fall and winter has been noted elsewhere in the Aleutians and the inference also is that Peregrines rely heavily on them in these seasons (Collins et al. 1945). Presumably, the frequency with which passerines are taken is higher in winter than summer and is higher than indicated by table 1. The resident passerines (Snow Buntings and Gray-crowned Rosy Finches) also are involved in relatively short food chains and, although a large percentage of the food is seeds, a variety of invertebrates are taken during the nestling feeding period.

Although there are common or conspicuous elements of the Amchitka avifauna in a size range of birds Peregrines readily kill, they are seldom if ever taken (table 1). These include such resident species as the Greater Scaup (*Aythya marila*), Harlequin Duck (*Histrionicus histrionicus*), and Winter Wren (*Troglodytes troglodytes*), and migrants such as shearwater (*Puffinus* sp.), Bufflehead (*Bucephala albeola*), American Golden Plover (*Pluvialis dominica*), Ruddy Turnstone (*Arenaria interpres*), and Parasitic Jaeger (*Stercorarius parasiticus*). Some of the same or similar species are readily taken by Peregrines in other tundra or taiga regions of Alaska (White and Cade 1971), and one wonders what the residue levels would be like in the Aleutian Peregrines if more of the above migrants were taken.

Table 1 shows that the resident species frequently taken [teal, ptarmigan, Rock Sandpiper (*Calidris ptilocnemis*), alcids, Norway Rat (*Rattus norvegicus*), and two passerines] form over 95% (by biomass) of the prey. The DDE values in table 2 reveal that the average in resident birds is only 0.23 ppm, while for the four migratory species that were analyzed, Wandering Tattler (*Heteroscelus incanus*), Lapland Longspur (*Calcarius lapponicus*), Arctic Tern (*Sterna paradisaea*), and Aleutian Tern (*Sterna aleutica*), it is 0.66 ppm. If the resident prey species commonly moved to other regions, one would expect higher residues in them and in turn greater concentrations in Peregrines. As much as 15 ppm DDE has been found in Cassin's Auklets (*Ptychoramphus aleuticus*) resident in California and one Ancient Murrelet wintering in California had 0.68 ppm DDE (Risebrough et al. 1967). In more southern waters, but close to or far from agricultural or industrial coasts, some of the same alcids that are on Amchitka have DDE values 2–4 orders of magnitude higher (Keith and Gruchy 1971). This suggests that bigger samples consisting of more alcid species from the Aleutians need to be analyzed and carefully monitored for their chlorinated hydrocarbon levels.

In the Queen Charlotte Islands, British Columbia, where Peregrines show the same preference for alcids as they do on Amchitka, the Ancient Murrelets have residues on the order of 7 ppm DDE in subcutaneous fat and 0.2 ppm DDE in pectoral muscle (Nelson 1970b). Peregrine eggs from these islands have approximately three times the amount of DDE as do those in the Aleutians, and the total population of Peregrines on Langara Island is lower (Nelson 1970a) than that reported a decade ago by Beebe (1960). This decline may be related, however, to factors other than pollutants. Finally, the Peregrines from the arctic slope of Alaska, which migrate across the continental United States and winter as far south as Argentina (White 1968), feed principally on migrant prey items that are contaminated or on resident South American species that may be contaminated. It is, therefore, not surprising that arctic Peregrines contain about four and one-half times more DDE than those in the Aleutians, and that their eggs are about three times thinner (Cade et al. 1971). Some populations of arctic Peregrines may be starting to decline (White and Cade 1971) in a way similar to that witnessed elsewhere (Hickey 1969).

There are at least four reasons for the relatively low levels of residues in the eggs of the Amchitka Peregrines: (1) the Peregrine population of established breeders is resident on Amchitka (White et al. 1971); (2) about 95% (biomass) of their diet is composed of resident prey species that contain low residues; (3) most of the migratory species that are potential prey are apparently not taken by the falcons and the few species that are taken contain relatively low residues; and (4) Amchitka is several hundreds of miles from the nearest localities where the DDT compounds are regularly used. Despite the fact that the Aleutian Peregrines contain less DDE than any other North American population so far sampled, and they appear healthy and in no imminent danger from serious chemical contamination, we have some concern about their future, as they are showing some eggshell-thinning. Further, preliminary analyses of their eggs for PCBs (polychlorinated biphenyls) suggest that there may be about four times more PCBs than DDE (determination by R. W. Risebrough). Routes and means of dispersal and levels of PCBs in several raptorial and fish-eating birds resident on Amchitka are now being investigated (Risebrough and White, unpubl. data). In contrast, the Queen Charlotte Peregrine eggs contain about a 1:3 PCB/DDE ratio (Nelson 1970b) and PCB/DDE ratios in Peregrines taken in California are also about that same order of magnitude (Risebrough et al. 1968). It is disturbing to find such PCB/DDE ratios in Peregrines residing at a site so remote from man since PCBs have some of the same biochemical and physiological actions as DDE (Peakall and Lincer 1970; Lincer and Peakall 1970), and the two may be additive in some effects (Dustman et al. 1971).

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